Water Requirements of the Iron and Steel Industry

By FAULKNER B. WALLING and LOUIS E. OTTS, Jr.

WATER REQUIREMENTS OF SELECTED INDUSTRIES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1330-H

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 67-220

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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WATER REQUIREMENTS OF THE IRON AND STEEL INDUSTRIES

By FAULKNER B. WALLING[1] and LOUIS E. OTTS, JR.[2]

ABSTRACT

Twenty-nine steel plants surveyed during 1957 and 1958 withdrew from various sources about 1,400 billion gallons of water annually and produced 40.8 million tons of ingot steel. This is equivalent to about 34,000 gallons of water per ton of steel. Fifteen iron ore mines and fifteen ore concentration plants together withdrew annually about 89,000 million gallons to produce 15 million tons of iron ore concentrate, or 5,900 gallons per ton of concentrate. About 97 percent of the water used in the steel plants came from surface sources, 2.2 percent was reclaimed sewage, and 1.2 percent was ground water. Steel plants supplied about 96 percent of their own water requirements, although only three plants used self-supplied water exclusively. Water used by the iron ore mines and concentration plants was also predominantly self supplied from surface source.

Water use in the iron and steel industry varied widely and depended on the availability of water, age and condition of plants and equipment, kinds of processes, and plant operating procedures. Gross water use in integrated steel plants ranged from 11,200 to 110,000 gallons per ton of steel ingots, and in steel processing plants it ranged from 4,180 to 26,700 gallons per ton. Water reuse also varied widely—from 0 to 18 times in integrated steel plants and from 0 to 44 times in steel processing plants. Availability of water seemed to be the prinicpal factor in determining the rate of reuse. Of the units within steel plants, a typical (median) blast furnace required 20,500 gallons of water per ton of pig iron. At the 1956–60 average rate of pig iron consumption, this amounts to about 13,000 gallons per ton of steel ingots or about 40 percent of that required by a typical integrated steel plant—33,200 gallons per ton. Different processes of iron ore concentration are devised specifically for the various kinds of ore. These processes result in a wide range of water use—from 124 to 11,300 gallons of water per ton of iron ore concentrate. Water use in concentration plants is related to the physical state of the ore. The data in this report indicate that grain size of the ore is the most important factor; the very fine grained taconite and jasper required the greatest amount of water. Reuse vas not widely practiced in the iron ore industry.

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Consumption of water by integrated steel plants ranged from 0 to 2,010 gallons per ton of ingot steel and by steel processing plants from 120 to 3,420 gallons per ton. Consumption by a typical integrated steel plant was 681 gallons per ton of ingot steel, about 1.8 percent of the intake and about 1 percent of the gross water use. Consumption by a typical steel processing plant was 646 gallons per ton, 18 percent of the intake, and 3.2 percent of the gross water use.

The quality of available water was found not to be a critical factor in choosing the location of steel plants, although changes in equipment and in operating procedures are necessary when poor-quality water is used. The use of saline water having a concentration of dissolved solids as much as 10,400 ppm (parts per million) was reported. This very saline water was used for cooling furnaces and for quenching slag. In operations such as rolling steel in which the water comes into contact with the steel being processed, better quality water is used, although water containing as much as 3,410 ppm dissolved solids has been used for this purpose. Treatment of water for use in the iron and steel industry was not widely practiced. Disinfection and treatment for scale and corrosion control were the most frequently used treatment methods.

INTRODUCTION

PURPOSE AND SCOPE

This report is one of a series describing the water requirements of selected industries of national importance. It is designed to furnish basic information on the water requirements of the iron and steel industry and should be useful in planning the industrial development of areas where water resources must be considered. Knowledge of the water requirements of all industries that use a significant amount of water is necessary to assure adequate management of water supplies of industrial and potentially industrial areas.

This investigation included field surveys, made during 1957 and 1958, of 16 installations in the iron ore industry and 29 installations in the steel industry. Location of these installations are shown in figure 52. The mines and plants visited represent a cross section of the iron and steel industry with respect to geographic distribution, plant size, and processes used. Fourteen of the installations in the iron industry were operated as mine-concentration plant combinations, although in some places the distance from the mine to the concentration plant was a few miles. Only one mine and one concentration plant operated as independent units. The steel plants include both integrated steel plants (plants that begin with concentrated iron ore and produce a rolled or cast product) and steel processing plants (plants that begin with pig iron or scrap and produce a rolled or cast product). Some plants consisting of single units such as coke ovens and blast furnaces were included in the survey, but the data for these were used only in computations for the various units.

FIGURE 52.—Location of mines and steel plants surveyed, 1957–58.

A survey was made to assess published data on water use in the iron and steel industry. These data are presented at appropriate places in the text.

O. D. Mussey collected the data upon which this report is based but did not participate in preparing the report; the authors are solely responsible for the conclusions presented. Acknowledgment is given to the many company officials who permitted Geological Survey personnel to visit their plants and who furnished water-use data and to Dr. R. D. Hoak, of the Mellon Institute, for his consultation and advice.

BASIS FOR REPORTING WATER-USE DATA

Data requested for each mine, concentration plant, and steel plant and for each unit within the steel plants included source of supply, amount of water used, quality of untreated intake water, and treatment of water. These data were requested for each important use—cooling, boiler feed, sanitation and service, and other uses within each plant and within each unit. For each use, amounts of intake water, gross water use, water consumed, and effluent were requested. Intake water is water added to a system to replace water consumed and effluent from the system. Effluent from a plant is discharged to a waste-disposal system, but effluent from a unit may be reused with or without treatment in another unit. Water is consumed mainly by evaporation, by spray from cooling towers, or by incorporation into a product. In most places the amount of water consumed is very difficult to determine and is usually taken as the difference between intake and effluent or is estimated by the plant operator. In once-through systems, effluent usually is not measured; hence, consumptive use is either not reported or is reported to be zero.

In this report, water use is generally classified according to the definitions of Mussey (1961). Mussey's definitions are: **process water,** water that comes into contact with an end product or with materials incorporated into an end product; **cooling water,** water used exclusively for cooling; **boiler-feed water,** water introduced into boilers for conversion to steam; and **sanitary and service water,** water used for drinking, showers, general cleaning, and flushing wastes. However, in hot-rolling mills, water used for descaling and cooling steel (process water) and water used for cooling rolls and bearings (cooling water) were reported together. Inasmuch as the steel industry generally considers all water used in rolling mills as cooling water, it is reported as such in this report. **Intake water** is water added to a system, **consumptive use** is water lost by evaporation or by incorporation into a product, and **effluent** is water discharged from the system. **Gross water use** equals the intake water plus water reused within the system. Effluent from a plant is discharged to a waste disposal system; however, within a plant, effluent from one unit may be used as intake for another unit. In most places the amount of water consumed was very difficult to determine and was usually considered to be the difference between intake and effluent or was estimated by the plant operator. In once-through systems, effluent generally is not measured; hence, consumptive use was either not reported or was reported to be zero.

Most units within a steel plant make only one major product such as coke, pig iron, or ingot steel, although many byproducts are obtained. For all units treated separately in this report, water use is referred to the major product. For example, water use in a coke plant is reported in gallons per ton of coke. However, because of the wide variety of products of integrated steel plants and steel processing plants, water use by these plants is reported in gallons per ton of ingot steel. In iron ore concentration plants, water use is referred to both raw and concentrated ore.

HOW WATER IS USED

Most of the water used in the iron and steel industry is used for cooling, to protect equipment and to improve the working conditions of the employees. A smaller, but still considerable, amount of water is used as process water to concentrate iron ore, cleanse coke-oven gases, quench coke and slag, and descale steel (in this report, water used to descale steel is classed as cooling water). A small amount of water is used for boiler-feed water and for sanitary and service water. Water used for dust control in mines and concentration plants, for drilling, and hydraulic stripping is classed as other use.

Some of the processes and equipment used in the iron and steel industry are described below to help the reader to visualize use of water in the industry.

MINES AND CONCENTRATION PLANTS

Rotary and churn drilling have been the most extensively used methods for drilling blast holes and for prospecting in soft rock. In rotary and churn drilling, the cuttings and water produce a slurry which is bailed or pumped from the drill hole. During the last few years, increasing use of hard ores, such as jasper and taconite, has hastened the use of jet piercing. Jet piercing uses a flame that has a high velocity, 6,000 fps (feet per second), and a high temperature, 4,300° F, to cause hard rock to spall or flake because of thermal stress. In this operation, water is used (a) to cool the burner and the blow

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pipe, (b) to help break up fused minerals, and (c) when flashed to steam in the hole, to assist in removing the cuttings.

Health and safety of mine employees require dust control, which is commonly accomplished by sprinkling water on roads and ore. In arid regions continuous sprinkling is sometimes required. This water is lost by evaporation.

Most of the iron ore mined in the United States contains only a low percentage of iron, and the ore generally has to be concentrated. The increased efficiency of a blast furnace that results from the use of an ore that is highly concentrated makes it economical to concentrate some ores that would otherwise be unusable without concentration. Several processes are used to concentrate iron ore. The choice of processes depends upon the physical state and mineral content of the ore. The more important characteristics of iron ore that affect the choice are liberation size (the particle size to which the ore must be crushed to liberate the desired mineral), the relative particle sizes of iron mineral and gangue, and the magnetic properties of the iron mineral. Ore in which the particles of gangue is small relative to the particles of iron mineral can be concentrated by simple washing. Magnetic ore can be concentrated by magnetic separation. For ore in which the difference in densities of the iron mineral and the gangue is the only characteristic that can be used for a separation, heavy-media separation or some form of classification is used.

Reduction of ore to liberation size, in which the particles may be as large as a few inches in diameter or as fine as flour, is done in various types and sizes of crushers and grinders. Coarse crushing, generally done in jaw and gyratory crushers, produces a large amount of dust which is suppressed by water sprays. This water is lost by evaporation—a consumptive use. When reduced to very small particles, ore containing a small amount of moisture tends to cake and resist further grinding and handling. To prevent such caking in ball or rod mills, water is added to form a slurry that will flow readily. Some of this water is lost by evaporation, but some is recovered in settling basins and clarifiers for reuse. Much ore requires more than one step in size reduction. Between each step some form of classification or sizing is used that requires additional water.

Iron ore containing gangue of mostly fine material (sand size or smaller) and iron minerals of relatively large particle size is concentrated by washing, generally on vibrating screens of trummels (rotating cylindrical screens). Aided by the scrubbing of the iron ore particles against each other, water sprayed over the ore loosens and washes away the fine particles of gangue. Much of the water used adheres to the iron ore concentrate and ultimately evaporates. Water containing the gangue is pumped to a tailings basin where the water may be recovered for reuse. Washing is also used in the recovery of fine material employed in other operations, such as heavy-media separation, or in any situation where it is necessary to remove fine particles from larger ones.

A widely used process for the concentration of iron ore is heavy-media separation (also called sink-float) which depends for its effectiveness only upon the difference in specific gravities of the iron minerals and gangue. The medium generally used in the iron ore industry is a liquid composed of water and finely ground ferrosilicon, a magnetic mineral, held in suspension by agitation. The concentration of the ferrosilicon is adjusted to give the liquid a specific gravity (about 3.2) intermediate between the specific gravity of the iron minerals and that of gangue. Ore to be treated is fed into the suspension in a vessel constructed so that the gangue which floats may be removed from the top and the concentrate withdrawn at the bottom. Much ferrosilicon is removed from the vessel with both the gangue and the concentrate, and because ferrosilicon is quite expensive it must be recovered. The ferrosilicon is first washed from the concentrate and the gangue over the fine screens and then recovered from the nonmagnetic fines by magnetic separation.

A magnetic separator consists basically of a magnet, an apparatus for bringing the ore into the magnetic field, and a moving collection surface between the stream of ore and the magnet. In most magnetic separators used to concentrate iron ore, the collection surface is a drum that rotates around the magnet. As magnetic particles enter the field they are drawn toward the magnet and are intercepted by the drum. The rotation of the drum carries the attached particles out of the magnetic field where they are discharged as concentrated ore. The gangue and any nonmagnetic ore present pass through to be discarded or to be re-treated. Water used in magnetic separators is primarily a transport medium and most of it can be recovered, but some is lost by evaporation.

