Water Requirements of the Copper Industry

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1330-E

U.S. DEPARTMENT OF THE INTERIOR
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By ORVILLE D. MUSSEY

WATER REQUIREMENTS OF SELECTED INDUSTRIES

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Present and future water requirements for the mining and metallurgy of copper

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1961

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - (paper cover)

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WATER REQUIREMENTS OF THE COPPER INDUSTRY

By Orville D. Mussey

ABSTRACT

The copper industry in 1955 used about 330 million gallons of water per day in the mining and manufacturing of primary copper. This amount is about 0.3 percent of the total estimated withdrawals of industrial water in the United States in 1955. These facts were determined by a survey, in 1956, of the amount and chemical quality of the water used by the copper industry.

A large part of this water was used in Arizona, Nevada, New Mexico, and Utah, where about five-sixths of the domestic copper is mined. Much of the remaining water use was near New York City where most of the electrolytic refineries are located, and the rest of the water was used in widely scattered places.

A little more than 100,000 gallons of water per ton of copper was used in the production of copper from domestic ores. Of this amount about 70,000 gallons per ton was used in mining and concentrating the ore, and about 30,000 gallons per ton was used to reduce the concentrate to refined copper. In areas where water was scarce or expensive, the unit water use was a little more than half the average. About 60 mgd (million gallons per day) or 18 percent of the water was used consumptively, and nearly all of the consumptive use occurred in the water-short areas of the West.

Of the water used in mining and manufacturing primary copper 75 percent was surface water and 25 percent was ground water, 89 percent of this water was self-supplied by the copper companies and 11 percent came from public supplies.

Much of the water used in producing primary copper was of comparatively poor quality; about 46 percent was saline—containing 1,000 ppm (parts per million) or more of dissolved solids—and 54 percent was fresh. Water that is used for concentration of copper ores by flotation or even any water that comes in contact with the ore at any time before it reaches the flotation plant must be free of petroleum products because they interfere with the flotation process. The water used in mining and ore concentration was higher in dissolved solids and was harder than the water used in smelting and refining. Water used in mining and ore concentration had a median dissolved solids content of about 400 ppm and a median hardness (as $CaCO_3$) of about 200 ppm. The median values for water used in smelting and refining were only half these amounts.

INTRODUCTION

More water is used to produce a ton of copper, on the average, than to produce a ton of any other major metal. This conclusion is obtained from a survey of the quality and quantity of water required by the copper industry. The purpose of this survey and similar surveys of other industries is to supply knowledge of water use so that new industrial plants will be able to select sites that are near adequate supplies of water of suitable quality without infringing on the requirements of established industries and other activities with which they will share the available water.

This report is limited to a study of the water use of that part of the copper industry concerned with mining copper ores and reducing domestic and imported ores and intermediates to refined copper; it does not include any subsequent processing or fabrication. This study also includes domestic and municipal water for housing and company towns where such facilities were established by the copper companies. The water used in the conversion of new and old scrap metal to unalloyed refined copper is also included because it is usually processed with primary copper and forms an integral part of the refinery output.

The investigation began with a review of the literature directed toward finding how much and what kind of water was used by the industry. Previously unpublished results of a 1951 survey of water use by the copper industry are also included in this report. Some quantitative and qualitative water-use information was found in the literature; details are shown at appropriate places in the text.

The review of the literature was followed by a field survey in the spring and summer of 1956. The field survey consisted of investigations at mines and leaching and flotation plants that produce the concentrates for about 98 percent of our primary domestic copper. Also the survey included visits to all the copper smelters and refineries in the United States. At each mine or plant, information was obtained on the source of water, adequacy of the supply, temperature of the water, treatment given the water, and any unusual practice in water use and the reasons for such practice. The acquistion of these types of information involved the determination of how much and what kind of water was used at each mine or plant, how the water was used, how much water was used consumptively, how much water was reused, the nature and quantity of the raw materials, and the finished product at each mine or plant. In addition, water from each source was classified as process or wash water, cooling water, boiler feed, sanitary and service, and miscellaneous.

Process or wash water is defined as water that comes in contact with an end product or with materials incorporated in an end product. Cooling water is water that is used only for cooling. Under these definitions water used to cool a product by being brought into contact with it is classified not as cooling water but as process water. Boiler-feed water is that introduced into boilers for conversion into steam. Sanitary and service water includes water for drinking, showers, general cleaning, and flushing wastes, which includes water used for granulating and flushing slag to disposal areas. This method of slag disposal was used at only a few smelters. Miscellaneous use included such things as company housing and water for local irrigation.

The results of the survey present a picture of the current water requirements of the copper industry. The total water-use figures are compared with the information obtained in the 1954 inventory of industrial water use by the Bureau of the Census. Trends and developments that might affect the use of water by the copper industry in the future are outlined.

MINING

OPEN-PIT OPERATIONS

Considerable water is used in controlling the silica dust from the gangue or from the country rock in the mines. This dust is a health hazard and might cause silicosis if the workers inhaled it in large amounts. Water is also used for dust control in coarse crushing which is done at many mines to facilitate handling of the ore en route to the ore-concentration plants.

Water is used for drilling, for sprinkling roads and piles of loose ore prior to handling, for steam locomotive boiler-feed, for sanitary and service, and for company housing. In extremely dry areas, considerable water is used for local irrigation and home and office air conditioning. Where no electric power is purchased, water is used for cooling and boiler feed in producing thermoelectric power.

UNDERGROUND OPERATIONS

Generally less water is used in underground than in open-pit operations, because less water is needed for dust control. For other purposes water uses in underground operations are similar to those listed for open-pit operations.

In addition, some water is needed for treating timber for mine use and, in one mine, for reducing temperatures.

TAILINGS

Old tailings are being reworked on a systematic basis in many areas. These old tailings are finely ground and ready for concentration or leaching. Little or no water is used in delivering old tailings to the flotation mills or leaching plants except possibly for dust control in handling.

METALLURGICAL METHODS

Nearly all low-grade copper sulfide ores and some native copper ores are reduced to copper in three separate steps. The ore is first concentrated by flotation, then reduced to a metallic condition by smelting, and finally purified in a refinery using electrolytic methods. A typical flow sheet combining all three steps is shown in plate 2*A*. Low-grade copper oxide ores are concentrated by leaching as shown in plate 2*B*. In both flow sheets the aim is to emphasize water use rather than the metallurgical process. The precipitated copper produced in the leaching process is mixed with concentrate from flotation in the reverberatory furnace and reduced to refined copper as shown in plate 2*A*. A small amount of copper ore is produced that is rich enough to go directly to the smelters. Details of the processes are discussed under the appropriate headings.

CONCENTRATION BY FLOTATION

Most of the copper ore mined consists of low-grade copper sulfides that are first concentrated by flotation. The ore is usually passed through primary and secondary crushers that use water only for dust control and bearing cooling (pl. 2*A*). Water is added to the ore as it enters the rod mill, which consists of a revolving drum partly filled with round steel rods. The ore and water passes through the mill where the ore is crushed between the rods in the rotating drums. From the rod mill the ore passes through a classifier which separates the fine material from the coarse. The coarse material is passed in a closed circuit to the ball mills for regrinding, and the fine material from both the rod mills and the ball mills passes on in water suspension to the distribution boxes.

At this point chemicals, including such substances as tall oil, are added. The finely ground ore mixed with four or five times its weight in water is passed on to the flotation cells. These cells are so arranged that air may be introduced through the bottom. The air bubbles rise to form a froth containing the sulfides in the ore which overflow and are separated from the useless gangue which passes out of the flotation cell with most of the water through an opening below the water surface. The sulfides (including the copper sulfide) rise in the flotation cell because the tall oil selectively coats the sulfides and the air bubbles cling to the oil coating, causing the sulfides to rise and remain at the surface. If the pH rises above 9, excessive frothing may result.

The gangue or tailings pass on to thickeners where much of the water is reclaimed for reuse, and the thickened tailings are flushed to a tailings pond where the solid materials settle out. Excess water in the tailings pond is returned to the concentration mill for reuse.

Concentrates at a few mills are reground and passed through fine flotation cells to increase the copper content of the concentrate.

In some dry areas, water is used for dust control on the tailings disposal areas.

Many of the western copper ores contain molybdenum sulfide which usually is removed in another series of flotation cells by differential flotation involving the use of another group of chemical additives. This requires the use of more water.

In Michigan the separation of native copper is accomplished in part by hand sorting, in part by bumping tables that separate the heavy copper from the lighter rock by shaking the ground ore on tilted surfaces in the presence of a slowly moving sheet of water, and in part by flotation, using chemical additives differing from those that were used for concentrating sulfide ores.

CONCENTRATION BY LEACHING

Copper oxides cannot be separated by flotation; so the copper is usually separated from the ore by a leaching fluid that is mostly water (pl. 2*B*). Ordinarily the ores are crushed to smaller than three-eights of an inch and placed in leaching tanks containing perhaps 10,000 tons of ore. Water is used for bearing cooling and dust control during crushing, but the crushed ore is rather dry. The fine material may be agglomerated by the use of water sprays to permit free passage of the leaching fluids through the ore. Sulfuric acid is usually added to the leaching fluid, but some ores contain enough sulfates to make this unnecessary. Each batch of ore is leached several times. Leaching solutions containing little or no copper sulfates are passed first through the lean ores that have already been leached several times and then through gradually richer ores until the leaching fluids are rich in copper sulfate.

From the leaching tanks the copper sulfate solution is passed to the iron launders. The launders consist of troughs containing sponge iron or iron scrap; usually shredded cans from which the tin has been melted and the paint or paper labels burned. The iron reacts with the copper sulfate solution, precipitating a black sand (called "cement copper") that contains about 90 percent copper. The iron sulfate solution remaining is usually transferred to an evaporation pit where the water is evaporated and the iron sulfate precipitated. If, in addition to the oxides of copper, the sulfide occurs in the ore in amounts too small to make recovery by flotation profitable, some recovery of the sulfides may be made by using both ferric sulfate and sulfuric acid in the leaching solution.

Some copper is leached from very low grade ores in place and some from waste materials of earlier mining operations.