Classifiers separate solids according to the velocity at which the particles settle through a fluid. Settling velocity depends upon both particle size and density. Among several types of classifiers used in the concentration of iron ore are the cyclone separators and hydroseparators. In cyclone separators used for iron ore, water that contains finely ground magnetite (less than 100 mesh) and iron ore to be treated is pumped tangentially into a cone-shaped tank. The centrifugal force of the swirling liquid causes the heavier particles (iron mineral) to move to the outside where they settle toward the lower outlet. The lighter particles are forced toward the center and the top outlet. The magnetite, used to increase the specific gravity of the liquid, is recovered from the gangue and the iron mineral by magnetic separation. Hydroseparators are similar to clarifiers used for water treatment except that they are small enough to produce an overflow that contains the finer and lighter particles; particles having a faster settling rate are withdrawn at the bottom. Classification, and most other concentration methods used in the iron ore industry, consumes little water. That retained by the concentrate is lost by evaporation, but most of the water discharged to tailings basins where it can be recovered if needed.

STEEL PLANTS

At steel plants, iron ore concentrate is reduced to iron and processed into useful steel products, and scrap steel is reprocessed into new products. Integrated steel plants, as defined for this report, consist of blast furnaces, one or more units for making steel from iron (open-hearth furnace, electric furnace, or converter), and a rolling mill or casting unit. An integrated plant may include coke ovens, wire-drawing machines, rod mills, and other iron working units. A steel processing plant is defined as an integrated plant without coke ovens and blast furnaces. Plate 4 shows a generalized layout of an integrated steel plant. The routing of water between units and within units varies greatly within the steel industry, depending upon availability of water, quality of water, and age of the steel plant.

COKING PLANTS

Most integrated steel plants surveyed operate byproduct coke ovens, in which coal is heated to about 1,900°F to expell most of the volatile matter. This process leaves only carbon and ash in the coke (coke from the ovens contains 1–3 percent volatile matter). The vapors evolved from the coke ovens contain several useful chemicals such as ammonia and benzene and a low percentage of fuel gases. This survey provided data on water used within the plant in the removal of byproduct chemicals, water vapor, and dust from the coke-oven gas, but it did not cover the use of water in the refining of the chemicals. Processing of coke-oven gas consists basically of cooling to condense water vapor and tars, absorption of ammonia in an acid solution, and scrubbing the gas to remove light oils (benzol, solvent naphtha, and other products).

Vapors from the coke enter primary coolers where the tars and water vapor are condensed, and some of the ammonia is dissolved in the condensate to form what is called ammonia liquor. Two types of primary coolers are commonly used for processing coke-oven gas.

In one type the vapors pass over a series of water-cooled coils. The cooling water from this type of cooler is circulated through a cooling tower for reuse or is discharged. In the other type the vapor passes through a spray of ammonia liquor which is cooled in a water-cooled heat exchanger and is reused. The ultimate cooling water in both types does not come into contact with the vapors and is not contaminated.

After primary cooling, the condensed tars are decanted from the ammonia liquor. The ammonia liquor can then be distilled to remove the ammonia as a gas which along with the ammonia remaining in the coke-oven gas is absorbed in sulfuric acid. The ammonium sulfate thus formed is crystallized, dried, and sold to be used as a fertilizer. Final cooling is done by passing the coke-oven gas through a spray of cooling water which is reused extensively and may finally disposed of in coke quenching. The gas is then scrubbed (passed through an absorption column) to remove the light oils.

After the vapors have been expelled, the coke is pushed into a car and as quickly as possible is moved to a quenching tower to be cooled by a spray. Quenching reduces the temperature to less than the combustion temperature, but enough heat is left in the coke to assure a low moisture content. Water for coke quenching, often including excess ammonia liquor from the gas coolers, commonly is circulated through the quenching tower until completely evaporated.

BLAST FURNACE

In the reduction of iron ore to iron, concentrated iron ore, coke, and a fluxing agent (limestone or dolomite) are charged into the top of the blast furnace while hot air is blown in through tuyeres near the bottom. Coke provides both the fuel for heating the reactants to reaction temperature and the reducing agent for the reduction of iron oxide to iron. Molten iron, being heavier than the other products, collects in the hearth from which it is periodically withdrawn; it is transferred to an open-hearth or an electric furnace or is cast into pigs. The fluxing agent fuses and forms a slag on top of the iron and dissolves many impurities that would otherwise contaminate the iron. The slag is periodically withdrawn and is sometimes quenched with water.

A typical blast furnace would be about 100 feet high (pl. 4) and would have a diameter of 30 feet at the largest section (about 19 ft above the bottom). The hearth would be a 10-foot-high cylindrical section at the bottom and have a tap hole at the bottom for removing the molten iron and have a slag notch at a height of 5 feet for removing the slag. The hot air is blown into the flared section, called the bosh, immediately above the hearth; the bosh extends to the mantle.

Above the mantle and supported by it, a stack tapers from an inside diameter of 30 feet to 20 feet at the top. A steel jacket surrounds the furnace and supports the thick refractory insulation which lines the furnace.

A blast furnace is normally in continuous operation for several years during which only minor repairs can be made. Refractory linings are in contact with materials and gases at a temperature that ranges from about 3,000°F in the hearth to 2,500°F at the mantle and 350°F at the top. At the higher temperatures, refractories become relatively soft and subject to erosion and corrosion, and without cooling their service life would be short. This necessary cooling is effected by circulating large quantities of water through plates (tanks, tapered to fit into the refractories) and pipes embedded in the furnace walls. The most intensive cooling is provided for the bosh where most of the heat is generated, but modern furnaces may have several hundred cooling plates above the mantle. Blast furnace hearths are usually cooled by water flowing through staves inside the hearth jacket, but some hearths above the ground may be cooled by water sprayed on the jacket. A water spray may also be used for emergency cooling when refractories are burned out, and small areas of the steel jacket are exposed to extreme temperatures. All water sprayed on the outside of a blast furnace is probably evaporated.

Large volumes of air are compressed for the blast furnace (usually by steam-driven turbo blowers), heated to 1,000°F to 1,500°F, and blown into the furnace near the bottom. The steam turbines require a considerable amount of cooling water for condensers. Tuyeres through which the air is blown into the furnace are cooled by water circulating through an annular space around the tip and a conical copper cooler in the wall around the tuyere. Copper coolers also surround the slag notch.

Gases from blast furnaces have a low heating value and are cleaned and cooled before being used to satisfy various heating requirements within the plant. In most plants, the gases flow through dry-dust collectors, spray towers, and finally through wet electrostatic precipitators. Most of the dust is removed in the dry-dust collector by gravitational and centrifugal forces. From the dust collector the gases enter the spray tower at the bottom and rise through water sprays. The towers commonly contain trays, baffles, rotating cones, and other devices to assure intimate contact between the dust and water. Final cleaning is usually done with an electrostatic precipitator in which gas and dust pass between two electrically charged surfaces. The dust particles become negatively charged and are collected on the positively charged surface. A thin film of water flows over the collecting surface and carries the dust to a waste-disposal system. Waste water from the spray tower and electrostatic precipitator is usually treated to remove the suspended solids.

OPEN-HEARTH FURNACE

Open-hearth furnaces refine and compound about 90 percent of the steel produced in the United States. Some large furnaces produce as much as 500 tons of steel in one batch, called a "heat." At the beginning of a "heat," limestone and a small amount of iron ore are charged through doors in the front of the furnace and then steel scrap and pig iron are added. Scrap and pig iron are melted as they are added to the furnace, and liquid pig iron, if used, is added after all cold-charged iron has melted. Oil- or gas-fired burners at both ends of the furnace heat the charge to a final temperature of about 3,000° F. Air for combustion enters through checkers at one end of the furnace while the exhaust gases pass out through similar checkers at the other end. Periodically the flow of gas is reversed; thus checkers that have been heated by exhaust gases in turn heat the incoming air.

Manganese, silica, phosphorus, sulfur, and carbon are the chief impurities that are oxidized and dissolved in the slag. To hasten oxidation of these impurities, oxygen may be added through an oxygen lance—a water-cooled tube projecting into the furnace. After the amounts of impurities have been reduced to less than specified concentrations and carbon and alloy metals and temperature have been adjusted, the steel is withdrawn and molded into ingots or cast products.

Many parts of open-hearth furnaces must be cooled to prevent destruction or warping. Burners and oxygen lances, which project inside the furnaces, are protected by water-cooled jackets. Door frames, doors, reversing valves, stack valves, and a few structural supports are protected by some type of cooling system. These parts are often of double-wall construction and have water circulating between the walls. Some sections of furnace refractories exposed to gas of high velocity and temperature may be cooled by pipe coolers. Wall sections that require cooling are bridge walls, monkey walls, downtakes, and burner doghouses. For the comfort and safety of workmen while tapping the furnace, back walls, where the tap holes are located, are sometimes cooled.

ELECTRIC FURNACE

Steel production in electric furnaces has climbed steadily during the last 50 years or so and in 1960 was about 10 percent of the total steel production in the United States. Electric furnaces are more easily controlled than open-hearth furnaces, and they are therefore more adaptable to the production of high-quality steel for which the demand is growing. All large electric furnaces are heated by electric arcs, but many small ones are heated by induction. Induction furnaces operate in a manner similar to that of an electrical transformer. A crucible inside a water- or an oil-cooled coil contains the metal charge. This coil may be of the transformer type or a coil of copper tubing imbedded in the refractory lining of the crucible. An electric current in the coil generates eddy currents in the metal to be melted and refined. Resistance to these eddy currents converts the electrical energy into heat.

Water cooling is used to prevent warping of metal parts and to maintain a seal at the top of the furnace and around the door. A water jacket in the rim of the lid or in the furnace rim in which the lid rests provides cooling for the top. Doors and door jambs are usually of double-wall construction and have water circulating through them. In electric-arc furnaces, water-cooled rings protect the electrodes. In induction furnaces, transformer-type coils are cooled by oil which in turn is cooled by water in a heat exchanger, whereas the copper-tube coils are cooled by water circulating through the tubing.

HOT-ROLLING MILLS

In the course of its manufacture, most of the world's steel is rolled by one or more hot-rolling mills. Generally, the rolling process begins in primary hot-rolling mills with ingots from open-hearth or electric furnaces. To bring them to a uniform temperature, commonly 2,150° F to 2,500° F depending on the composition of the steel and characteristics of the rolling mill, ingots are placed in heating furnaces, termed "soaking pits." After several hours in the soaking pits, ingots are rolled into blooms, slabs, or billets. These terms are used somewhat loosely, but, generally, blooms are composed of large square cross sections, billets of small square cross sections (seldom greater than 4 in. square), and slabs of rectangular cross sections. Products of primary rolling mills go to secondary hot-rolling mills where a large variety of products are made. Some of these are finished products such as structural steel and rails, but some steel strip, rod, and plate undergo further processing by cold rolling or drawing.

Various types of hot-rolling mills are used in the steel industry. The essential features of any of these types are a pair of rolls revolving in opposite directions, a mechanism, commonly called a table, for directing the steel to the rolls, and a table for handling the rolled pieces. The table in front of the rolls forces the steel against the rolls which grip and pull the steel between them. Steel is, thus, reduced to a thickness equal to the distance between the rolls, and if the rolls are grooved it is shaped according to the groove design. A stand (set of rolls) having two horizontal rolls one above the other is called a two-high stand. Two backup rolls, generally much larger than the operating rolls, may be placed against the two operating rolls to prevent their distortion. These are called four-high stands. Both two- and four-high stands may be either reversing mills in which the steel passes back and forth between the same rolls or continuous mills in which the steel passes through several stands in tandem. In three-high mills, which have three rolls arranged vertically, steel passes forward between the middle roll and bottom roll and backward between the middle and top rolls. Directions of rotation of the rolls in three-high mills are not reversed. Water use in all types of hot-rolling mills is basically the same, being mainly for scale removal and temperature control.

When steel is heated to the high temperature desired for hot rolling, its surface is oxidized and a hard scale is formed. If not removed before rolling, this scale would be rolled into the steel and would cause surface defects. A common method of scale removal is to spray water under a pressure of as much as 2,000 psi (pounds per square inch) against the steel immediately before it enters the rolls. Scale thus removed is flushed to a scale pit where it is recovered for use in blast furnaces. Because much fine scale passes through these pits, the water is treated in settling basins or clarifiers before reuse.

Cooling water is sprayed on the rolls during hot rolling to prevent distortion and to reduce erosion of the roll surfaces. Because considerable heat is produced by the rolling processes, water also serves to keep the steel at its proper rolling temperature. Upon emergence from rolling mills, steel may be sprayed with water to hasten cooling. This spray prevents excessive scale formation. Roll bearings also require cooling. Spent cooling water flows to the scale pit along with that used for scale removal and may be reused after clarification and cooling.

OTHER USES

Cleaning steel (for inspection, cold rolling, and the application of protective coatings) requires a relatively small amount of water for preparation of cleaning solutions. Acid solutions are used for pickling (to remove iron oxide scale). Acid concentration varies considerably depending upon the method of pickling and shapes to be pickled. Generally, continuous pickling of strip or wire uses an initial acid concentration of 25–50 percent, whereas the batch process uses solutions of 5–10 percent acid. Alkaline solutions such as caustic soda or soda ash may be used for removing animal fats or mineral oils that adhere to the steel after cold rolling or drawing. After cleaning, all solutions are removed by rinsing with clean water.

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Deformation of steel by rolling or drawing generates heat that usually must be removed. In hot-rolling mills, cooling is accomplished by spraying water on the rolls, but in cold-rolling mills, water that contains a soluble oil is sprayed between the rolls and incoming steel for both cooling and lubrication. Heat generated in wire drawing is dissipated by a blast of cold air over a cumulative block (roll on which the wire is wound and removed periodically), but for noncumulative blocks (a roll on which wire is wound in several loops and removed continuously much as with a capstan) a spray of water on the inside of the block is used.

Various types of heating furnaces are needed to bring the steel to the proper temperature for rolling. Water is used to cool metal parts in these heating furnaces—doors, valves, and dampers.

QUANTITY OF WATER USED

PUBLISHED INFORMATION

Published information on water use in the iron and steel industry is limited, especially, on use for the various processing units. A brief survey of the literature for this report uncovered no water-use information, other than general statements, on most ore-concentration processes and on some steel refining processes.

When comparing the results of this survey with other published information, the reader should keep in mind the possibility that different methods were used to determine average water-use values. For example, Cannon (1964) reported that the average water intake by the steel industry was 17,311 gallons per ton of steel, but the U.S. Senate Select Committee on Water Resources (U.S. Congress, 1960) reported that water intake in 1954 was 31,842 gallons per ton of steel. The large difference between these two figures results from different methods of calculation. The value reported by the Senate Select Committee was obtained by dividing the total water intake of all blast, open-hearth, and electric furnaces and rolling mills in the United States by the tons of ingots or castings produced. The value reported by Cannon is an average for five regions—Western Great Lakes, Ohio River, Upper Mississippi, Great Basin and California. The water intake for each region is the average of the water intake by individual integrated steel plants. Thus, water use in the Great Basin, where a relatively small amount of steel is produced and where water is necessarily reused extensively, is given as much weight in Cannon's average as is water use in the Ohio River region, with its large steel production.

Published information on water use is shown in table 1. These data have been converted insofar as possible to the units used in this report, but in many places the exact product is not always clear. For example, the 20,790 gallons per ton of steel reported by the National

Association of Manufacturers and the U.S. Chamber of Commerce may be referred to steel ingots or to finished steel. Generally, steel production is reported in tons of ingots unless otherwise stated and water use is reported in gallons per ton of ingots.

FINDINGS OF THIS SURVEY

The steel plants surveyed for this report withdrew annually, from various sources, about 1,400 billion gallons of water and produced 40.8 million tons of ingot steel, about 30 percent of the total steel production in the United States. This is equivalent to about 34,000 gallons of water per ton of ingot steel. Data for most steel plants surveyed was for 1957, but some plants reported 1956 data. These figures compare favorably with the 31,842 gallons per ton reported by the Senate Select Committee, whose data were calculated by the same method used in this report but included data for all steel plants in the United States. This correlation indicates that the sampling was reasonable. No standard for judging the adequacy of the survey of iron mines and concentration plants is available. However, the mines and concentration plants included in the survey produced about 16 percent of the concentrate production in the United States. Because they were selected in the same way as the steel plants they should be representative of the iron ore industry. The production (mining and concentration) of about 15 million tons of iron ore concentrate required about 89,000 million gallons of water, which is about 5,900 gallons per ton of concentrate, or 2,300 gallons of water per ton of raw ore. Data for these mines was for 1956. The nationwide average values used above should not be confused with values reported in the following table which are arithmetic averages of amounts of water used in the individual plants.

SOURCES OF WATER

Most of the steel plants surveyed obtained water from both surface and underground sources. Generally, ground water was used in limited quantities and was used where relatively good quality water was required. About 97 percent of the water used by all the steel plants surveyed came from surface sources, 2.2 percent was reclaimed sewage, and 1.2 percent came from ground-water sources. Of the 29 plants surveyed, only three plants used self-supplied water exclusively, and only two plants used public water supplies exclusively (part *A*, table 2*). However, 96 percent of the total amount of water used by all the steel plants was self-supplied. Parts *B* and *C* of table 2 indicate that there are no significant differences between sources of water for integrated steel plants and steel processing plants.

Parts *D* and *E* of table 2 indicate that the water used by iron ore mines and concentration plants is also predominantly supplied by company-owned facilities from surface sources.

TABLE 1.—*Published information on water use*

Source of information	Plants surveyed	Water use	Remarks
Ore concentration plants			
Taggart (1945)		150–350 gpm for 50–150 tons of raw ore per day.	Screening Alabama brown ore.
Do		2,000 gal per ton of raw ore	Washing Alabama brown ore; 100–150 cu yd per hr.
Johannes (1957)	Minnesota iron mines	600–6,000 gal per ton of concentrated ore.	Wash ore required the least amount of water; taconite required the most.
Ruble and Anderson (1962)	Minnesota iron ranges	6,000–12,000 gal per ton of concentrated ore.	Includes reuse as well as intake water.
Knoerr and Lutjens (1956)	Reserve Mining Co., Silver Bay, Minn.	10,000 gal per ton of concentrated ore.	Taconite processing.
Steel plants			
Gorman (1943)		42,000 gal of water per ton of steel.	Water required to produce finished steel.
		18,000–19,200 gal of water per ton of steel ingots.	Water required to produce steel ingots.
American Iron and Steel Institute (1948).		36,000 gal per ton of finished steel.	
Youngquist (1942)		65,000 gal per ton of finished steel.	
National Association of Manufacturers and The Conservation Foundation (1950).		6,000–110,000 gal per ton of steel.	Rolled steel (hot-rolled plates, cold-rolled strip).
Nebolsine (1954b)		40,000–45,000 gal per ton of steel.	Intake by a typical steel plant.
		30,000 gal per ton of finished steel.	Intake where water conservation is practiced.

		65,000 gal per ton of finished steel.	Intake by plants on the Great Lakes where practically unlimited supplies are available.
Leffler (1956)		34,800 gal per ton of finished steel.	
Peirce and Hancock (1960)	U.S. Steel Corp., Geneva, Utah.	40,000 gal per ton of finished steel.	Water for cleaning, washing, and cooling.
U.S. Congress (1960)		31,842 gal per ton of steel	Based on total water used by steel industry and total steel production.
Johnson (1963)	Bethlehem Steel, Sparrows Point, Md.	55,000 gal per ton of steel	Intake at capacity operation.
Do	Kaiser Steel, Fontana, Calif.	1,400–1,600 gal per ton of steel	Intake.
Cannon (1964)		17,311 gal per ton of steel	Arithmetic average of average water intake in the following basins: Western Great Lakes, Ohio River, Upper Mississippi, Great Basin, and California area.
National Association of Manufacturers and the Chamber of Commerce of the United States (1965).		20,790 gal per ton of steel	
Coke plant			
Nebolsine, 1954b		5,000 gal per ton of finished steel.	

TABLE 1.—*Published information on water use*—Continued

Source of information	Plants surveyed	Water use	Remarks
Blast furnaces			
American Iron and Steel Institute (1948).		11,000 gal per ton of pig iron	
Chemical Engineering (1951)		12,000 gal per ton of pig iron	Recommended for estimating utility cost during preliminary design.
Nebolsine (1954b)		10,000 gal per ton of finished steel.	
McDaniel (1947)	One unidentified plant	3,300–4,600 gal per ton of pig iron capacity.	Bosh and stack-cooling systems only. The smaller amount of water was used before chemical cleaning of cooling system; the larger amount after cleaning.
Black and McDermott (1954)		800–4,300 gal per ton of pig iron.	Primary gas-washing tower.
		1,100–1,700 gal per ton of pig iron.	Secondary gas-washing disintegrators, rotary.
		1,200–1,300 gal per ton of pig iron.	Secondary gas-washing disintegrators, stationary.
		220–1,100 gal per ton pig iron	Electrostatic precipitators.
		4,000–8,500 gal per ton of pig iron.	Furnace cooling water.

Open-hearth furnaces			
American Iron and Steel Institute (1948).		17,000–20,000 gal per ton of steel ingots.	Typical furnace.
Nebolsine (1954b)		5,000 gal per ton of finished steel. Range: 3,900–21,000 gal per ton of steel ingots.	
Hot-rolling mills			
Nebolsine (1954b)		10,000 gal per ton of steel	
Continuous casting machine			
Miller and Dancy (1963)		2,000–2,500 gal per ton of castings used for cooling molds plus as much as 1,000 gal per ton for spraying the steel after it leaves the mold.	Experimental casting machine; water velocity in the mold cooling jacket was about 25 fps.

TABLE 2.—*Source and amount of water intake of iron and steel plants surveyed*

[Data are in millions of gallons per day unless otherwise indicated]

Source	No. of plants	Type of water								Percentage of total water intake
		Surface				Ground	Sewage	Surface and ground, mixed	All water	
		Fresh	Saline	Mixed	Total					
A. All steel plants [Includes integrated steel plants, steel processing plants, and coking plants and blast furnaces operated separately]										
Public supply	2	1.8	------	------	1.8	0.4	------	------	2.2	0.1
Self supplied	3	31.4	26.3	------	57.7	12.4	------	------	70.1	1.8
Public supply and self supplied	24	2,950	666	------	3,610	32.4	83.2	------	3,720	98
Public supply	------	49.5	------	------	49.5	2.2	83.2	------	135	3.6
Self supplied	------	2,900	666	------	3,560	30.2	------	------	3,590	94
All sources	29	2,982	692	------	3,670	45.0	83.2	------	3,800	100
Percentage of total water intake	------	78	18	------	97	1.2	2.2	------	100	------
B. Integrated steel plants										
Self supplied	2	31.4	26.3	------	57.7	10.4	------	------	68.1	1.9
Public supply and self supplied	16	2,820	666	------	3,490	29.0	83.2	------	3,600	98
Public supply	------	36.4	------	------	36.4	2.15	83.2	------	122	3.3
Self supplied	------	2,780	666	------	3,450	26.8	------	------	3,480	95
All sources	18	2,850	692	------	3,550	39.4	83.2	------	3,670	100
Percentage of total water intake	------	78	19	------	97	1.1	2.3	------	100	------

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C. Steel processing plants

Public supply	2	1.76	------	1.76	0.413	------	------	2.17	3.8
Self supplied	1	------	------	------	2.02	------	------	2.02	3.5
Public supply and self supplied	4	50.0	------	50.0	3.39	------	------	53.4	93
Public supply	------	5.35	------	5.35	------	------	------	5.35	9.3
Self supplied	------	44.6	------	44.6	3.39	------	------	48.0	83
All sources	7	51.8	------	51.8	5.82	------	------	57.6	100
Percentage of total water intake	------	90	------	90	10	------	------	100	------

D. Iron ore mines

[Fifteen mines were surveyed but two reported that no water was used]

Public supply	2	0.268	------	0.268	------	------	------	0.268	21
Self supplied	6	.140	------	.140	0.362	------	------	.502	39
Public supply and self supplied	5	.515	------	.515	.010	------	------	.525	40
Public supply	------	------	------	------	.010	------	------	.010	.7
Self supplied	------	.515	------	.515	------	------	------	.515	40
All sources	13	.923	------	.923	.372	------	------	1.295	100
Percentage of total water intake	------	71	------	71	29	------	------	100	------

E. Ore processing plants

Self supplied	9	30.4	------	30.4	0.467	------	1.30	32.2	311
Public supply and self supplied	6	245	------	245	.006	------	------	245	88
Public supply	------	.094	------	.094	------	------	------	.094	.03
Self supplied	------	245	------	245	.006	------	------	245	88
All sources	15	275	------	275	.473	------	1.30	277	100
Percentage of total water intake	------	99	------	99	.2	------	.5	100	------

GROSS WATER USE

As shown by table 3, gross water use in integrated steel plants ranged from 11,200 to 110,000 gallons per ton of ingot steel with a median of 33,200 and in steel processing plants from 4,180 to 26,700 gallons per ton with a median of 20,400. Some of this difference in water use in steel plants can be attributed to variations in products and units, but even in some units, such as blast furnaces, that have virtually the same function, the range was notable. Gross water use in blast furnaces ranged from 5,220 to 31,000 gallons per ton of pig iron. In open-hearth furnaces the range was from 2,260 to 8,810 gallons per ton of ingot steel. Several factors, more or less significant in all units of steel plants, account for these differences in water use. Inasmuch as more than 95 percent of the gross water use in steel plants was for cooling, those factors that affect the amount of cooling water are by far the most important. Some factors that affect cooling-water requirements are age and condition of the plant, procedures of operation, and quality of cooling water.