At one plant, refined copper is obtained from the leaching solution by electrolysis.

Water is used for sanitary and service, for company housing, and at one plant for manufacturing sponge iron and sulfuric acid.

SMELTING

The concentrates from flotation, together with suitable fluxing materials, make up the charge to a reverberatory furnace. This furnace consists of a chamber about 110 feet long and 30 feet wide, lined with firebrick, and fired with natural gas, oil, or powdered coal. High grade copper ores and copper sands from the leaching process may be added to the charge. Air and fuel are blown in at one end, and exhaust gases are removed at the other. Furnace temperatures reach about 1,500°C. Because it contains considerable copper, the dust in the flue gases is returned to the furnace. Much of the heat in the flue gases is recovered in waste heat boilers and used to produce electrical energy.

After the charge is melted, the slag is drawn off the top and discarded. The heavier matte—consisting chiefly of copper, sulfur, and iron—is placed in converters while it is still molten.

Water is used for cooling the reverberatory furnace and for boiler feed and condenser cooling in the generation of power from steam produced in the waste-heat boilers. Where water is plentiful it is sometimes used to granulate the slag and flush it to the tailings dump.

A copper converter usually consists of a horizontal brick-lined steel cylinder with arrangements for introducing air through tuyeres in the cylinder wall. The charge is introduced through an opening in the top, and the converter can be rotated on its axis so that the contents may be discharged through the same opening when the reactions are completed. After the matte is poured into the converter, a high-silica flux is added, and air is blown in through the tuyeres. The sulfur is burned off, furnishing heat for the operation, and the iron is converted to iron oxide that combines with the silica to form a slag lighter than the copper. The slag, which usually contains 2 to 5 percent copper, is drawn off and routed to the reverberatory furnace. Excess heat in the converters may be controlled by adding high-quality copper scrap. The copper, including some copper oxide, is transferred to a holding furnace where the copper oxides are reduced to a minimum by plunging green wooden poles into the melt.

Where there is a local demand for sulfuric acid, it may be manufactured by using the sulfur dioxide produced in the reverberatory furnace and the converter; considerable water is used in such a plant.

After the oxygen has been removed in the holding furnace, the copper is poured into casting molds, usually in the shape of copper anodes ready for electrolytic refining. For convenience these molds are mounted on the rim of a large-diameter wheel revolving about a vertical axle that brings each mold in position first for pouring and then to receive water sprays that cool the casting and form steam, which excludes air and prevents the formation of copper oxides.

The castings continue to cool under the sprays, and after a half-turn on the wheel, are removed from the molds and are placed, hot and glowing, in a water tank called a bosh bath where they remain until they are cooled sufficiently to prevent oxidation. The empty molds are further cooled by spraying and then coated with powdered bone ash in water suspension to facilitate removal of the next casting.

Much of the water in the bosh bath and sprays is evaporated and dissipated into the atmosphere, and more water is evaporated in cooling towers in which the hot water withdrawn from the bosh bath is cooled for reuse. Where fresh water is scarce and salt water available, some fresh water may be saved by cooling the bosh water by using salt water once through in heat exchange units.

Smelted copper from the native copper deposits of the Upper Peninsula of Michigan may be marketed as Lake copper and is suitable for use as refined copper for some purposes.

Copper scrap may be added to the furnace and cast into anodes for refining together with or separate from the copper concentrates.

REFINING

The copper anodes produced at the smelters are about 98 percent copper and contain many kinds of impurities including most of the valuable metals contained in the concentrate. These anodes are placed in special tanks containing a water solution of copper sulfate and dilute sulfuric acid and are alternated between cathode starting sheets made of refined copper. The temperature of the electrolyte is maintained between 130° and 150°F.

The copper is transferred from the anodes to the cathodes by electrolytic action. The impurities, including gold, silver, and other valuable material, either go into solution in the electrolyte, sink to the bottom of the tank, or adhere to the anodes from which they are washed in order to recover the valuable mud. Some impurities such as arsenic, iron, and nickel are dissolved in the electrolyte. Some of the electrolytic solution is continuously withdrawn and replaced by new or rejuvenated solution to maintain satisfactory quality in the electrolyte. Various methods, depending on the impurities and the local market for the byproducts, are used to process the electrolyte that is withdrawn. Some of these methods involve evaporation of the water from the electrolyte that is withdrawn.

Most copper refineries treat the anode mud to recover the gold, silver, and other valuable byproducts, but some refineries ship the mud elsewhere for processing.

The cathodes are washed with distilled water (or other water of high quality) and placed in a melting furnace from which the molten copper is cast in the form of wirebars, billets, cakes, ingots, and ingot bars, in a procedure similar to that used in casting the anodes. Some electric-arc furnaces are used for melting cathodes.

About 90 percent of the refined copper from domestic ores is electrolytically refined, and the remaining 10 percent is cast in commercial shapes after only fire refining (McMahon and Greenspoon, 1958).

Water is used for boiler feed to produce steam for maintaining the temperature of the electrolyte. The condensate from the steam used for heating is reused to wash the cathodes and to incorporate into the replacement electrolyte. Water is used for boiler feed and for cooling at some refineries making their own electric power. It is also used for cooling the melting furnace and the casting wheel and in the bosh bath. Water is used for general and sanitary purposes, for company housing, and for irrigation. In one plant, the potential energy contained in city water under pressure is used to operate hydraulic elevators before it enters the cooling water system. Some saline water is used for cooling through heat exchangers.

QUANTITY OF WATER USED

EARLIER STUDIES

Early in 1951, R. W. Sundstrom made a survey of water use in the copper industry in Arizona and Texas. Minimum, average, and maximum unit water-use values for various types of operations and the number of plants on which the data are based are shown in table 1. Unit water-use values for the various types of operation shown in table 1 do not include water requirements for company housing or community activities; the water use in company towns is shown as a separate item.

TABLE 1.—*Water use in the copper industry in Arizona and Texas, 1951*

[Unpublished data collected by R. W. Sundstrom. Water use shown in gallons per ton of ore except as otherwise indicated]

Type of operation	Number of plants	Water use		
		Minimum	Average	Maximum
Mining	8	2.5	30	750
Flotation	8	174	330	610
Leaching	2	---	112	---
Smelting	8	[1].5	[1]3.1	[1]7.7
Refining	1	---	[1]1.0	---
Company town	8	0	[2]410,000	[2]1,700,000

[1] Gallons per pound of copper.
[2] Gallons per day.

MINING

The literature contains numerous references to and descriptions of water supplies used in copper mining operations, but no information was found on the amount of water used per pound of copper or per ton of ore.

The fieldwork for the present report consisted of investigations of water use at 21 mines in Arizona, Michigan, Montana, Nevada, New Mexico, Pennsylvania, Utah, and Washington. These mines produced about 98 percent of the 1955 output of domestic copper. Open-pit and underground operations and combinations of the two were included in the survey. Median production of the 21 selected mines in 1955 was 4.2 million short tons of ore, which yielded 70 million pounds of copper.

Of the 21 mines, 17 used self-supplied water, 1 used public supplies, and 3 used water from both self-supplied water and public supplies. Several mines used self-supplied water from more than one source. A total of 15.8 mgd (million gallons per day) was used at the mines where water use was inventoried, which indicates that 16 mgd would be a reasonable value for total water use in copper mining in the United States. About 79 percent of this water was self-supplied, and 21 percent was obtained from public supplies; 63 percent was surface water, and 37 percent was ground water. Three percent of the total water used was saline (containing 1,000 ppm or more of dissolved solids); three-fifths of this saline water was ground water, and two-fifths was surface water.

The total amount of water supplied to each mine and the total production of ore and copper for 1955 was obtained, and an attempt was made to classify water use by type and nature of service. At all but two mines, estimates were given for the amounts of water used for cooling, processing and washing, boiler feed, sanitary and service, and company housing. Inquiries were made regarding the amount of water used consumptively, but consumptive water use was more difficult to determine, particularly for some purposes. Water is used consumptively when it is evaporated, transpired, or incorporated into a product or byproduct. At 13 mines, the amounts of water intake and outflow were sufficiently well metered to make possible determinations of total consumptive use. Consumptive water use for some purposes was determined for 18 mines.

Table 2 presents an analysis of the unit water-use values for different kinds of water service that were obtained at the 21 mines included in the study. Maximum, minimum, median, and quartile water-use values in gallons per ton of ore and per pound of copper as well as the number of mines reporting are shown for each category.

At most mines it is necessary or advisable to furnish all or part of the employee housing. This usually involved supplying water for use in the company-owned buildings. Where housing was furnished, the amount ranged from supplying a few houses for key personnel to establishing a complete town with schools, hospital, amusements, and facilities for supplying all the town's needs. This sometimes involved

TABLE 2.—*Unit use of water in the mining of copper ore, 1955*

Purpose and kind of water use	Number of mines reporting	Gallons per ton of ore					Gallons per pound of copper				
		Minimum	Lower quartile	Median	Upper quartile	Maximum	Minimum	Lower quartile	Median	Upper quartile	Maximum
Cooling:											
Supplied	19	0	0	2.7	12	208	0	0	0.17	0.64	13.8
Consumed	17	0	0	.9	4.7	48.6	0	0	.04	.28	1.1
Processing and washing:											
Supplied	19	0	0	7.5	17	47.7	0	0	.50	.86	2.21
Consumed	18	0	0	5.0	17	47.7	0	0	.40	.82	2.13
Boiler feed:											
Supplied	20	0	0	0	.34	76.2	0	0	0	.021	4.26
Consumed	18	0	0	0	.26	76.2	0	0	0	.018	4.26
Sanitary and service:											
Supplied	19	0	1.3	2.1	12	147	0	.068	.12	.35	5.23
Consumed	16	0	.01	1.1	1.9	14.7	0	.001	.064	.11	.52
Company housing:											
Supplied	19	0	2.0	12	26	114	0	.11	.54	1.3	6.08
Consumed	14	0	.22	1.8	5.2	96.3	0	.015	.12	.32	.92
All purposes:											
Supplied	21	2.2	16	41	100	244	.22	1.0	2.0	4.2	16.2
Consumed	13	2.9	6.8	13	24	192	.18	.48	.83	1.24	1.91

extensive water use. The electric power used at copper mines is usually purchased from the public utilities, but at nine mines it was necessary or expedient to produce all or part of the electric power requirements, which involved considerable water use. Unit water use for all purposes except company housing and production of electrical energy correlates with the relative abundance of water in the area. At 16 mines in areas where the annual runoff was less than the equivalent of 1 inch of rain on the drainage area, the median water use was 0.9 gallon per pound of copper produced; water used for housing or production of electric power was not included. At the other 5 mines contacted, where the annual runoff was more than the equivalent of 10 inches of rain on the drainage area, the median water use was 1.9 gallons per pound of copper produced; water used for housing or production of electric power was not included. This difference is all the more remarkable because all the desert open-pit mines that require considerable water for dust control are located in the area of low runoff.