Changes in the designs of units within steel plants have required changes in cooling systems over the years. Also, during the use of furnaces the insulation is eroded and is periodically replaced. When the insulation is in good condition, less cooling water is required to protect the metal parts of furnaces than when metal parts are exposed directly to the hot furnace gases.

The duration of a "heat"—the time that steel being refined and compounded is held at high temperature in open-hearth or electric furnaces—affects the amount of water required per ton of steel. The kinds of steel produced, the percentage of cold-charged iron or steel, and the use or nonuse of oxygen are some of the things that determine the time required to produce steel in open-hearth and electric furnaces. Cold-charged iron increases the time, whereas the use of oxygen may decrease the time necessary to make steel.

To prevent scale deposits or corrosion when using water of poor quality an operator often will use a greater amount than would ordinarily be used. Scaling tendencies of water that contains scale-forming elements generally is enhanced by increased temperature. Likewise, some water, especially saline water, is more corrosive when hot. Because of this, the temperature increase of some water in its passage through a furnace is kept as low as 10°F. A blast furnace that is operated with a 10°F increase in water temperature will require twice as much water as one operated at a 20°F increase, the more common condition. Some water used for cooling contains solids in suspension and, regardless of the temperature, is circulated at velocities high enough to prevent the deposition of these solids in the system. Water brought into a plant at high temperature is less effective as a cooling agent than cold water. Consequently, more hot water than cold water is required to effect the same degree of cooling.

The amount of water used in mining operations is insignificant when compared with other operations in the iron and steel industry, but concentration of iron ore may require large quantities of water. The maximum amount of water used for concentration of ore was 14,700 gallons per ton of concentrate and the median was 2,040 gallons per ton (table 4). For the years 1956–60 the production of a ton of ingot steel required 1 ton of iron ore concentrate. This means that water used for concentration of ore is a large percentage of the total water used in the iron and steel industry. Generally, fine-grained ores such as jasper and taconite require more water for concentration than other ores. It should be noted, however, that data on the physical properties of the ores treated by the plants surveyed for this report were not investigated; only the iron mineral was identified without an indication of the liberation size.

Gross water requirements of the various units are given in gallons per ton of product of the unit in parts D to I of table 3. To determine the significance of each unit in the gross use by integrated plants requires that these values be converted to gallons per ton of steel ingots. This is done on the basis of the average consumption of coke and pig iron and the average production of steel ingots and castings during the period 1956–60. During this period an average of 56 tons of coke, 115 tons of iron ore concentrate, and 67 tons of pig iron were consumed in the production of 102 tons of steel ingots and castings. The gross water use of typical (median) units converted to gallons per ton of steel ingots is: coking plants, 3,000; blast furnaces, 13,000; open-hearth furnaces, 5,130; electric furnaces 3,040; primary hot-rolling mills, 2,000; secondary hot-rollings mills, 6,000. On the same basis, iron ore concentration required 2,300 gallons per ton of steel ingots.

INTAKE AND REUSE

Water intake is more subject to control than is gross water use, being determined primarily by the extent of reuse. The lower limit for intake is the consumptive use of a plant, and the upper limit is the gross use. Both limits have been reached in the steel plants surveyed. In integrated plants, intake ranged from 1,340 gallons per ton of steel ingots to 66,300 gallons per ton, whereas in steel processing plants, the range was from 341 to 16,000 gallons per ton.

TABLE 3.—*Water use in the steel industry*

	Purpose of water use							Plant total
	Cooling			Boiler feed	Process	Sanitary and service	Other	
	Once through	Recirculated	Total					
***A*. Integrated steel plants and steel processing plants** [Gallons of water per ton of ingot steel]								
Water intake:								
Number of plants	22	22	25	24	15	25	9	25
Minimum	.79	45.0	151	12.6	.68	4.19	12.6	341
Lower quartile	9,990	483	9,880	126	137	99.7	268	10,300
Median	16,300	2,460	17,500	290	245	190	409	18,200
Upper quartile	27,400	5,440	27,700	442	1,230	310	1,940	31,000
Maximum	64,100	13,000	66,200	1,510	4,950	3,430	5,000	66,300
Average	21,200	3,320	21,600	327	851	395	1,210	21,800
Gross use (including reuse):								
Number of plants	22	22	25	24	15	25	9	25
Minimum	.79	1,200	3,750	12.6	39.9	4.19	12.6	4,180
Lower quartile	9,990	3,560	19,500	196	137	100	268	20,000
Median	16,300	11,700	26,030	350	245	190	409	27,300
Upper quartile	27,400	19,400	36,000	570	1,250	310	2,120	39,200
Maximum	64,100	80,900	108,000	3,320	4,950	3,430	5,000	110,000
Average	21,200	14,900	31,700	496	901	395	1,250	33,700
Consumption:								
Number of plants	21	21	23	22	13	23	9	23
Minimum	0	0	0	0	0	0	0	0
Lower quartile	0	4.77	0	7.17	0	0	0	120
Median	0	50.5	105	71.4	51.3	0	0	295
Upper quartile	104	432	446	185	97.7	0	0	788
Maximum	793	3,300	3,300	1,250	283	196	7.08	3,420
Average	88.3	403	449	157	68.0	8.61	.79	647

Effluent:								
Number of plants	21	21	23	22	13	23	9	23
Minimum	.79	0	0	0	0	4.19	5.51	4.19
Lower quartile	9,400	310	8,810	1.74	68.9	80.3	268	9,180
Median	15,400	1,900	17,400	121	209	190	409	16,200
Upper quartile	26,300	5,440	26,800	303	798	273	1,940	30,200
Maximum	63,800	13,000	65,700	557	2,880	3,430	5,000	65,500
Average	20,800	3,070	31,800	172	532	398	1,210	21,500

***B.* Integrated steel plants**

[Gallons of water per ton of ingot steel]

Water intake:								
Number of plants	17	15	18	18	15	18	8	18
Minimum	8,460	45.0	901	65.0	0.68	27.9	251	1,340
Lower quartile	13,300	901	16,500	185	137	143	300	13,900
Median	18,300	3,350	25,000	292	245	220	574	24,300
Upper quartile	36,400	5,570	38,200	534	1,230	426	2,260	37,000
Maximum	64,100	13,000	66,200	1,510	4,950	3,430	5,000	66,300
Average	25,500	4,260	27,600	364	851	502	1,360	27,700
Gross use (including reuse):								
Number of plants	17	15	18	18	15	18	8	18
Minimum	8,460	1,200	10,900	29	39.9	27.9	251	11,200
Lower quartile	13,300	3,510	23,700	273	137	143	300	24,400
Median	18,300	11,500	29,200	371	245	220	574	33,200
Upper quartile	36,400	17,700	48,200	595	1,250	436	2,350	50,900
Maximum	64,100	80,900	108,000	3,320	4,950	3,430	5,000	110,000
Average	25,500	15,500	37,000	586	901	502	1,410	39,500
Consumption:								
Number of plants	16	14	16	16	13	16	8	16
Minimum	0	0	0	0	0	0	0	0
Lower quartile	0	0	0	2.39	0	0	0	21.4
Median	0	17.8	17.8	47.9	51.3	0	0	284
Upper quartile	201	117	228	188	97.7	0	0	681
Maximum	793	1,350	1,610	1,250	283	196	0	2,010
Average	110	175	263	159	68.0	12.4	0	491

TABLE 3.—*Water use in the steel industry*—Continued

	Purpose of water use							Plant total
	Cooling			Boiler feed	Process	Sanitary and service	Other	
	Once through	Recirculated	Total					
***B.* Integrated steel plants—Continued** [Gallons of water per ton of ingot steel]								
Effluent:								
Number of plants	16	14	16	16	13	16	8	16
Minimum	8, 200	22. 5	8, 650	0	0	27. 9	251	9, 180
Lower quartile	13, 200	428	16, 700	10. 5	68. 9	132	300	14, 900
Median	17, 800	4, 150	25, 000	249	209	197	574	24, 300
Upper quartile	39, 800	6, 260	42, 100	319	798	477	2, 260	42, 100
Maximum	63, 800	13, 000	65, 700	557	2, 880	3, 430	5, 000	65, 500
Average	25, 200	4, 330	29, 000	212	532	522	1, 360	28, 500
***C.* Steel processing plants** [Gallons of water per ton of ingot steel]								
Water intake:								
Number of plants	5	7	7	6	----------	7	----------	7
Minimum	. 79	150	151	12. 6	----------	4. 19	----------	341
Lower quartile	810	475	1, 680	72. 6	----------	37. 1	----------	1, 680
Median	7, 780	1, 170	3, 300	116	----------	119	----------	3, 680
Upper quartile	11, 800	2, 690	10, 500	423	----------	201	----------	11, 200
Maximum	15, 400	3, 300	15, 900	601	----------	263	----------	16, 000
Average	6, 620	1, 420	6, 150	217	----------	120	----------	6, 400
Gross use (including reuse):								
Number of plants	5	7	7	6	----------	7	----------	7
Minimum	. 79	2, 130	3, 750	12. 6	----------	4. 19	----------	4, 180
Lower quartile	810	6, 450	14, 200	72. 6	----------	37. 1	----------	14, 900
Median	7, 780	11, 800	20, 100	129	----------	119	----------	20, 400
Upper quartile	11, 800	25, 400	25, 400	442	----------	201	----------	25, 400

Maximum	15, 400	26, 300	26, 300	601	----------	263	----------	26, 700
Average	6, 620	13, 500	18, 200	225	----------	120	----------	18, 500
Consumption:								
Number of plants	5	7	7	6	----------	7	----------	7
Minimum	0	12. 2	44. 8	0	----------	0	----------	120
Lower quartile	0	44. 8	105	14. 6	----------	0	----------	124
Median	0	213	213	87. 2	----------	0	----------	646
Upper quartile	46. 3	1, 680	1, 680	240	----------	0	----------	1, 680
Maximum	92. 6	3, 300	3, 300	601	----------	0	----------	3, 420
Average	18. 5	859	872	152	----------	0	----------	1, 000
Effluent:								
Number of plants	5	7	7	6	----------	7	----------	7
Minimum	. 79	0	0	0	----------	4. 19	----------	4. 19
Lower quartile	760	0	0	0	----------	37. 1	----------	221
Median	7, 780	272	1, 990	10. 9	----------	85. 8	----------	2, 020
Upper quartile	11, 800	517	10, 400	103	----------	201	----------	10, 500
Maximum	15, 400	2, 640	15, 600	345	----------	263	----------	15, 700
Average	6, 600	561	5, 260	64. 9	----------	115	----------	5, 390

***D.* Coking plants**

[Gallons of water per ton of coke]

Water intake:								
Number of plants	15	11	17	7	10	11	----------	17
Minimum	899	17.3	35.8	1.67	83.9	8.52	----------	88.7
Lower quartile	2,130	64.0	1,860	63.8	135	9.49	----------	2,120
Median	5,150	102	3,890	71.1	531	34.4	----------	3,890
Upper quartile	5,810	475	5,790	83.8	895	69.1	----------	6,220
Maximum	9,220	686	9,560	231	1,770	335	----------	9,960
Average	4,280	230	3,930	85.3	610	61.2	----------	4,180
Gross use (including reuse):								
Number of plants	15	11	17	7	10	11	----------	17
Minimum	899	235	1,630	1.67	83.9	8.52	----------	2,700
Lower quartile	2,130	735	3,630	63.8	135	9.49	----------	4,180
Median	5,150	1,470	5,380	78.4	531	34.4	----------	5,470
Upper quartile	5,810	4,600	6,700	218	895	69.1	----------	6,920
Maximum	9,220	7,070	12,600	231	1,770	335	----------	13,600
Average	4,280	2,580	5,450	109	610	61.2	----------	5,900

TABLE 3.—*Water use in the steel industry*—Continued

	Purpose of water use							Plant total
	Cooling			Boiler feed	Process	Sanitary and service	Other	
	Once through	Recirculated	Total					
D. Coking plants—Continued [Gallons of water per ton of coke]								
Consumption:								
Number of plants	14	10	15	7	10	10	----------	15
Minimum	0	0	0	0	0	0	----------	0
Lower quartile	0	12.5	0	0	10.6	0	----------	1.67
Median	0	36.3	17.3	0	85.6	0	----------	143
Upper quartile	0	131	91.3	32.3	196	0.27	----------	253
Maximum	536	276	536	67.5	253	69.1	----------	570
Average	40.9	78.9	90.7	14.5	109	7.02	----------	175
Effluent:								
Number of plants	14	9	15	7	10	10	----------	15
Minimum	899	0	0	0	0	8.39	----------	69.1
Lower quartile	2,110	24.5	2,210	0	67.4	8.97	----------	2,250
Median	4,130	83.8	3,890	71.1	364	37.8	----------	3,890
Upper quartile	5,710	340	5,680	83.8	835	77.3	----------	5,810
Maximum	9,220	622	9,300	231	1,590	335	----------	9,390
Average	4,070	182	3,900	70.8	501	66.3	----------	4,120
E. Blast furnaces [Gallons of water per ton of pig iron]								
Water intake:								
Number of plants	17	12	20	8	5	13	4	20
Minimum	446	571	632	59.9	68.0	5.11	350	503
Lower quartile	4,550	678	10,200	103	175	14.7	448	10,200

Median	11, 900	2, 860	13, 900	267	1, 330	27. 7	1, 940	15, 200
Upper quartile	22, 800	9, 960	21, 200	532	2, 410	70. 8	4, 400	22, 100
Maximum	29, 800	19, 400	29, 800	873	2, 670	2, 230	4, 820	29, 900
Average	13, 700	5, 700	15, 100	327	1, 300	271	2, 260	15, 700
Gross use (including reuse):								
Number of plants	17	12	20	8	5	13	4	20
Minimum	446	680	5, 220	130	68. 0	5. 11	350	5, 220
Lower quartile	4, 550	4, 710	12, 700	211	124	14. 7	448	15, 000
Median	11, 900	11, 100	19, 300	315	1, 330	27. 7	1, 940	20, 500
Upper quartile	22, 800	22, 800	26, 000	614	2, 410	75. 8	4, 400	26, 700
Maximum	29, 800	26, 000	29, 800	873	2, 670	2, 230	4, 820	31, 000
Average	13, 700	12, 400	19, 100	389	1, 300	271	2, 260	20, 300
Consumption:								
Number of plants	16	11	18	8	4	11	4	18
Minimum	0	0	0	0	68. 0	0	0	0
Lower quartile	0	0	0	0	84. 3	0	0	0
Median	0	0	0	72. 0	171	0	0	25. 2
Upper quartile	0	293	98. 8	150	840	0	0	253
Maximum	491	857	951	265	1, 050	1. 42	0	2, 270
Average	36. 6	150	124	86. 9	365	0. 13	0	244
Effluent:								
Number of plants	16	11	18	8	4	11	4	18
Minimum	446	293	2, 490	0	0	5. 11	350	2, 830
Lower quartile	3, 190	623	10, 400	2. 39	300	19. 0	448	10, 400
Median	11, 000	3, 320	13, 900	208	1, 410	49. 4	1, 940	15, 000
Upper quartile	22, 500	10, 400	20, 400	522	1, 860	80. 8	4, 400	22, 300
Maximum	29, 800	18, 900	29, 800	608	1, 940	2, 230	4, 820	29, 800
Average	13, 200	6, 000	15, 400	240	1, 190	318	2, 260	16, 000

TABLE 3.—*Water use in the steel industry*—Continued

	Purpose of water use							
	Cooling			Boiler feed	Process	Sanitary and service	Other	Plant total
	Once through	Recirculated	Total					
***F.* Open-hearth furnaces** [Gallons of water per ton of ingot steel]								
Water intake:								
Number of plants	15	7	19	7	----------	12	----------	19
Minimum	118	114	114	23.8	----------	5.42	----------	93.0
Lower quartile	2,910	162	866	25.4	----------	20.2	----------	946
Median	4,020	467	3,130	61.6	----------	34.3	----------	3,160
Upper quartile	5,090	710	4,820	68.7	----------	57.9	----------	5,190
Maximum	6,720	2,690	6,720	153	----------	562	----------	6,720
Average	3,810	737	3,280	61.7	----------	78.6	----------	3,380
Gross use (including reuse):								
Number of plants	15	7	19	7	----------	12	----------	19
Minimum	118	1,170	2,180	23.8	----------	5.42	----------	2,260
Lower quartile	2,910	3,800	3,800	25.4	----------	20.2	----------	3,810
Median	4,020	5,750	5,050	61.6	----------	34.3	----------	5,130
Upper quartile	5,090	6,570	6,370	68.7	----------	57.9	----------	6,370
Maximum	6,720	8,750	8,750	153	----------	562	----------	8,810
Average	3,810	5,260	4,950	61.7	----------	95.1	----------	5,060
Consumption:								
Number of plants	14	6	17	7	----------	11	----------	17
Minimum	0	0	0	0	----------	0	----------	0
Lower quartile	0	33.6	0	22.5	----------	0	----------	0
Median	0	175	0	31.5	----------	0	----------	24.5
Upper quartile	0	451	175	65.7	----------	0	----------	210
Maximum	375	621	621	76.5	----------	0	----------	645
Average	26.8	235	105	38.1	----------	0	----------	122
Effluent:								
Number of plants	14	6	17	7	----------	11	----------	17

Minimum	118	0	0	0	...	10.1	...	65.7
Lower quartile	2,730	12.2	1,450	0	...	28.9	...	1,500
Median	3,950	176	3,130	2.25	...	34.9	...	3,160
Upper quartile	4,600	1,130	4,630	68.7	...	59.1	...	4,900
Maximum	6,920	2,640	6,920	76.5	...	562	...	6,340
Average	3,640	605	3,210	23.5	...	85.3	...	3,280

***G.* Electric furnaces**

[Gallons of water per ton of ingot steel]

Water intake:								
Number of plants	...	5	7	...	...	...	...	7
Minimum	...	15.7	15.7	...	...	...	...	16.5
Lower quartile	...	125	166	...	...	...	...	166
Median	...	475	475	...	...	...	...	475
Upper quartile	...	565	604	...	...	...	...	604
Maximum	...	604	4,940	...	...	...	...	4,940
Average	...	371	994	...	...	...	...	1,010
Gross use (including reuse):								
Number of plants	...	5	7	...	...	...	...	7
Minimum	...	1,210	166	...	...	...	...	166
Lower quartile	...	1,550	1,210	...	...	...	...	1,210
Median	...	2,310	2,130	...	...	...	...	2,130
Upper quartile	...	4,520	4,940	...	...	...	...	4,940
Maximum	...	5,100	5,100	...	...	...	...	5,100
Average	...	2,850	2,720	...	...	...	...	2,780
Consumption:								
Number of plants	...	5	7	...	...	...	...	7
Minimum	...	12.2	0	...	...	...	...	0
Lower quartile	...	14.0	0	...	...	...	...	0
Median	...	60.8	15.7	...	...	...	...	15.7
Upper quartile	...	195	157	...	...	...	...	157
Maximum	...	232	232	...	...	...	...	232
Average	...	95.5	68.4	...	...	...	...	68.2

TABLE 3.—*Water use in the steel industry*—Continued

	Purpose of water use							Plant total
	Cooling			Boiler feed	Process	Sanitary and service	Other	
	Once through	Recirculated	Total					
G. Electric furnaces—Continued [Gallons of water per ton of ingot steel]								
Effluent:								
Number of plants	------	5	7	------	------	------	------	7
Minimum	------	0	0	------	------	------	------	.79
Lower quartile	------	39.2	78.3	------	------	------	------	157
Median	------	294	294	------	------	------	------	294
Upper quartile	------	503	549	------	------	------	------	543
Maximum	------	543	4,940	------	------	------	------	4,940
Average	------	276	926	------	------	------	------	938
H. Primary hot-rolling mills [Gallons of water per ton of semifinished steel]								
Water intake:								
Number of plants	14	5	16	5	------	9	4	16
Minimum	191	27.9	57.6	7.28	------	6.44	87.8	64.1
Lower quartile	1,030	42.8	946	9.19	------	9.41	87.8	1,080
Median	1,530	286	1,390	27.7	------	33.8	485	1,650
Upper quartile	5,450	761	4,590	143	------	340	1,750	4,620
Maximum	11,300	1,100	11,300	253	------	553	2,040	12,100
Average	3,270	379	2,980	66.3	------	154	774	3,280
Gross use (including reuse):								
Number of plants	14	5	16	5	------	9	4	16
Minimum	191	454	637	7.28	------	6.44	87.8	637
Lower quartile	1,030	593	1,080	9.19	------	9.41	87.8	1,190

Median	1,530	942	2,070	27.7	----------	33.8	485	2,600
Upper quartile	5,450	4,610	6,720	143	----------	418	1,750	6,950
Maximum	11,300	7,300	11,300	253	----------	553	2,040	12,100
Average	3,270	2,270	3,570	66.3	----------	179	774	3,880
Consumption:								
Number of plants	14	4	15	5	----------	8	4	15
Minimum	0	0	0	7.28	----------	0	0	0
Lower quartile	0	0	0	9.19	----------	0	0	0
Median	0	95.5	0	16.9	----------	0	0	13.4
Upper quartile	23.0	813	51.7	127	----------	0	0	66.7
Maximum	95.3	1,020	1,020	228	----------	0	0	1,020
Average	16.2	303	95.9	57.8	----------	0	0	115
Effluent:								
Number of plants	14	4	15	5	----------	8	4	15
Minimum	95.3	27.9	73.0	0	----------	6.92	87.8	146
Lower quartile	1,010	39.2	904	0	----------	14.8	87.8	1,040
Median	1,530	84.2	1,420	1.93	----------	53.4	88.1	1,840
Upper quartile	5,450	340	4,980	20.4	----------	442	1,550	4,980
Maximum	11,300	421	11,300	25.3	----------	553	2,040	11,800
Average	3,250	154	3,070	8.53	----------	173	576	3,320

I. Secondary hot-rolling mills

[Gallons of water per ton of finished steel]

Water intake:								
Number of plants	13	9	17	5	----------	11	4	17
Minimum	365	117	117	8.95	----------	2.24	24.8	126
Lower quartile	3,230	336	2,010	17.0	----------	9.02	----------	2,030
Median	5,960	1,820	3,680	30.2	----------	54.3	257	4,050
Upper quartile	7,640	2,900	7,670	51.2	----------	371	----------	7,880
Maximum	24,500	5,380	24,500	54.2	----------	1,090	663	25,600
Average	6,760	1,930	6,190	6.71	----------	211	300	6,480