FLOTATION

The literature contains considerable information on unit water use in concentrating copper ores by flotation and water-gravity separation or a combination of both methods. The search for unit water-use values was not exhaustive, but all the unit water-use values that were found, whether for concentration of ores principally by flotation or water-gravity separation or a combination of both, are shown in table 3. Many of the water-use values given are for foreign countries, and such water-use figures were converted to U.S. gallons. Where the information was available, pertinent information such as whether or not any electric power was produced or any company housing was furnished is indicated in table 3. Make-up water use includes only the new water that is pumped into a system where part of the water may be reused. Gross circulation water use is the total new and reused water flowing in a circuit. Where no water is reused, the make-up is equal to the gross circulation, and the water is in a once-through circuit.

Water conservation in concentrating copper ores by flotation is widely practiced in the arid Southwest. Merz (1956 p. 418) says that "There are some nine copper ore plants in Arizona that recycle tailing pond water." As an example Merz (1956, p. 418) also says that "The Kennecott Copper Co. installation at Hurley. N. Mex., reclaims all available waste water including septic tank effluent from three small towns."

The fieldwork for the present report consisted of investigations of water use at 24 plants or mills, in Arizona, Michigan, Montana, Nevada, New Mexico, Pennsylvania, Tennessee, Utah, and Washington,

TABLE 3.—*Previously published data showing unit use of water in the concentration of copper ores principally by water-gravity separation and flotation*

Company	Location	Concentration method	Date of data	Water use, in U.S. gallons per ton of copper ore		Electric power	Water used for company housing	Source of information
				Make-up	Gross circulation			
Aldermac Copper Corp., Ltd.	Aldermac, Quebec, Canada.	Flotation	Prior to 1945	740	740	Purchased		Taggart, 1945, sec. 2, p. 56.
Braden Copper Co.	Sewell, Chile	Water-gravity separation and flotation.	Prior to 1927	770				Taggart, 1927, p. 100.
Britannia Mining & Smelting Co., Ltd.	Britannia Beach, British Columbia, Canada.	Flotation	1931	1,300	1,300	No thermo-electric power.		Munro and Pearse, 1932, p. 22.
Do.	do	do	Prior to 1945	840	840	Hydroelectric		Taggart, 1945, sec. 2, p. 57.
Calumet & Hecla Mining Co.	Torch Lake, Mich.	Water-gravity separation.	Prior to 1927	6,700	6,700			Taggart, 1927, p. 78, 1276.
Do.		Water-gravity separation and flotation.	Prior to 1945	5,400	5,400			Taggart, 1945, sec. 20, p. 13.
Cananea Consolidated Copper Co.	Cananea, Sonora, Mexico.	do	Prior to 1927	1,900	1,900			Taggart, 1927, p. 1276.
Chino Consolidated Mining Co.	Hurley, N. Mex.	do	do		1,700			Do.
Copper Range Consolidated Mining Co.	Freda, Mich.	Water-gravity separation.	do	7,200	7,200			Taggart, 1927, p. 78, 1276.
Copper Range Co.	do	Water-gravity separation and flotation.	Prior to 1945	1,700	1,700	Purchased		Taggart, 1945, sec. 2, p. 30.
Engels Copper Mining Co.	Engelmine, Utah	Flotation	do	840	840			Taggart, 1927, p. 90, 1276.
Do.	Plumas County, Calif.	do	1929	680		Purchased		Nelson, 1932, p. 18.
Granby Consolidated Mining, Smelting, & Power Co., Ltd.	Allenby, British Columbia.	do	do	780	1,180			Taylor, 1930, p. 177.
Inspiration Consolidated Copper Co.	Inspiration, Ariz.	Water-gravity separation and flotation.	1925	280	910			Taggart, 1927, p. 104.
Do.	do	do	Prior to 1927	460	910			Taggart, 1927, p. 1276.
Do.	do	Flotation	Prior to 1945	220	860			Taggart, 1945, sec. 20, p. 13.
Magma Copper Co.	Superior, Ariz.	Water-gravity separation and flotation.	1929	300	1,400	Purchased		Rose and McNabb, 1930, p. 4.
Do.	do	do	Prior to 1945	300	1,080	Part purchased.		Taggart, 1945, sec. 2, p. 39.
Do.	do	do	do	240	960			Taggart, 1945, sec. 20, p. 13.
Do.	do	do	1944		960	Part purchased.		Caldwell, 1944, p. 7.
Miami Copper Co.	Miami, Ariz.	do	1930	140	490	Produced		Hunt, 1932, p. 2.
Do.	do	Flotation	Prior to 1927	220	670			Taggart, 1927, p. 95.
Do.	do	do	do	340	840			Taggart, 1927, p. 1276.
Do.	do	do	1916	330	1,430			Mining and Scientific Press, 1916, p. 639.

Minas de Matahambre, S.A.	Matahambre, Pinar del Rio, Cuba.	do	1930	170	670	Produced elsewhere.		Chapman, 1936, p. 164; Kirchner and others, 1931, p. 10.
Do	do	do	Prior to 1945	480	530	do		Taggart, 1945, sec. 2. p. 37.
Do	do	do	do	720	720			Taggart, 1945, sec. 20, p. 13.
Moctezuma Copper Co.	Nacozari, Sonora, Mexico.	Water-gravity separation and flotation.	Prior to 1927	450	1,200			Taggart, 1927, p. 84.
Do	do	do	do	640	2,500			Taggart, 1927, p. 1276.
Do	do	Flotation	1924	700	1,300			McDonald, 1924, p. 445-454.
Mt. Lyell Mining & Railway Co., Ltd.	Mt. Lyell, Tasmania	Flotation	Prior to 1945	600	600	Hydroelectric		Taggart, 1945, sec. 2, p. 59.
Mountain City Copper Co.	Rio Tinto, Nev	do	do	300	1,350	Purchased		Taggart, 1945, sec. 2, p. 38.
Mufulira Copper Mines, Ltd.	Mufulira, Northern Rhodesia.	do	do	420	2,100	Produced		Taggart, 1945, sec. 2, p. 40.
Nevada Consolidated Copper Corp.	Hayden, Ariz	do	do	660		do		Taggart, 1945, sec. 2, p. 43.
Do	do	do	1928	730	730	do	Yes	Chapman, 1936, p. 164; Garms, 1930, p. 2, 21, 22.
Do	Hurley, N. Mex	do	1930	340	850	do	do	Hodges, 1931, p. 1, 15.
Do	do	do	Prior to 1945	240	790	do		Taggart, 1945, sec. 2. p. 49.
Noranda Mines, Ltd	Noranda, Quebec, Canada.	do	do	530	540	Purchased		Taggart, 1945, sec. 2, p. 65.
Ohio Copper Co	Lark, Utah	Leaching and flotation	do	550	550			Taggart, 1945, sec. 2, p. 68.
Old Dominion Co	Globe, Ariz	Flotation	1929	1,100	1,100	Produced		Forrester and Cramer, 1931, p. 19, 27.
Do	do	do	1930	1,020	1,020	do		Forrester and Cramer, 1931, p. 27.
Outokumpu Oy	Outokumpu, Finland	do	Prior to 1945	960	960	Purchased		Taggart, 1945, sec. 2, p. 61.
Phelps Dodge Corp	Ajo, Ariz	do	1938	200	1,000	Produced		Barker, 1939, p. 448.
Do	do	do	Prior to 1945	220	960	do		Taggart, 1945, sec. 2, p. 44.
Do	Bisbee, Ariz	Water-gravity separation and flotation.	1921	380	1,520	Purchased		Trimble, 1921, p. 1079-1081.
Do	do	do	Prior to 1927	380	1,500			Taggart, 1927, p. 1276.
Do	do	do	1929	280	1,450	Company diesel.		Whittenau and Cramer, 1931, p. 21.
Do	do	do	Prior to 1945	420	1,440			Taggart, 1945, sec. 20, p. 13.
Do	Morenci, Ariz	do	do	330	1,320		Yes	Crowfoot, 1931, p. 26.
Do	do	do	1930	280	1,560		do	Do.
Do	do	do	Prior to 1927	280	1,130			Taggart, 1927, p. 102.
Do	do	do	do	320	1,060			Taggart, 1927, p. 1276.
Do	do	Flotation	Prior to 1945	190	960			Taggart, 1945, sec. 2, p. 50.
Do	do	do	1945	218				Cody, 1949, p. 42.
Do	Nacozari, Sonora, Mexico.	do	1929	520	1,200	Company diesel.		Rose and Cramer, 1930, p. 36.
Do	do	do	Prior to 1945	530	1,200			Taggart, 1945, sec. 20, p. 13.
Tennessee Copper Co	Copperhill, Tenn	do	do	840	840	Purchased		Taggart, 1945, sec. 2, p. 67.
United Verde Copper Co.	Clarkdale, Ariz	do	1929	370	700	Part produced		Kuzell and Barker, 1930, p. 24.
Do	do	do	Prior to 1945	360	700			Taggart, 1945, sec. 20, p. 13.
Utah Copper Co. (Magna plant).	Garfield, Utah	Flotation	1929	880	880	Purchased	Company wells; water for mill purchased.	Chapman, 1936, p. 164; Martin, 1931, p. 21.
Utah Copper Co	do	do	Prior to 1945	410	610	do		Taggart, 1945, sec. 2, p. 42.
Verde Central Mines, Inc.	Jerome, Ariz	do	1929	420	920	do		Dickson and Smith, 1931, p. 9.

that were engaged in concentrating sulfide or native copper ores. These mills accounted for substantially all the ore concentrated by the flotation process; more than 90 percent of the copper ore produced in the United States in 1955. All the mills were using the flotation process, but some of the mills concentrating native copper had water-gravity separation equipment still intact but only in occasional use. The median-size mill processed 3,400,000 short tons of ore and produced 100,000 short tons of concentrate, which yielded 45 million pounds of copper annually.

All the 24 mills used self-supplied water and 4 also used municipal supplies. About half of the mills used self-supplied water from more than one source. A total of slightly more than 200 mgd was used at the flotation mills; 92 percent of this water was self-supplied, and the remaining 8 percent was obtained from public supplies. Surface water furnished about 75 percent and ground water 25 percent of all water used. About 41 percent of the water used was saline; 70 percent of this saline water was surface water, and the remaining 30 percent was ground water.

The total amount of water supplied to each flotation mill and the total production of copper during 1955 was obtained for each mill. At all but one mill the number of short tons of ore processed during the year was also obtained. An attempt was made to classify water use by type and nature of service. At all but two mills, estimates were obtained of the water used for cooling, processing and washing, boiler feed, and company housing. Only 18 flotation mills could furnish information on water for sanitary and service use. Consumptive water use at the flotation mills was investigated, but insufficient information was available to determine consumptive use for all the various kinds of water use at each mill. Consumptive water use for various purposes was determined at from 15 to 23 mills. The gross circulation in the mill circuit for process and washing was also determined for 21 mills.

An analysis of unit water-use values for different kinds of water service at the flotation mills is shown in table 4. Maximum, minimum, median, and quartile water-use values in gallons per ton of ore processed and per pound of copper and the number of mills reporting are shown for each category.

The concentration mills were divided into two groups: those in the water-short areas (evidenced by annual runoff equivalent to 1 inch or less of rain on the drainage area) and those in water-abundant areas (evidenced by annual runoff equal to or greater than 10 inches of rain on the drainage area). Intake of water for concentration mills in water-short areas averaged 350 gallons per ton of ore processed, but in water-abundant areas the intake averaged 2,100 gallons per ton

TABLE 4.—*Unit use of water in the concentration of copper ores by flotation, 1955*

Purpose and kind of water use	Gallons per ton of ore						Gallons per pound of copper					
	Number of mills reporting	Minimum	Lower quartile	Median	Upper quartile	Maximum	Number of mills reporting	Minimum	Lower quartile	Median	Upper quartile	Maximum
Cooling:												
Make-up used	24	0	0	10	20	610	24	0	0	1.2	3.2	116
Consumed	22	0	0	0	15	37.2	22	0	0	0	1	2.5
Process and washing:												
Gross circulated	21	554	720	920	1,400	5,340	21	4.92	43	60	80	1,020
Make-up used	23	36.8	190	300	830	4,650	24	1.30	13	18	48	884
Consumed	19	0	45	150	210	658	19	0	1.8	8	15	19.5
Boiler feed:												
Make-up used	24	0	0	0	.6	8.8	24	0	0	0	.04	.5
Consumed	23	0	0	0	.6	8.8	23	0	0	0	.006	.5
Sanitary and service:												
Supplied	18	.4	1.1	4.8	13	47	18	.02	.08	.23	.07	4.9
Consumed	15	0	.14	.88	2.3	6.3	15	0	.01	.058	.15	.34
Company housing:												
Supplied	22	0	0	6.2	11	245	22	0	0	.24	.72	13
Consumed	21	0	0	.30	4.9	33	21	0	0	.015	.23	2.2
All purposes:												
Supplied	23	37.7	200	350	880	5,260	24	1.36	13	19	60	1,000
Consumed	17	0	60	150	230	327	17	0	2.3	9.0	15.8	21.6

of ore. This low water intake together with the arid condition prevailing in water-short areas resulted in increased consumptive use of water in the water-short areas where 200 gallons per ton of ore processed was used consumptively as compared with only 24 gallons per ton in water-abundant areas. Although 14 mills produce all or part of their electric power and 17 mills furnish all or part of the water for housing their employees, their water uses were so small in relation to the processing use that it was not necessary to eliminate water use for power and housing to establish a satisfactory relation between water use in water-short and water-abundant areas.

LEACHING

Unit water-use values both in gallons per ton of ore processed and gallons per pound of copper produced were found for two plants for several different years. These water-use values with other pertinent information are shown in table 5. One of the plants listed is usually classified as a copper refinery because it produces refined copper. However, its water requirements more nearly resemble those of a leaching plant because it leaches the copper out of the ore. Copper cathodes are produced directly from the copper solutions by electrodeposition.

The fieldwork for the present report consisted of investigations of water use at nine leaching plants in Arizona, Michigan, Montana, Nevada, New Mexico, and Utah. These plants processed about 9 percent of our primary domestic copper in 1955; nearly all the leached domestic copper. Most of the raw material for the leaching plants consists of oxide ores or old tailings containing copper oxides, but some ore also containing copper sulfide is used.

TABLE 5.—*Previously published data showing unit use of water in the concentration of copper ores by leaching*

[Data on Calumet & Arizona Mining Co. from Bell (1930, p. 25) and on Inspiration Consolidated Copper Co. from Aldrich and Scott (1933, p. 657)]

Company and location	Type of plant	Date	Tons of ore per year	Pounds of copper recovered per year	Water use		Remarks
					Gallons per ton of ore	Gallons per pound of copper	
Calumet & Arizona Mining Co., Ajo, Ariz.	Leaching	1923	1, 807, 335	38, 868, 570	58. 9	2. 74	Thermal electric power produced at this plant.
Do	do	1928	1, 074, 056	19, 245, 308	49. 7	2. 78	Do.
Inspiration Consolidated Copper Co., Inspiration, Ariz.	do [1]	1927	2, 955, 014	59, 812, 793	24. 3	1. 20	
Do	do [1]	1928	3, 041, 334	58, 120, 707	24. 1	1. 26	
Do	do [1]	1929	3, 052, 692	73, 826, 889	105	4. 32	
Do	do [1]	1930	2, 517, 855	65, 721, 904	95. 7	3. 67	
Do	do [1]	1931	2, 405, 057	64, 976, 779	84. 5	3. 14	

[1] Principal product is electrolytic copper.

Some plants leach low-grade oxide ore in place. One leaching plant removes copper from copper-bearing junk metal. The median-size plant produced concentrate yielding 15 million pounds of copper annually.

All the leaching plants operated on self-supplied water. A little more than 8 mgd was used at the leaching plants included in the inventory. Total water use for leaching plants in the United States would not exceed 10 mgd. About 93 percent of the water was ground water and 17 percent was surface water. About 16 percent of the total water supplies was saline; all from ground-water sources.

The total production of copper and the total water use for cooling, process and washing, boiler feed, and the total amount of water used for all purposes was obtained for each leaching plant. Only three plants were able to supply information on the tonnage of ore handled and not all plants were able to supply data on sanitary and service water, company-housing water, and consumptive water use in various categories. Gross circulation of water for process and washing, the principal water-use category, was obtained for seven plants.

An analysis of the use of water at the leaching plants is shown in table 6; the table includes maximum and minimum unit water-use values, and median values if sufficient samples were available.

The principal use of water at the leaching plants is for process and washing. No relation could be established between the amount of water used per pound of copper and any other single factor. However, we can reason that ore containing a small percentage of water will use more water for leaching than ore containing a large percentage of water. It is also obvious that more water will be required to leach

TABLE 6.—*Unit use of water in the concentration of copper ores by leaching, 1955*

Purpose and kind of water use	Gallons per ton of ore				Gallons per pound of copper			
	Number of plants reporting	Minimum	Median	Maximum	Number of plants reporting	Minimum	Median	Maximum
Cooling:								
Make-up used	6	0	0	39.6	8	0	0.13	2.3
Consumed	6	0	0	24.8	7	0	0	1.5
Process and washing:								
Gross circulated	--------	--------	--------	--------	7	15.4	48	147
Make-up used	3	70	--------	8,580	8	4.1	12.4	58.7
Consumed	3	0	--------	112	8	0	7.2	58.7
Boiler feed:								
Make-up used	6	0	0	2.2	8	0	0	.13
Consumed	6	0	0	2.2	7	0	0	.13
Sanitary and service:								
Supplied	--------	--------	--------	--------	4	.04	.2	.34
Consumed	--------	--------	--------	--------	3	.002	--------	.34
Company housing:								
Supplied	4	0	--------	11.9	4	0	--------	.81
Consumed	3	0	--------	5.9	3	0	--------	.35
All purposes:								
Supplied	3	122	--------	8,580	8	6.9	15	58.7
Consumed	--------	--------	--------	--------	5	6.3	10	58.7

a pound of copper from lean ore than to leach it from rich ore. The amount of evaporation from water surfaces and wetted ore varies with the size of the exposed water surface, provided weather conditions are similar; so evaporation losses will be relatively high at leaching operations where exposed areas of water and wetted material surfaces per unit of product are relatively high. This theorizing regarding variations of unit water use could not be substantiated from the inventory because of the small number of plants involved.

SMELTING

The field investigations included all the copper smelters in the country: 18 smelters in Arizona, Michigan, Montana, Nevada, New Jersey, New Mexico, New York, Texas, Utah, and Washington. Three of the plants that were classified as smelters for water-use purposes are usually designated as copper refineries on the basis of the end product. Production of the individual smelters in 1955 ranged between 8½ and 570 million pounds of copper annually. The median-sized smelter produced 116 million pounds of copper in 1955.

Of the 18 copper smelters, 13 used self-supplied water, 1 used public supplies, and 4 used water from both sources. At 3 smelters, self-supplied water from more than one source was used. Nearly 86 mgd was used at the copper smelters in the United States in 1955. About 80 percent of this water was self-supplied and 20 percent was obtained from public supplies. Surface water constituted about 77 percent and ground water the remaining 23 percent of all the water used. More than 47 percent of the water used was saline and the remainder was fresh. About four-sevenths of the saline water was surface water (all from the ocean), and the remaining three-sevenths was ground water.