TABLE 3.—*Water use in the steel industry*—Continued

	Purpose of water use							Plant total
	Cooling			Boiler feed	Process	Sanitary and service	Other	
	Once through	Recirculated	Total					
I. Secondary hot-rolling mills—Continued [Gallons of water per ton of ingot steel]								
Gross use (including reuse):								
Number of plants	13	9	17	5	----------	11	4	17
Minimum	365	206	2,780	8.95	----------	2.24	24.8	2,820
Lower quartile	3,230	2,060	5,720	17.0	----------	9.02	----------	5,980
Median	5,960	6,310	7,640	30.2	----------	54.3	257	7,690
Upper quartile	7,640	21,400	14,400	51.2	----------	371	----------	10,600
Maximum	24,500	37,000	37,300	54.2	----------	1,090	663	37,800
Average	6,820	12,300	11,700	33.4	----------	229	300	12,000
Consumption:								
Number of plants	13	8	16	5	----------	11	4	17
Minimum	0	0	0	8.95	----------	0	0	0
Lower quartile	0	0	0	12.0	----------	0	----------	0
Median	0	356	10	22.3	----------	0	0	44.5
Upper quartile	10	1,950	421	51.2	----------	0	----------	394
Maximum	346	2,590	2,830	54.2	----------	0	0	2,880
Average	49.1	894	487	29.0	----------	0	0	477
Effluent:								
Number of plants	13	8	16	5	----------	11	4	17
Minimum	122	0	0	0	----------	2.24	24.8	5.06
Lower quartile	3,230	0	3,680	0	----------	9.02	----------	991
Median	5,960	364	4,580	2.84	----------	54.3	257	3,690
Upper quartile	7,200	2,390	7,700	9.40	----------	371	----------	4,860
Maximum	24,400	5,380	24,400	15.1	----------	1,090	663	25,400
Average	6,700	1,260	6,070	4.33	----------	211	300	5,990

Reuse of water ranged from 0 to 18 times in integrated steel plants and from 0 to 44 times in steel processing plants. In a few plants, the only water withdrawn from the source was that required to replace water used consumptively. The reasons for this wide range in reuse are not clear, but shortage of water seems to be the most important factor. Plants in the Western United States generally reused more water than those in the East. A large percentage of the steel processing plants surveyed are west of the Mississippi River where water is less abundant than in the East. In contrast, most of the integrated steel plants are in the water-rich areas of the East. A typical (median) steel processing plant used about 20,400 gallons per ton of steel ingots of which 82 percent was reused water, whereas a typical integrated plant reused only 26 percent of its gross water use of 33,200 gallons per ton of steel ingots.

Each time water is used for cooling or for most other purposes in a steel plant, some water is lost by evaporation. This loss of water leaves the remaining water with a higher dissolved-solids concentration than before it was used. With repeated reuse, the concentration of dissolved solids eventually becomes too high for many uses of the water. In some plants, the deterioration of water quality is overcome by reuse in a "cascade" system. In this type system, water is used first in places where good quality water is required, and then as the quality is degraded it is diverted to other uses that are less sensitive to water quality. (See pl. 4.) Finally, the remaining water may be completely evaporated in quenching slag.

Water was not reused extensively in the iron ore industry, but some concentration plants and mines did reuse water. Because the flow of water into and out of tailings basins often cannot be completely determined, the actual amount of water reused is not accurately known.

CONSUMPTION

Because most of the water used in steel plants is for cooling, consumption should be closely related to the heat loss from the plants. Parts *B* and *C* of table 3 show that a typical integrated steel plant consumes about 1.8 percent of the new water intake and about 1 percent of the gross water requirement and that a typical processing plant consumes about 18 percent of the intake and 3.2 percent of the gross. More extensive reuse, of course, is the reason for most of the difference in percentage of intake consumed by integrated plants and percentage of intake consumed by processing plants. The difference in percentage of gross water consumed by these two classes of plants is the result of more intensive use of cooling water in open-hearth furnaces, electric furnaces, and rolling mills than in blast furnaces and the processes

TABLE 4.—*Water use in the iron ore industry*

	Mines and concentration plants [1]								Mines only [2]	Concentration plants only [3]
	Gallons of water per ton of raw ore				Gallons of water per ton of concentrate				Gallons of water per ton of raw ore	Gallons of water per ton of concentrate
	Process water	Sanitary and service water	Other water	Total	Process water	Sanitary and service water	Other water	Total	Total	Total
Water intake:										
Number reporting	14	14	14	14	14	14	14	14	15	15
Minimum	39. 1	0	0	71. 8	43. 0	0	0	79	0	43
Lower quartile	153	. 2	. 3	159	336	. 7	. 9	341	1. 0	224
Median	635	1. 0	3. 5	645	1, 630	2. 2	9. 6	1, 670	3. 6	1, 320
Upper quartile	1, 020	5. 5	15. 4	1, 050	3, 300	10. 7	20. 2	3, 530	9. 8	3, 260
Maximum	3, 200	18. 2	195	4, 570	10, 100	20. 0	616	14, 400	74. 1	14, 400
Average	838	3. 0	19. 1	951	2, 390	5. 9	55. 7	2, 740	11. 6	2, 550
Gross water (including reuse):										
Number reporting	14	14	14	14	14	14	14	14	15	15
Minimum	79. 4	0	0	183	124	0	0	287	0	124
Lower quartile	511	. 2	. 3	511	952	. 7	. 8	963	1. 0	900
Median	838	1. 0	3. 5	881	2, 110	2. 2	9. 6	2, 150	3. 6	2, 040
Upper quartile	1, 190	5. 5	15. 4	1, 200	3, 510	10. 7	20. 2	3, 680	9. 8	3, 260
Maximum	3, 280	18. 2	195	4, 650	10, 400	20. 0	616	14, 700	104	14, 700
Average	1, 050	3. 0	19. 1	1, 170	2, 820	5. 8	55. 7	3, 170	16. 7	2, 980
Consumption:										
Number reporting	13	14	13	13	13	14	13	13	14	14
Minimum	0	0	0	. 0	0	0	0	0	0	0
Lower quartile	2. 5	0	. 3	7. 1	3. 6	0	. 7	13. 3	. 3	2. 2
Median	12. 7	0	1. 8	18. 5	25. 1	0	5. 6	35. 7	3. 1	24. 2
Upper quartile	76. 0	0	5. 1	47. 7	211	0	13. 2	212	5. 2	205

Maximum	124	.4	18.2	140	448	.5	55.9	505	14.5	448
Average	37.6	.03	4.1	42.9	109	.03	9.5	121	3.7	103
Effluent:										
Numbering reporting	13	14	13	13	13	14	13	13	14	14
Minimum	0	0	0	.6	0	0	0	1.5	0	0
Lower quartile	91.8	.2	0	105	175	.3	0	197	0	112
Median	533	.9	0	534	1,320	2.2	0	1,320	.1	1,160
Upper quartile	913	5.5	0	929	2,530	10.7	0	2,650	7.7	2,600
Maximum	3,190	18.2	193	4,550	10,100	20	611	14,400	68.9	14,400
Average	770	3.0	16.3	890	2,040	5.8	49.2	2,400	8.5	2,230

[1] Includes mines and concentration plants that operate as one installation.
[2] Includes one mine that operates independently of a concentrate plant.
[3] Includes one concentrate plant that operates independently of a mine.

used for cooling the water—towers, spray ponds, or natural water bodies. The average temperature increase of cooling water in blast furnaces is about 20°F and that in the open-hearth and electric furnaces is about 50°F (American Iron and Steel Institute, 1948); therefore, a greater percentage of the total water in circulation would be used consumptively in open-hearth and electric furnaces than in blast furnaces.

Heat added to cooling water is dissipated in cooling towers, spray ponds, lakes, or streams primarily by three processes—evaporation, conduction to the atmosphere, and radiation. According to Harbeck (1953), in a hypothetical situation based on Lake Hefner near Oklahoma City, Okla., most of the heat added to the lake would be dissipated through evaporation of water during the summer. During winter, slightly less than half would be dissipated through evaporation. For Lake Colorado City in Texas, Harbeck, Koberg, and Hughes (1959) found that on an annual basis the ratio of forced evaporation (evaporation due only to the addition of heat from a powerplant) to heat added was 710 acre-feet per billion kilowatthours of power. This means that for each 10°F increase in temperature of the cooling water an amount of water equal to 0.6 percent of the cooling water was evaporated. A generally accepted figure for evaporation in evaporative cooling equipment is 1 percent of the water circulated for each 10°F of cooling range. Additional losses occur due to "drift" or spray—for mechanical-draft towers about 0.5 percent, for atmospheric towers about 1 percent, and for spray ponds as much as 10 percent (Marks, 1951). Heat loss, and therefore evaporation, from streams probably is more similar to heat loss from a lake than to that from cooling towers and other mechanical devices.

Many plants, generally those that use once-through cooling systems, reported no consumptive use of water, but, as shown, consumptive use of cooling water is unavoidable under ordinary operating procedures. Although this generally undetermined loss of water probably is less than water loss from a cooling tower for the same heat load, it should not be ignored in a comparison of water use by different systems.

Consumption of water by ore concentration plants, which ranged from 0 to 448 gallons per ton of concentrate, seemed to be unrelated to type or condition of the ore and to the manner of operation.

QUALITY OF WATER

Quality of water must be considered in the design and operation of equipment in the steel industry, but it is not usually a critical factor in the determination of plant location. If enough water is available, its quality is probably acceptable or can be made acceptable by treatment at a reasonable cost. For uses such as furnace cooling, which require large quantities of water, construction materials for the water system can be chosen for their ability to resist the corrosiveness of various kinds of water. The relatively small amounts of high-quality water needed for such uses as boiler feed or human consumption can be provided by necessary treatment.

QUALITY OF WATER REQUIRED

Standards of water quality for the steel industry have not been generally accepted because of the wide variation in equipment, products, and procedures, but a few examples of limits on quality characteristics have been mentioned in the literature. Bethlehem Steel Corp. set a limit of 175 ppm (parts per million) on the chloride concentration for effluent received from the Baltimore, Md., sewage-treatment plant (Hill, 1945). This water is used for cooling of rolling mills and descaling steel and for other purposes for which saline water is not suitable. Studies at Bethlehem's Sparrows Point Plant and elsewhere in the United States suggested the following water-quality criteria for use in the steel industry (Wolman, 1948): Temperature below 75°F, chloride less than 175 ppm, pH between 6.8 and 7.0, hardness less than 50 ppm, suspended matter less than 25 ppm, organic content as low as possible, and corrosion potential at the lowest possible level. Cartwright and Dowding (1958, p. 28) suggested that water used in a continuous strip mill should meet the following criteria:

Use	*Quality requirements*
General cooling	Suspended solids less than 25 ppm, chloride reasonably low.
Hot-mill descaling.	Suspended solids less than 15 ppm, chloride less than 200 ppm.
Cold rolling and rolling oil solution.	Hardness less than 57 ppm.
Boiler feed	Hardness less than 14.3 ppm.

Criteria suggested by Wolman as well as that of Cartwright and Dowding apparently are intended to apply to rolling mills, for much more concentrated water has been used successfully for cooling furnaces and for other purposes in many plants. Highly saline water can be used for cooling condensers in powerplants, cooling furnaces, cleaning and cooling gases, quenching slag, and other similar uses, but scale-forming compounds such as calcium sulfate can cause serious loss of efficiency in cooling systems.

Two examples show the effect of using poor-quality water without treatment. Corrosion caused by a high dissolved-oxygen concentration and probably by electrolytic action was a problem in a steel plant in England in which copper cooling plates were connected by iron pipes (Lloyd, 1957). In the cooling system of a blast furnace within that plant, corrosion products reduced the flow of water from 4,654 gpm (gallons per minute) at startup to 1,597 gpm in about 5 years. In general the greatest loss of cooling capacity occurred in the system which served the hottest part of the furnace—bosh, hearth, and tuyeres. McDaniel (1947) reported that the removal of scale from a blast-furnace cooling system increased the flow of water from about 3.3 mgd (million gallons per day) to about 4.5 mgd. Because no change occurred in the effluent temperature, this increase in flow represents an equivalent increase in cooling and, thus, furnace protection.