The total amount of water supplied to each smelter and the total production of copper during 1955 was obtained for each plant. The plants were asked the type and nature of the water service but complete information was not available at all the plants. Also, not all plants were able to supply the total circulation in both the cooling-water circuits and the process- and wash-water circuits. An attempt was made to arrive at estimates of consumptive water use for each type of water service, but sufficient information was not available at all the smelters. At least nine plants were able to supply information on water uses in each of the categories, and a summary of the unit water-use data is shown in table 7, which presents maximum, minimum, median, and quartile values of unit water use at the smelters. The number of plants reporting each kind of water service is also shown in table 7.

TABLE 7.—*Unit use of water in the smelting of copper ores, 1955*

Purpose and kind of water use	Number of plants reporting	Gallons per pound of copper				
		Minimum	Lower quartile	Median	Upper quartile	Maximum
Cooling:						
Gross circulated	9	0	0.6	6.1	28	88.8
Make-up used	18	0	.2	1.2	5.8	39.2
Consumed	16	0	.025	.15	.53	1.75
Processing and washing:						
Gross circulated	13	0	.04	.41	4.3	31.8
Make-up used	17	0	.067	.29	1.9	31.8
Consumed	11	0	.0245	.10	.295	.78
Boiler feed:						
Make-up used	18	0	.008	.08	.28	.68
Consumed	13	0	.0007	.018	.105	.37
Sanitary and service:						
Supplied	14	.009	.027	.16	1.3	7.40
Consumed	9	0	.011	.031	.19	4.39
Company housing:						
Supplied	17	0	0	.01	.18	3.68
Consumed	17	0	0	.006	.12	3.68
All purposes:						
Supplied	18	.236	.96	4.9	19	39.9
Consumed	10	.172	.35	.67	1.4	2.40

The amount of water used at copper smelters per unit of product is related to the abundance of water in the area. For seven smelters in areas where the annual runoff did not exceed the equivalent of 1 inch of rainfall on the drainage basin, the median water use was 1.6 gallons per pound of copper produced. However, at the other 11 smelters where the annual runoff was more than the equivalent of 10 inches of rain on the drainage basin, the median water use at the smelters was 21 gallons per pound of copper produced.

REFINING

The field investigations included all the plants producing electrolytic copper in the country; nine refineries in Maryland, Montana, New Jersey, New York, Texas, Utah, and Washington. Annual output of the individual plants in 1955 ranged from 160 million pounds to 520 million pounds, and the median plant output was 310 million pounds.

Of the nine refineries, two used only public supplies, one used only self-supplied water, and six used water from both sources. A little less than 44 mgd was used at the electrolytic copper refineries in the United States in 1955. About 91 percent of this water was self-supplied, and 9 percent was obtained from public supplies. Nearly 91 percent of the water used came from surface-water sources and the remainder was ground water. Nearly 88 percent of the water was saline, and the remainder was fresh water. About 97 percent of the saline water used at the refineries came from the ocean, and it was used primarily for cooling.

The total amount of water supplied to each refinery and the total production of copper during 1955 was obtained for each plant. Information was requested regarding gross circulation, make-up, and consumption for various kinds of water service, but some of the plants were unable to furnish information in all categories. Maximum minimum, median, and quartile values of water use in gallons per pound of copper produced and the number of plants reporting for each category are shown in table 8.

Five of the nine refineries produce all or part of the electrical energy required to operate the plants. Considerable cooling water is used in producing electricity. If the cooling-water requirement (a small part of which is used for other than condenser cooling at some plants) is subtracted from the total water supplied, the remaining water use ranges between 0.32 and 0.796 gallon per pound of copper with a median use of 0.40 gallon per pound of copper for the nine refineries.

TABLE 8.—*Unit use of water in the electrolytic refining of copper, 1955*

Purpose and kind of water use	Number of plants reporting	Gallons per pound of copper				
		Minimum	Lower quartile	Median	Upper quartile	Maximum
Cooling:						
Gross circulated	8	0	0.1	1.9	8.2	20.4
Make-up used	9	0	.1	.63	5.3	20.4
Consumed	9	0	0	0	.05	.245
Process and washing:						
Gross circulated	6	.039	.064	.20	6.0	21.8
Make-up used	9	.039	.07	.31	.51	.73
Consumed	7	.003	.031	.125	.325	.73
Boiler feed:						
Make-up used	9	0	.08	.17	.24	.28
Consumed	4	0	----------	----------	----------	.28
Sanitary and service:						
Supplied	9	.012	.0032	.0082	.0175	.30
Consumed	4	0	----------	----------	----------	.002
Company housing:						
Supplied	8	0	0	0	0	.094
Consumed	8	0	0	0	0	.058
All purposes:						
Supplied	9	.44	.74	1.2	7.2	20.8
Consumed	3	.26	----------	----------	----------	.32

QUALITY OF WATER USED

At each of the copper production facilities visited during the 1956 survey, questions were asked about the type of water treatment and the purpose for which treated water was used. Disposal of the effluents from each type of water use was investigated. Data were obtained on the physical and chemical characteristics of the untreated water supplies. These data were supplemented by additional information on water quality collected by the U.S. Geological Survey as a part of its program of investigation of the quality of water of the United States. A series of tables was prepared showing the quality characteristics of the raw waters supplied to each kind of copper production facility. Another series of tables listed the water-treatment methods used by each kind of facility.

MINING

Because mining can be done only where suitable ore is available, the mining industry has less control over the quality of its raw water supply than other industries that are free to select sites at which satisfactory water supplies may be obtained. The greater part of the present and potential copper mining in the United States is located in arid or semiarid regions. Most of the waters used to supply these mines have a hardness as $CaCO_3$ of less than 380 ppm. The hardness is mostly carbonate. These waters contain less than 210 ppm of calcium and less than 380 ppm of bicarbonate. The waters having the higher hardness have noncarbonate hardness as a result of the salts of calcium sulfate. These waters contain as much as 510 ppm of calcium and 378 ppm of sulfate. The calcium sulfate waters contain the higher concentrations of dissolved solids (between 1,000 and 13,900 ppm). All other waters contain less than 1,000 ppm of dissolved solids. Most of the mine water supplies contain less than 50 ppm of chloride, but a few mines used waters containing between 100 and 200 ppm of chloride.

The water for domestic and certain other special-purpose use at the mines is usually among the better quality waters that may be economically developed in the area. On the other hand, almost any kind of water may be used for dust control in open-pit mining and in crushing operations. Maximum, minimum, median, and quartile values of the quality characteristics of the untreated water used at copper mines and the number of mines reporting each characteristic are shown in table 9. About one-sixth of the information came

TABLE 9.—*Statistical characteristics of chemical constituents and physical properties of untreated water used at copper mines*

[Chemical constituents expressed in parts per million. These are based on individual observations and are not balanced analyses]

Constituent or property	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	19	3.0	15	24	33	47
Iron (Fe)	15	Trace	Trace	.15	.42	1,800
Manganese (Mn)	6	.00		.00		2.8
Calcium (Ca)	21	13	36	64	143	509
Magnesium (Mg)	20	3	5.0	13	32	80
Sodium (Na)	13	1.1	5.4	22	40	177
Potassium (K)	6	.9		1.5		6
Bicarbonate (HCO_3)	18	50	120	180	250	378
Carbonate (CO_3)	13	0	0	0	0	5
Sulfate (SO_4)	21	2.8	20	43	105	1,700
Chloride (Cl)	21	2.7	6.9	21	39	196
Fluoride (F)	8	.0	.0	.5	1.4	2.5
Nitrate (NO_3)	5	.6		1.3		10
Dissolved solids	20	51	220	390	900	13,900
Hardness as $CaCO_3$	18	46	135	220	380	1,640
Noncarbonate hardness as $CaCO_3$	8	4	6	35	380	1,490
pH	15	6.1	7.5	7.6	7.7	8.5
Color	7	2	2	4	8	12
Temperature (°F)	11	54	59	64	72	100

from analyses by the Geological Survey, and the remainder was furnished by the copper mining companies. An examination of the table indicates that considerable inferior quality water is used at the mines. Nearly all water of inferior quality is used for dust control.

WATER TREATMENT

A wide variety of treatment methods is employed to make the water used at the mines more suitable for the purposes for which the are intended. Most of the domestic water supplies are chlorinated except previously treated public supplies and the water from a few wells. The purpose of the other water-treatment methods used at the mines is to control corrosion or scale formation. All the types of treatment used for all or part of the water of the 21 mines visited in the 1956 survey are shown in table 10.

TABLE 10.—*Water treatment in the copper industry, 1956*

[Does not include prior treatment of purchased water]

Type of treatment	Number of—					Total
	Mines	Flotation plants	Leaching plants	Smelters	Electrolytic refineries	
No treatment	6	10	3	3	1	23
Coagulation and sedimentation:						
Alum	1	---	---	1	---	2
Flocculation	1	---	---	1	---	2
Ferric sulfate	---	---	1	---	---	1
Sedimentation	---	1	---	---	---	1
Total	2	1	1	2	---	---
Filtration	1	1	---	2	2	---
Softening:						
Hot lime soda	2	2	2	4	1	11
Cold lime soda	2	2	1	3	---	8
Zeolite	2	4	1	6	4	17
Soda ash	1	---	---	2	1	4
Distillation	---	---	---	2	---	2
Total	7	8	4	17	6	---
Disinfection:						
Chlorination	14	10	5	10	1	40
Ammoniation	---	1	---	1	---	2
Fungicide	---	1	---	---	---	1
Algaecides	---	---	---	1	1	2
Total	14	12	5	12	2	---
Prevention of embrittlement, corrosion, or scale:						
Phosphate	6	6	2	7	3	24
Sulfuric acid	3	5	2	3	---	13
pH control	1	3	---	2	---	6
Deaeration	1	1	1	---	---	3
Embrittlement control	1	1	1	---	---	3
Tannin	1	1	1	1	---	4
Distillation	1	1	1	---	6	9
Lime	1	4	---	---	---	5
Sodium sulfite	---	---	---	1	2	3
Sodium lignin sulfonate	---	---	1	---	---	1
Total	15	22	9	14	11	---

FLOTATION

No comprehensive search of the literature for data on chemical quality of water used for flotation was made. Herbert A. Swenson (written communication, 1954) states that "In general, water quality criteria for ore flotation are not critical. Practically any water that is free of acid, mud, or slimes, may be used. Where possible a supply low in metallic sulfates is preferred." One 1945 analysis of water used at the Moreno plant of Phelps Dodge Corporation is shown in table 11.

TABLE 11.—*Chemical analysis of water used for flotation concentrator at Morenci Reduction Works, Phelps Dodge Corp., Morenci, Arizona, July 1945*

[Constituents in parts per million. From Cody (1949)]

Silica (SiO_2)	21	Bicarbonate (HCO_3)	250
Iron (Fe)		Carbonate (CO_3)	3
Calcium (Ca)	41	Sulfate (SO_4)	20
Magnesium (Mg)	14	Chloride (Cl)	5.1
Sodium (Na)	63	Dissolved solids: Residue on evaporation at 180°C	351
Potassium (K)			

Concentration of copper ores is not necessarily conducted at the mine site, but the cost of transporting the usual grade of ore prohibits moving it more than about 30 miles. Most ores are concentrated close to the mines. Ore may be moved to a mill site at a distance for concentration if the cost of transporting the ore is less than the extra cost of developing and bringing water to a site closer to the mine. As a result, the waters used in flotation are similar to the waters used in the mines, but generally they are not so hard. Although concentrations of sulfates exceeding 2,400 ppm and chlorides exceeding 330 ppm were observed, the median value for concentrations of sulfate was less than 60 ppm, and for chloride it was less than 35 ppm. Inquiry as to the kind of process water needed for flotation disclosed that even a small amount of petroleum products interfered with copper recovery. However, even several thousand parts per million of sodium chloride did not interfere with copper recovery but did add to the corrosion costs at the mills.

Table 12 presents maximum, minimum, median, and quartile values of the quality characteristics of the untreated water used at copper flotation mills and the number of mills reporting each characteristic. About one-quarter of the data on which table 12 is based was obtained from analyses by the Geological Survey, and the rest was obtained from the copper companies. Some water of inferior quality is used for dust control on the tailings dumps. Seven mills concentrating copper ores by flotation in Arizona and New Mexico use sewage plant effluents for a part of the process water make-up (McGauhey, 1957).

TABLE 12.—*Statistical characteristics of chemical constituents and physical properties of untreated water used in the concentration of copper ores by flotation*

[Chemical constituents expressed in parts per million. These are based on individual observations and are not balanced analyses]

Constituent or property	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	19	3.0	9.	24	37	86
Iron (Fe)	17	0	Trace	.14	1.0	1,800
Manganese (Mn)	8	0	.00	.00	.11	42
Calcium (Ca)	20	6.1	22	55	150	539
Magnesium (Mg)	19	1.6	5.1	12	35	125
Sodium (Na)	10	1.1	2.6	19	195	248
Potassium (K)	6	.9	------	3.9	------	25
Bicarbonate (HCO_3)	17	0	72	160	337	354
Carbonate (CO_3)	16	0	0	0	0	49
Sulfate (SO_4)	20	2.8	13	58	320	2,440
Chloride (Cl)	22	3.2	12	34	88	338
Fluoride (F)	9	.0	.0	.3	1.3	2.5
Nitrate (NO_3)	7	.0	------	1.3	------	10
Dissolved solids	19	42	135	405	1,250	13,900
Hardness as $CaCO_3$	16	22	74	170	440	2,480
Noncarbonate hardness as $CaCO_3$	8	6	10	115	720	2,480
pH	17	4.0	7.4	7.6	7.9	9.9
Color	8	2	2	4	5	6
Average temperature (°F)	8	51	62	67	69	70

WATER TREATMENT

A large number of different treatment methods are used to make the waters more suitable for flotation and to reduce damage from corrosion of the mill machinery. Domestic water not obtained from public supplies was usually chlorinated, and some water was chlorinated for algae control. Table 10 lists all the types of treatment used for all or part of the water used at the 24 flotation mills visited in the 1956 survey and the number of mills using each type of treatment.

LEACHING

In the United States, copper ores from which the copper may be separated by leaching are low-grade ores that yield perhaps 15 pounds or less of copper per ton. Economic considerations require that leaching be conducted at or very close to the copper mines; so the waters available for copper leaching closely resemble those used for copper mining and concentration by flotation. The hardness of the waters used at copper leaching plants is slightly higher than that of the waters used in copper mining. Water with a low pH is desirable to dissolve iron sulfates and copper from the ore. If no sulfates are available in the ore, sulfuric acid usually is added.

Maximun, minimum, and median values of the quality characteristics of the untreated water used in copper leaching operations and the number of plants reporting each characteristic are shown in table 13. Except for one chemical analysis made by the U.S. Geological Survey, the data on which table 13 is based were obtained from the copper companies.

TABLE 13.—*Statistical characteristics of chemical constituents and physical properties of untreated water used in the concentration of copper ores by leaching*

[Chemical constituents expressed in parts per million. These are based on individual observations and are not balanced analyses]

Constituent or property	Number of samples	Minimum	Median	Maximum
Silica (SiO_2)	5	20	25	47
Iron (Fe)	6	Trace	.01	35
Manganese (Mn)	5	0	Trace	9
Calcium (Ca)	7	16	100	433
Magnesium (Mg)	7	4.0	14	116
Sodium (Na)	4	5.3	16	29
Potassium (K)	2	1.8	-----	2.4
Bicarbonate (HCO_3)	4	64	200	378
Carbonate (CO_3)	3	0	-----	0
Sulfate (SO_4)	7	11	46	1,210
Chloride (Cl)	7	3.0	16	30
Fluoride (F)	2	.4	-----	.9
Dissolved solids	6	98	370	2,000
Hardness as $CaCO_3$	5	56	245	954
Noncarbonate hardness as $CaCO_3$	2	4	-----	758
pH	4	6.3	7.5	7.8
Color	2	8	-----	12
Temperature (°F)	3	62	-----	67

WATER TREATMENT

Many different treatment methods are employed to make the water more suitable for the purpose for which it is to be used. Some treatment makes the water less corrosive, other treatment makes it more suitable for leaching, still other treatment makes it satisfactory for domestic use. Table 10 presents a list of all the types of treatment used and the number of plants using each type of treatment for all or part of the water used at the nine leaching plants visited during the 1956 survey.

SMELTING

Although many copper smelters are located at or very close to copper mines or copper ore concentrating plants, they are not limited to such sites. A large part of the copper concentrates is moved considerable distances to places where water of better quality than that usually found at copper mines is available. Considerable waste heat is contained in the gases from the reverberatory furnaces and converters. The usual practice of utilizing this heat for power production requires water for boiler feed and condenser cooling. Thirteen of the eighteen smelters included in the 1956 inventory produce all or part of their electric power. Where there is a demand for sulfuric acid, the sulfur dioxide in the waste gases may be profitably converted to sulfuric acid. This involves the use of about 4,000 gallons of water per ton of sulfuric acid produced (Faith, Keyes, and Clark, 1957, p. 743).

Maximum, minimum, median, and quartile values of the quality characteristics of the untreated water used at the copper smelters and the number of smelters reporting each characteristic are shown in table 14. About 40 percent of the data on which table 14 is based were obtained from analyses by the Geological Survey, and the remainder of the data were supplied by the copper companies. Three smelters use ocean water for cooling, but no analyses of ocean water were included in table 14.

TABLE 14.—*Statistical characteristics of chemical constituents and physical properties of untreated water used at copper smelters*

[Chemical constituents expressed in parts per million. These are based on individual observations and are not balanced analyses. Analysis of ocean water used at three plants not included]

Constituent or property	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	18	2.5	6.5	16	36	46
Iron (Fe)	14	0	Trace	.08	.15	.34
Manganese (Mn)	10	.00	.00	.00	Trace	.29
Calcium (Ca)	19	5.3	14	36	110	433
Magnesium (Mg)	18	1.3	3.6	8.1	20	103
Sodium (Na)	12	1.1	1.4	18	135	3,670
Potassium (K)	8	.6	.8	1.5	5.4	89
Bicarbonate (HCO_3)	16	10	46	120	245	354
Carbonate (CO_3)	13	0	0	0	0	15
Sulfate (SO_4)	19	2.1	12	50	160	1,210
Chloride (Cl)	20	2.6	6.2	26	60	6,280
Fluoride (F)	10	0	.0	.1	.8	2.5
Nitrate (NO_3)	9	.0	.1	.7	2.9	10
Dissolved solids	17	34	68	290	960	11,300
Hardness as $CaCO_3$	14	20	47	102	260	1,220
Noncarbonate hardness as $CaCO_3$	8	0	4	8	74	958
pH	16	6.8	7.2	7.5	7.9	8.5
Color	7	0	------	2	------	5
Turbidity	2	1	------	------	------	2
Temperature (°F)	6	54	------	68	------	98

WATER TREATMENT

A large variety of treatment methods are used to modify the different kinds of water used at the smelters. Nearly all the domestic supplies are chlorinated either by the copper companies or by the agencies from which the water was purchased. The variety of treatment methods results from the need for making a variety of different waters more suitable for use for boiler feed water make-up and for cooling. Table 10 shows all the different types of treatment used for all or part of the water at the 18 smelters visited during the 1956 survey.

REFINING

Only a third of the electrolytic copper refineries in the United States are located close to the mines. The remaining two-thirds are located along the coasts close to a logical route that the copper might follow enroute from the mines to the fabricators. Most of the unrefined copper received at the refineries is about 98 percent pure; so it is economically feasible to ship the copper anodes thousands of miles before refining. The coastal refineries also received imported copper, copper produced from imported copper concentrates, and some copper scrap that can best be utilized by electrolytic refining. Because some water of very high quality is needed at all refineries, they are usually located at places where such water is available. For some purposes water of very low chloride content is desired. About half of the copper refineries produce electric power requiring water for boiler feed and condenser cooling. Four plants use ocean water for cooling; the warm water is returned to the ocean after it has passed through heat-exchangers.