QUALITY OF INTAKE WATER

Data on quality and treatment of intake water were requested from each mine and steel plant visited. Where possible these data were supplemented by analyses collected in the Geological Survey's basic-data programs and studies of public water supplies. Water from each source is considered separately even though one plant may have several different sources. Only one analysis from each source was used to obtain the statistics shown in the tables of water-quality data. In general, if more than one analysis of a source was available the analysis representing the least desirable condition was used.

The mining industry gives only slight consideration to water quality except for boiler-feed water, sanitary and service water, and water used for jet piercing. Information on the quality of water used at mines and concentration plants was not adequate to support a firm statement on quality requirements, partly, perhaps, because of the location of iron mines in areas of generally good quality water. For example, in the eight analyses reported the highest concentration of dissolved solids was 580 ppm and the maximum hardness, as calcium carbonate, was 278 ppm.

Data on quality of intake water for steel mills was more plentiful than that for mines but was also incomplete. However, a reasonably good appraisal of the quality of water used by steel plants was obtained. Tables were prepared to show the range in concentration of chemical constituents in untreated intake water for use as (a) cooling and process water in steel plants, (b) cooling and process water in hot-rolling mills, and (c) boiler-feed water. Minimum, lower quartile, median, upper quartile, and maximum concentrations reported for each constituent are shown in these tables along with the number of times the constituent was reported. Values shown in each column—minimum, lower quartile, and other values—do not necessarily represent a particular water analysis but may be values from several different analyses. For example, the minimum concentration of calcium, 1.6 ppm, was the minimum of all calcium concentrations reported without consideration of other factors.

Parts *A* and *B* of table 5, which show the chemical characteristics of untreated intake water used by steel plants and hot-rolling mills for cooling and process water, differ significantly only in the maximum concentrations. Saline water is commonly used for cooling and process water in units such as blast furnaces, but the use of highly mineralized water in contact with rolled steel is undesirable. Even so, water containing 1,900 ppm chloride has been used in hot-rolling mills. As shown by part *C* of table 5, much better water is used for boiler feed than for cooling and process water.

TABLE 5.—*Chemical quality of water at source of supply*

[Purchased water may have been treated. Values except pH in parts per million. These values are based on observation of individual properties and do not represent complete analyses]

Constituent or property	Number of analyses	Minimum	Lower quartile	Median	Upper quartile	Maximum
***A.* Water to be used for cooling and processing in steel plants**						
Silica (SiO_2)	33	0.2	3.6	6.0	11	30
Iron (Fe)	27	.00	.07	.11	.20	6.3
Calcium (Ca)	32	1.6	22	40	62	281
Magnesium (Mg)	32	.6	5.0	8.2	12	392
Sodium and Potassium (Na+K)	32	2.5	9.4	24	54	3,340
Bicarbonate (HCO_3)	35	0	24	78	128	390
Carbonate (CO_3)	34	0	0	0	0	36
Sulfate (SO_4)	34	3.0	25	57	152	566
Chloride (Cl)	36	1.6	12	25	44	6,000
Dissolved solids	34	19	164	255	394	10,400
Hardness as $CaCO_3$:						
Total	36	6	87	129	235	1,850
Noncarbonate	32	0	23	40	110	1,800
pH	33	5.1	6.9	7.4	7.7	9.9
***B.* Water to be used for cooling and processing in hot-rolling mills**						
Silica (SiO_2)	22	0.2	2.4	5.2	10	21
Iron (Fe)	18	.00	.04	.10	.19	.40
Calcium (Ca)	20	1.6	19	40	50	281
Magnesium (Mg)	20	.6	5.0	7.4	11	54
Sodium and potassium (Na+K)	20	2.5	5.6	24	48	877
Bicarbonate (HCO_3)	23	2	35	93	122	390
Carbonate (CO_3)	23	0	0	0	0	36
Sulfate (SO_4)	22	3.0	20	34	140	440
Chloride (Cl)	24	1.6	15	26	68	1,900
Dissolved solids	22	22	154	242	373	3,410
Hardness as $CaCO_3$:						
Total	24	6	92	129	242	923
Noncarbonate	20	0	14	35	65	894
pH	23	6.1	6.9	7.6	7.7	9.9

TABLE 5.—*Chemical quality of water at source of supply*—Continued

[Purchased water may have been treated. Values except pH in parts per million. These values are based on observation of individual properties and do not represent complete analyses]

Constituent or property	Number of analyses	Minimum	Lower quartile	Median	Upper quartile	Maximum
C. **Water to be used for boiler feed in steel plants**						
Silica (SiO_2)	24	0.2	2.7	7.4	11	30
Iron (Fe)	17	.00	.04	.10	.16	6.3
Calcium (Ca)	23	1.6	21	39	60	77
Magnesium (Mg)	23	.6	7.0	8.3	11	29
Sodium and potassium (Na+K)	23	2.5	9.0	24	45	97
Bicarbonate (HCO_3)	25	2	34	103	139	390
Carbonate (CO_3)	24	0	0	0	0	36
Sulfate (SO_4)	23	3.5	21	30	148	440
Chloride (Cl)	25	1.6	11	22	42	125
Dissolved solids	23	22	164	231	360	659
Hardness as $CaCO_3$:						
Total	25	6	68	128	217	641
Noncarbonate	23	0	10	35	94	169
pH	21	5.1	7.0	7.4	7.8	9.9

TREATMENT OF INTAKE WATER

Treatment of intake water for use in mines was not widely practiced. None of the mines visited treated intake water used for processing ore but, in some mines, plant effluent required considerable clarification before reuse for processing fine-grained ores. Of the six mines that reported water use in boilers, only two treated intake feed water; one that used lake water demineralized its intake feed water and the other softened and disinfected intake water pumped from the mines. Ground water and water from municipal supplies usually were not treated by the mining companies for sanitary and service use, but surface water usually was disinfected and sometimes clarified.

Much of the intake water used for cooling and process water in steel plants was not treated. As shown in table 6*A*, treatment of cooling water usually consisted of only disinfection to prevent biologic growth and the addition of chemicals such as phospates, sulfites, and chromates to control scale and corrosion. Table 6*B* shows that the most frequent treatment given to process water was disinfection to control biologic growth in distribution lines and even this was unusual. Generally, disinfection is essential for effluents from sewage-treatment plants. Treated sewage contains an abundance of nutrient compounds such as phosphates and nitrates that promote the growth of bacterial slimes and algae. A residual of the disinfectant, usually chlorine, must be maintained in the water throughout the plant. Most process water is used for quenching coke and slag which does not require good water.

Most intake water used for boiler feed (table 6*C*) was softened or internal treatment for scale and corrosion control in the boilers was used. Internal treatment within the boilers generally consisted of the addition of phosphate compounds, organic compounds, or adjustment of pH.

TABLE 6.—*Treatment of intake water*

Figures refer to frequency of use of various types of water treatment. Prior treatment of purchased wate is not considered]

Type of treatment	Self supplied			Purchased water		Total
	Ground	Surface		Ground	Surface	
		Fresh	Saline			
***A.* Water used for cooling**						
No treatment	5	12	1	2	12	32
Screening	------	3	------	------	------	3
Clarification	------	3	1	------	------	4
Softening	1	1	------	1	1	4
Disinfection	------	7	1	------	2	10
Scale and corrosion control	3	3	1	1	2	10
***B.* Water used for processing**						
Not treatment	2	7	------	1	7	17
Screening	------	2	------	------	------	2
Clarification	------	2	------	------	------	2
Softening	------	1	------	------	------	1
Disinfection	------	3	1	1	2	7
Scale and corrosion control	------	1	------	1	------	2
***C.* Water used for boiler feed**						
Clarification	1	2	------	------	------	3
Softening	3	8	------	------	4	15
Disinfection	------	------	------	------	1	1
Scale and corrosion control	3	4	------	1	4	12
Demineralization	------	------	------	------	1	1

FUTURE WATER REQUIREMENTS

As shown by figure 53, steel production in the United States has grown rapidly since 1900. The Business and Defense Service Administration of the U.S. Department of Commerce has estimated that steel production will continue to rise and will reach 238 million ingot tons by 1980 and 320 millions tons by 2000 (U.S. Congress, 1960). Production of domestic iron ore is not expected to keep pace with steel production. Figure 54 shows that importation of foreign iron ore has increased rapidly since 1955, and this trend is expected to continue.

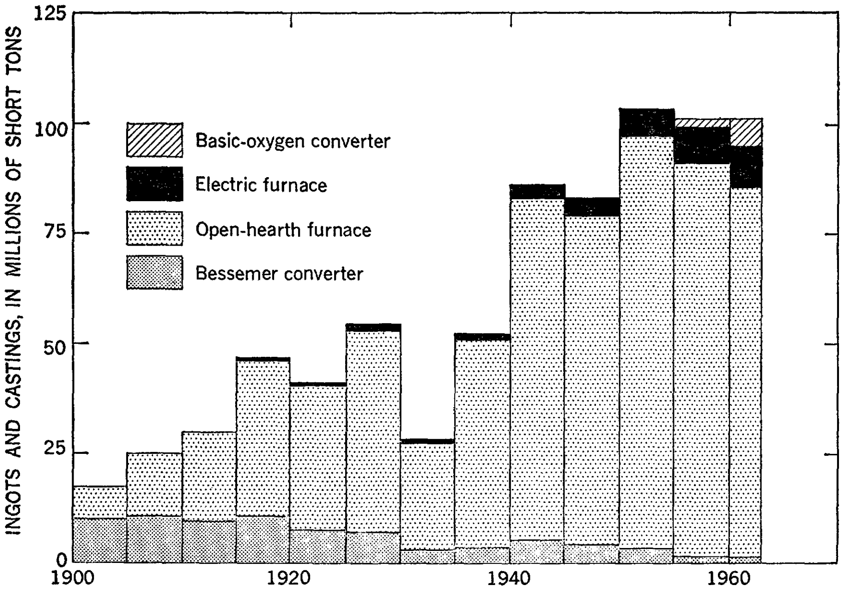

FIGURE 53.—Annual steel production by the various processes, 1900–63.

Harrison (1960) estimates that by 1980 the steel industry in the United States will require 190 million tons of usable iron ore per year, of which 45 percent will be imported, 29 percent will be standard-grade domestic ore, and 26 percent will be agglomerates from domestic taconite and jasper. This estimate indicates little change in the total amount of usable ore produced in the United States, but low-grade ores will tend to replace high-grade domestic ores. Although this growing dependence on imported iron ore probably will cause a greater increase in steel production in regions served by ocean transportation than in other areas, no area is expected to experience an actual decline in production. Water use by the iron and steel industry probably will increase because of the growth of the industry, but new developments in steel processing, increasing dependence on low-grade ore, more stringent water management and waste-water control regulations are likely to alter the ratio of water use to steel production.

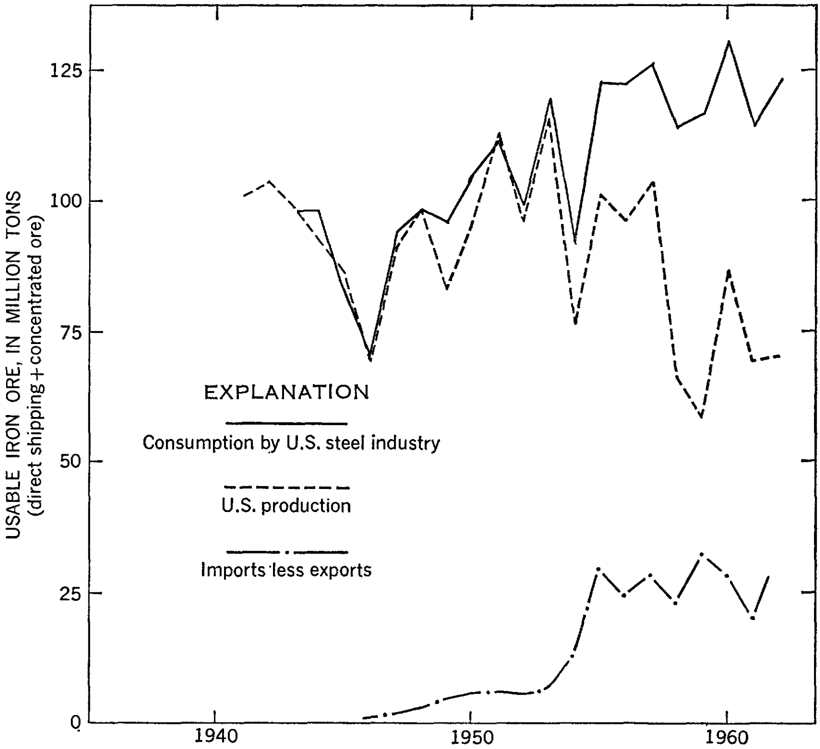

FIGURE 54.—Iron ore production and consumption in the United States, 1940–62.