Table 15 shows the maximum, minimum, median, and quartile values of the quality characteristics of the untreated water used at the electrolytic copper refineries and the number of plants reporting each characteristic. About 78 percent of the data on which table 15 is based were obtained from analyses by the Geological Survey, and the rest of the data were obtained from the copper companies. No ocean-water analyses were included in table 15.

TABLE 15.—*Statistical characteristics of chemical constituents and physical properties of untreated water used at electrolytic copper refineries*

[Chemical constituents expressed in parts per million. These are based on individual observations and are not balanced analyses. Analysis of ocean water used at four plants not included]

Constituent or property	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	9	2.5	6.2	14	25	44
Iron (Fe)	9	.0	.00	.05	.17	.28
Manganese (Mn)	8	.0	.00	.00	.05	.29
Calcium (Ca)	9	5.3	13	22	31	40
Magnesium (Mg)	9	1.3	1.8	4.3	9.6	27
Sodium (Na)	7	1.4	----------	5.2	----------	151
Potassium (K)	5	.6	----------	1.4	----------	3.8
Bicarbonate (HCO_3)	9	10	21	52	144	185
Carbonate (CO_3)	6	0	0	0	0	0
Sulfate (SO_4)	9	2.1	12	28	56	140
Chloride (Cl)	9	2.6	5.5	8.0	17	411
Fluoride (F)	8	.0	.0	.1	.4	.8
Nitrate (NO_3)	8	0	----------	.4	----------	22
Dissolved solids	9	34	73	110	300	1,150
Hardness as $CaCO_3$	9	20	39	67	112	200
Noncarbonate hardness as $CaCO_3$	7	0	----------	15	----------	54
pH	9	6.8	7.4	7.8	8.0	8.1
Color	6	0	----------	4	----------	5
Turbidity	6	0.1	----------	1.0	----------	8

WATER TREATMENT

The pattern of water-treatment methods used at the refineries differs considerably from that in other phases of copper production. Nearly all the domestic water is obtained from public supplies; so chlorination is not generally practiced. Some very high quality water is required for process and washing; so unless unusually high quality water is available, distillation and zeolite treatment is needed to improve the quality. A few other treatments were used, most of which were intended to make the water more suitable for boiler feed. A listing of the various water-treatment methods used at the electrolytic copper refineries together with the number of plants using each method is shown in table 10.

CHARACTERISTICS OF LIQUID WASTES

The liquid wastes of the copper industry usually do not present a difficult disposal problem. Domestic sewage wastes from the plants and at a few places from company dwellings or towns also are usually processed in Imhoff tanks or similar disposal units. However, at some of the flotation mills, domestic sewage is discharged with the tailings to the disposal area where contact with the water containing copper salts acts as a bactericide. The most objectionable liquid waste is a solution containing high concentrations of iron sulfate from the iron launders in the leaching of copper-oxide ores. Ordinarily the iron sulfate solution is discharged to evaporation pits. Some cooling water is discharged at the smelters and the refineries and at a few mines and plants that produce their own electricity. Mine drainage water that is surplus to the needs of the mines and ore beneficiation plants is wasted at only a few locations visited in the 1956 inventory.

COMPARISON WITH OTHER SURVEYS

The Bureau of the Census collects information concerning the amount of water used at mines and plants where primary copper is produced. At many of these installations other minerals and products also are mined or manufactured. The total water use at any mine or plant is listed by the Bureau of the Census under the principal mineral or product produced. Thus, some water use reported includes water used to produce other material than copper, and conversely some water used to produce copper is listed under another category.

The census of mineral industries for 1954 shows 59,000 mg (million gallons) used to mine copper, and the census of manufactures for 1954 shows 42,000 mg used to manufacture primary copper. The sum of these values, 101,000 mg, represents the equivalent, for 1954, of all steps in the process of producing copper from mining to refining as used in this report. Data from McMahon and Greenspoon (1958) show that the production of copper in 1955 was 18 percent greater than in 1954. Assuming that the water use was also 18 percent greater gives a total of 119,000 mg for 1955 from Bureau of the Census figures as compared with 121,000 mg determined by this survey. This difference is well within the probable error of either investigation.

FUTURE WATER REQUIREMENTS

Copper is a comparatively scarce metal. The known copper ore reserves of the United States that can be profitably mined with known techniques at current copper prices will be exhausted in about 30 years if mining continues at current rates (Meyer, 1956, p. 233).

There are additional deposits of lower grade copper ores. The copper mining industry probably will utilize ores of progressively lower grades as it has in the past. Because the amount of water used for concentrating the ores by flotation or extracting the copper by leaching varies about as the tonnage of ore involved rather than with the copper extracted, the total water used in mining, flotation, and leaching per pound of copper produced may be expected to gradually increase.

The annual consumption of copper in the United States during the years 1910 to 1956, inclusive, has varied widely, from less than 300 thousand tons in 1932 to more than 1,600 thousand tons in 1941. (See fig. 31.) This fluctuation in demand for copper results in corresponding price changes and variations in production. Peaks in cycles of annual domestic copper production have increased only slightly since World War I. About 1940 we changed from a copper-surplus to a copper-short nation. Annual domestic copper production for future years is very difficult to predict and probably will depend, to a large extent, on national and international business and political conditions prevailing at the time. However, copper production during years of war or expanding industrial output probably will be greater than production during years of peace or recession.

Before 1907 most of copper produced in the United States came from Michigan and Montana. Since 1907, the bulk of our domestic copper has been produced in the Southwest (Alderfer and Michl, 1950, p. 90). Figure 32 shows the 1955 mine production of recoverable copper by States. No mine production is shown for States

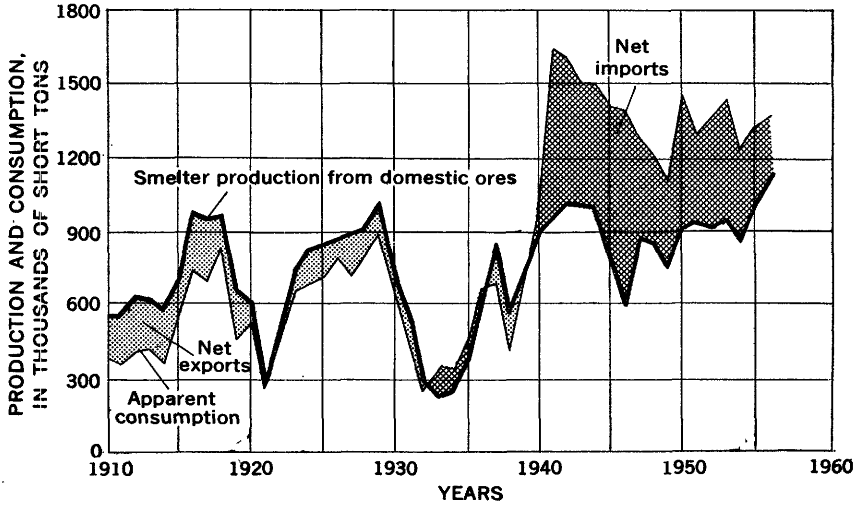

FIGURE 31.—Production and consumption of copper in the United States, 1910–56. (Source: U.S. Bureau of Mines, 1956, Minerals yearbook).

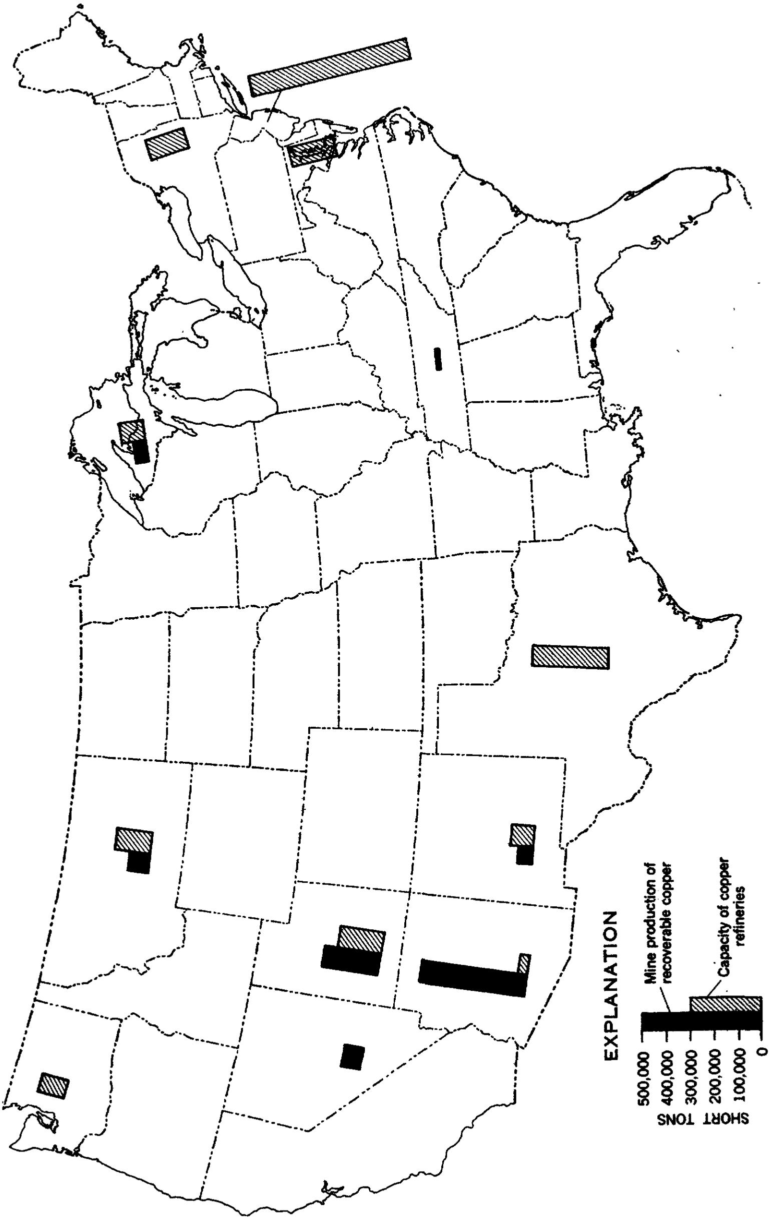

FIGURE 32.—Mine production of recoverable copper and capacity of copper refineries, by States, 1955. (Source: U.S. Bureau of Mines, 1955, Minerals yearbook; and American Bureau of Metal Statistics, 1955, Yearbook.)

where 1955 output was less than 6,000 tons of copper. Arizona, Nevada, New Mexico, and Utah produced more than five-sixths of the recoverable domestic copper mined in the United States in 1955. Water use for mining, flotation, and most of the smelting takes place not far from the mines.

The copper refineries are generally located along the route that the copper might travel from the smelters to the fabrication plants. Refinery capacity by States is also shown in figure 32. The total refinery capacity is considerably greater than mine production of recoverable copper. There are several reasons for this large difference. Not all refineries operate at capacity throughout the year. Refineries process secondary or reclaimed scrap copper and imported copper as well as newly mined domestic copper.

In many cases, records of mine and plant output in tons of ore and pounds of copper as well as gallons of water used over a period of years were available to the author. There is a definite tendency for mine and plant output to increase over a period of years. This is accompanied by an increase in water use.

Some ores that contain copper oxides and copper sulfides are treated first by leaching and then by flotation to recover greater amounts of copper than would be possible with treatment by only one method (Iron Age, 1956, p. 40). This type of ore probably will be mined more extensively as ores that can be utilized by simple extraction procedures are depleted, and the double treatment will require more water per ton of ore.

On the other hand, there is the possibility that some water-saving practices may be developed. Because petroleum products, even in very small quantities, interfere with the flotation of copper sulfides, water rather than ordinary road oil is used for dust control on haulage roads in open-pit sulfide-copper mines. Lignin sulfonate has been successfully used in tests of dust control on haulage roads in the open-pit mines in arid parts of the Southwest with resultant savings of water (Harmon, 1957, p. 1). Because of the difficulty of keeping the lignin sulfonate out of the ore, the Bureau of Mines recommends that at mines where froth flotation methods are used for concentrating the ore, tests be made to see if the lignin sulfonate interferes with the concentration methods before any such roads are constructed in the pits.

SUMMARY

QUANTITATIVE WATER REQUIREMENTS

Water from many sources was utilized in producing primary copper. Some water was purchased from public supplies, but most of it was obtained from facilities developed by the copper companies. The water was obtained from both surface-and ground-water supplies, and some of it was fresh and some was saline. The amounts of each kind of water used for each type of operation in copper production during 1955 are summarized in table 16. More than 120,000 million gallons (or about 330 mgd) was used for all purposes in producing copper in 1955.

TABLE 16.—*Source and amount of water used in various operations in the copper industry, 1955*

Type of operation	Water intake, in millions of gallons						
	Public supplies		Self supplied				Total
	Ground water	Surface water	Ground water		Surface water		
			Fresh	Saline	Fresh	Saline	
Mining	190	1,000	1,790	100	2,400	70	5,550
Flotation	220	4,900	8,250	8,230	31,600	14,400	67,600
Leaching	0	0	2,190	460	190	0	2,840
Smelting [1]	5,450	350	590	610	14,000	7,700	28,700
Electrolytic refining	800	650	630	40	180	13,600	15,900
Total	6,660	6,900	13,450	9,440	48,370	35,770	120,590

[1] Includes fire refining.

The unit water-use values for various types of operations determined from the 1955 survey are summarized in table 17. The total production of copper during 1955 in the plants included in the survey, the total water use in 1955, and the values of average and median unit water use per pound and per ton of copper are included in the table. The average unit water-use values for all types of operation except leaching are greater than the median values. A large part of the copper production is in areas where water costs are quite high. For this reason water-use practices have been established in those areas that result in unit water-use values considerably lower than average. The median values of unit water use given in table 17 probably would be approached in areas where water costs were high. All except one of the copper-leaching sites included in the 1955 survey are in areas where water is scarce. It is probably more than a coincidence that the median value of unit water use for leaching differs less than 2 percent from the average.

TABLE 17.—*Average and median water use in the production of copper, by operations, 1955*

Type of operation	Copper processed (million pounds)	Water use			
		Gallons per pound of copper		Gallons per ton of copper	
		Average	Median	Average	Median
Mining	2,050	2.71	2.0	5,400	4,000
Flotation	1,920	35.2	19	70,400	38,000
Leaching	192	14.8	15	29,600	30,000
Smelting [1]	2,780	10.3	4.9	20,600	9,800
Electrolytic refining	2,970	5.35	1.2	10,700	2,400

[1] Includes fire refining.

There are several paths which may be followed in producing primary copper from domestic ores. First of all, the ore must be mined and nearly all the ore must be concentrated before smelting. About 91 percent of our domestic copper is derived from ore that is concentrated by flotation, and the remaining 9 percent is obtained by leaching. All the concentrate must be smelted, and about 10 percent of the copper is smelted with so much care that it is marketed as fire-refined copper. About 90 percent of the copper is electrolytically refined (McMahon and Greenspoon, 1958, p. 428). Thus, the ore may follow one of four different paths in its reduction to primary copper; namely, mining, flotation, smelting, and electrolytic refining; mining, flotation, and smelting to fire-refined copper; mining, leaching, smelting, and electrolytic refining; or mining, leaching, and smelting to fire-refined copper. Average values of water use in producing copper by each of these different methods, expressed in gallons per unit of finished product are presented in table 18. A weighted average value for all methods is also shown in the table. Other columns show the sum of the median values of unit water use for each of the various types of operation employed by each process for reducing ore to primary copper. These values, obtained by adding the medians, are presented as reasonable values of anticipated unit water use for producing copper in areas where water is scarce or comparatively high priced. Because most of our domestic copper is produced using flotation and electrolytic refining, a unit water use of about 27 gallons per pound of copper might be considered reasonable in areas where water was scarce or high priced.

TABLE 18.—*Average and median unit water use in the production of domestic copper by various methods, 1955*

Operations employed (in addition to mining and smelting)	Total water use in production of refined copper shapes			
	Gallon per pound of copper		Gallon per ton of copper	
	Average	Sum of medians [1]	Average	Sum of medians [1]
Flotation and electrolytic refining	53.6	27.1	107.000	54,200
Flotation and fire refining	48.2	25.9	96,400	51,800
Leaching and electrolytic refining	33.2	23.1	66,400	46,200
Leaching and fire refining	27.8	21.9	55,600	43,800
Weighted average of all methods	51.1		102,000	

[1] This column shows the sum of the median values of water use for each of the operations employed.

QUALITATIVE WATER REQUIREMENTS

Most of the water needed in copper mining is used to control silica dust in the open-pit mines. Water used for dust control may be of poor quality, but in the sulfide mines it must be free of petroleum products which remain with the ores and interfere with concentration by flotation. Domestic water supplies used at the mines usually are chlorinated.

The waters used for concentration of copper ores by flotation generally are similar to, but not so hard as, the waters used in mining. Water used for flotation should be free of acid, mud, slime, and particularly petroleum products. More than a quarter of the flotation plants reuse sewage effluents for process water. Some process water is treated to reduce corrosion damage, and domestic water not obtained from public supplies is usually chlorinated.

The water used in the leaching process is similar to, but slightly harder than that used in the copper mines. Water with a low pH is desired. Domestic water is usually chlorinated. Process water receives various treatments, some to make it less corrosive and others to make it more suitable for leaching.

Copper smelters are usually located where better quality water is available than that used for mining, flotation, or leaching. Considerable boiler-feed water, preferably of good quality, is needed to utilize the waste heat that is a byproduct of copper smelting. Cooling water is also needed for producing steam power and, in some localities, for manufacturing sulfuric acid. Water treatment methods are those usually employed for boiler feed and cooling water.

The electrolytic copper refineries generally use a better quality of untreated water than is available in any other phase of producing primary copper. However, most of the copper is refined near the coast, and ocean water is used for cooling by means of heat exchangers in four plants. Nearly all the potable water is obtained from public supplies and does not require chlorination. Some distilled or zeolite-treated water is used for washing cathodes.

Table 19 presents a comparison of the median values of four significant constituents and one significant property of the untreated water used in each type of operation involved in mining and manufacturing primary copper.

TABLE 19.—*Median values of selected constituents and properties from analyses of untreated water for the copper-industry survey of 1956*

[Chemical constituents in parts per million]

Constituent or property	Mining	Flotation	Leaching	Smelting	Refining
Bicarbonate	180	160	200	120	52
Sulfate	43	58	46	50	28
Dissolved solids	390	405	370	290	110
Hardness (as $CaCO_3$)	220	170	245	102	67
pH	7.6	7.6	7.5	7.5	7.8

TRENDS IN WATER REQUIREMENTS

Domestic copper ore reserves that might be mined at present copper prices probably will be exhausted in about 30 years. However, we probably will continue to mine ores of progressively lower grades as we have in the past. Some ores that can be concentrated only by employing both flotation and leaching probably will also be utilized. Unless new methods or techniques are developed more water will be used for each pound of copper produced than at present. On the other hand, the use of lignin sulfonate as a road binder for dust control on haulage roads in open-pit mines might tend to decrease water use in the future. The net change probably would be an increase in water use per pound of copper produced.

Large fluctuations in copper production and resultant water use may be anticipated in the industry. The greatest production and the greatest water use may be expected in time of war or industrial expansion.

Most of the water use in copper production is concentrated in Arizona, Nevada, New Mexico, and Utah which currently produce five-sixths of the domestic supply. These States probably will continue to supply most of the domestic copper ore and continue to use most of the water needed for copper production. Most of the large electrolytic copper refineries are located near New York City. This is a logical and economical site for the refineries; so most of the electrolytic copper refining and the need for water for the refineries probably will continue at or near the present location.

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U.S. GOVERNMENT PRINTING OFFICE: 1961