Reuse of water within the steel industry has been an effective means of reducing water intake, and several factors favor increased reuse of water in the future. As a measure for conserving or saving water, reuse is effective only when water is withdrawn from storage, such as ground-water storage, and is reused before being discharged to a stream. This practice reduces the amount of water removed from storage. Where water is withdrawn from a stream or lake and is discharged after use to the same body of water, there is generally no saving of water from reuse, inasmuch as consumptive use is not reduced. (See page 375.) However, consumptive use may be a minor consideration in most places. Probably of greater concern is the discharge of hot water or water containing waste substances that may render the receiving water less useful for many purposes. Treatment of waste water to correct deficiencies of quality will often be required to comply with pollution-control regulations. For a large percentage of the effluent from steel plants, only cooling would be required, and once cooled, this water will often be more suitable than the new water available to a plant. Thus, where treatment of effluent is required, reuse may become desirable for economic reasons. The decision to reuse water will depend, first, upon how much water is available and, second, upon an economic evaluation of the various ways of conserving water and of preserving its quality. It seems reasonable to expect that the trend toward greater reuse of water will continue as the ratio of supply to demand decreases and as quality requirements for plant effluents become more exacting.

A trend toward extensive use of fine-grained ores such as taconite and jasper will undoubtedly be accompanied by an increase in water use in the iron ore industry, because the amount of water needed to process iron ore depends to a great extent on the reduction in particle size necessary to liberate the desired mineral. The percentage of the total requirements of iron ore supplied from various sources is shown in figure 55. The percentage of direct-shipping ore mined in the United States, which requires no concentration, has dropped from 78 percent in 1943 to 21 percent in 1962, whereas the percentage of concentrates has remained nearly constant and the percentage of agglomerates, which include concentrates from taconite and jasper, has increased rapidly since 1958. An increase in water use for iron ore concentration is to be expected, not only because of the use of fine-grained ores, but also because steel companies have found that high-grade ore sufficiently increases the capacity of blast furnaces to make it profitable to concentrate ores that were once used without concentration and to agglomerate more finely divided ores.

Several recent developments in steel processing promise to alter the steel industry considerably, and some of these changes probably will result in lower consumption of water. Figure 53 illustrates the growth of the steel industry and shows that the bulk of the steel produced in the United States was made in open-hearth furnaces. However, having become almost competitive with the open-hearth furnace, the electric furnace has gained rapidly in importance since 1950, and this trend is expected to continue (Case and others, 1953) ; the basic oxygen converter has also become an important steel-production apparatus in the United States and may be a serious rival of the open-hearth furnace in large tonnage production. Both the electric furnace and the basic oxygen converter use and consume less water per ton of steel than the open-hearth furnance; furthermore, direct reduction of iron ore by one or more of the numerous possible processes is expected to replace the blast furnace in a large percentage of the increased iron production capacity in the United States (U.S. Congress, 1960). These direct-reduction processes offer possibilities of reducing water consumption. Other means of reducing water consumption are available should they prove necessary or economical. These include salvaging heat that is normally wasted by evaporation

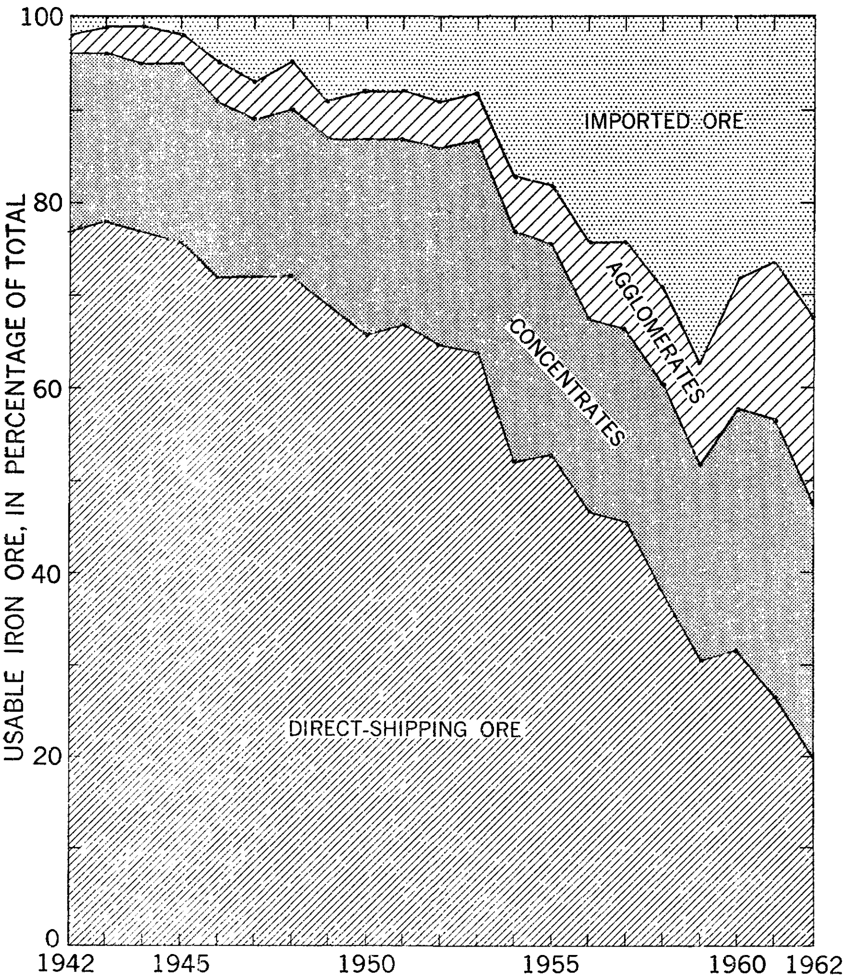

FIGURE 55.—Sources of iron ore for the United States steel industry, 1942–62.

of cooling water and using it for power production or other useful purposes (Durham, 1964; Feltoe and Moreton, 1954) and using air-cooled heat exchangers for furnace-cooling water (Calvert and Blumfelt, 1963. Both the above methods involve the dissipation of heat by means other than evaporation of water.

SUMMARY

A wide range of water use in the iron and steel industry has resulted from a variety of factors such as the quantity and quality of available water and types of facilities. Gross water use in integrated steel plants ranged from 11,200 to 110,000 gallons per ton of steel ingots and in steel processing plants from 4,180 to 26,700 gallons per ton. Inasmuch as more than 95 percent of the water used in steel plants is used for cooling, the factors that affect the use of cooling water are most important for the steel industry as a whole. These factors are quality of water, age and condition of facilities, and operating procedures. Water intake by integrated steel plants ranged from 1,340 to 66,300 gallons per ton of steel ingots and by steel processing plants from 241 to 16,000 gallons per ton. Water intake is determined to a large extent by the rate of reuse which is affected primarily by the availability of water. Plants in the water-short areas of the Western United States reused water more extensively than did plants in the East. Gross water use in iron ore mines ranged from 0 to 104 gallons per ton of raw ore, and intake ranged from 0 to 74.1 gallons per ton of raw ore. In iron ore concentration plants, gross water use ranged from 124 to 14,700 gallons per ton of iron ore concentrate. Generally the iron ore industry reused little water.

Most of the water used in steel plants is for cooling (table 7), and only a very small percentage of the intake is consumed (evaporated). Except for water used in rolling mills for cooling and scale removal, temperature is the only characteristic of cooling water that is seriously affected during any one pass through the system. However, a slight increase in the concentration of dissolved solids caused by evaporation losses must be considered in any plan for intensive reuse. The effects of this deterioration of chemical quality may be minimized by using the water first in those operations that are more sensitive to water quality and then successively in less sensitive operations (cascade system). This reuse of cooling water without treatment except disinfection and passage through cooling towers or ponds allows much flexibility in water-system design.

As indicated by table 8, water was obtained from surface- and ground-water sources and reclaimed sewage, but surface sources were by far most important, supplying more than 96 percent of the total water intake. Although reclaimed sewage is used in relatively small amounts, its use is significant because it demonstrates one important method of solving some water problems. As with most water reuse, quality often is a problem in the reuse of sewage. The abundance of nutrients such as phosphorus and nitrogen in effluents from sewage-treatment plants promotes troublesome abnormal growths of bacterial slimes and algae, but these generally can be prevented by disinfection. Table 8 also shows that 18.2 percent of the water used in steel plants was saline (more than 1,000 ppm dissolved solids), but only a small part of this percentage was very saline (10,000–35,000 ppm). The use of saline water entails additional costs owing to the need for cor-

TABLE 7.—*Median and average water use in the iron and steel industry, in gallons per ton of product indicated*

Plants or units	Product	Median water use						Average water use					
		Intake		Gross use		Consumption		Intake		Gross use		Consumption	
		Cooling water	Total	Cooling water	Total	Cooling water	Total	Cooling water	Total	Cooling water	Total	Cooling water	Total
Steel plants:													
Integrated and processing, combined.	Ingot steel	17,500	18,200	26,200	27,000	105	295	21,600	21,800	31,900	33,600	449	647
Integrated	do	25,000	24,300	29,600	32,400	17.8	284	27,600	27,700	37,500	39,800	263	491
Processing	do	3,300	3,680	20,100	20,400	213	646	6,150	6,400	18,200	18,300	872	1,000
Coking plant	Coke	3,890	3,890	5,380	5,450	17.3	143	3,930	4,180	5,370	5,850	90.7	175
Furnaces:													
Blast	Pig iron	13,900	15,200	19,000	20,200	0	25.2	15,100	15,700	19,000	20,100	124	244
Open-hearth	Ingot steel	3,130	3,160	4,750	4,810	0	24.5	3,280	3,380	4,870	4,990	105	122
Electric	do	475	475	2,130	2,130	15.7	15.7	994	1,010	2,720	2,780	68.4	68.2
Hot-rolling mills:													
Primary	Semifinished steel	1,390	1,650	2,070	2,600	0	13.4	2,980	3,280	3,570	3,880	95.8	115
Secondary	Finished steel	3,680	4,050	7,640	7,690	10	44.5	6,190	6,480	11,700	12,000	487	477
Mines	Raw ore	--------	3.6	--------	3.6	--------	3.1	--------	11.6	--------	16.7	--------	3.7
Ore concentration plants	Iron ore concentrate	--------	1,320	--------	2,040	--------	24.2	--------	2,550	--------	2,980	--------	103

rosion-resistant construction materials or the need to pump larger quantities than are necessary with fresh water to prevent scale formation.

TABLE 8.—*Sources of water used in the iron and steel industry, in percent*

Source	Iron ore mines		Ore concentration plants		Steel plants	
	Self supplied	Purchased	Self supplied	Purchased	Self supplied	Purchased
Surface water:						
Fresh	50.1	21.2	99.4	<0.1	77.1	1.3
Saline					18.2	
Ground water	27.9	.8	.2		1.1	<.1
Mixed ground water and surface water			.5			
Reclaimed sewage						2.2

In addition to changes in the economics of water management, changes in processes in both iron ore concentration and steel production are likely to alter the water needs of the industry. Increasing use of fine-grained iron ores probably will be accompanied by increased water use, although not necessarily increased consumptive use. New steel production methods and new equipment for old methods may effect a decrease in both gross use and consumption.

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