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# Water Use in Industries of the Future: Steel Industry<sup>1</sup>

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## 8.1 Steel Industry

*Contributed by Rick Johnson, in CH2M HILL's Herndon, Virginia, office*

### 8.1.1 Steel Industry Overview

Steel is an industry in evolution from large, integrated, multiple-product facilities to smaller facilities focused on specific products or markets. The energy intensity of the steel industry has been steadily decreasing since 1950 (Stubbles, 2000). Independently, the water use intensity of the steel industry has also been decreasing, principally because water is being recycled in the production facilities (AISI, 2001). Increasing demands for water resources will make continued recycling of water a business imperative in the steel industry as well as other basic industries.

The steel industry can be categorized into three types of facilities:

- Integrated mills, which use ore, coke, limestone, energy, and water to make multiple products for a wide variety of markets
- Minimills, which use scrap steel to make a narrow list of products for multiple markets
- Finishing mills, which use intermediate steel products to make products for focused markets

### 8.1.2 Water Use in Various Steel Industry Operations

Table 8.1-1 shows the various unit operations that make up the steel industry universe. Integrated mills may have all of the operations listed in the table. Minimills, as constructed in the late 20<sup>th</sup> century, are built around an electric arc furnace melt shop, a caster, and rolling mills to produce plate products; structural products; bar, rod, and wire products; and flat-

rolled products for the construction market. Finishing mills generally buy hot- or cold-rolled flat steel products and then form or coat products to meet market demands.

The water use patterns in these operations vary considerably, depending on process requirements. Water is used in the steel industry for three purposes:

- Material conditioning. Water is used for dust control in sinter feeds, slurring or quenching dust and slag in blast furnaces, mill scale removal in hot-rolling operations, solvent for acid in pickling operations, or rinsing in other rolling operations.
- Air pollution control. Primary operations, particularly in integrated mills, use water in wet scrubbers for air pollution abatement. Water is also used for acid control in pickling operations and for wet scrubbers in coating operations that have caustic washing operations.
- Heat transfer. Primary iron- and steel-making processes require heating the raw materials beyond the melting point of iron, in the range of 2,600 – 3,000 degrees Fahrenheit (°F), while hot-rolling operations require heating the materials to 2,100 - 2,300 °F. The equipment used for processing is protected by a combination of refractory linings and water-cooling of the refractory and shell of the equipment. Coke oven gas, blast furnace gas, and the offgas from basic oxygen furnaces and electric arc furnaces must be treated to remove air pollutants. In the case of coke oven gas and blast furnace gas, this is generally accomplished by using the gases as process fuels and alternatives to fossil fuels in boilers for cogeneration of steam and electricity. Heat transfer applications account for the largest use of water in integrated steel plants.

**TABLE 8.1-1**  
Water Use for Various Unit Operations in the Steel Industry

Process Area	Material Conditioning	Air Pollution Control	Heat Transfer	Unit Energy Consumption (Stubbles, 2000)	Recycled/ Re-used Fraction
Cokemaking	200 gallons per ton coke	250-300 gallons per ton coke	8,000 - 8,500 gallons per ton coke	5.1 MM BTU/ton coke	0% (newer plants may recycle cooling water)
Boilers for Converting Coke Oven Gas, Tars, and Light Oils			40,000 - 120,000 gallons per ton coke	7.5 MM BTU/ton coke exported energy in the form of gas, tars, and light oils	Varies depending on the age of the boilers
Sinter Plant	20 - 30 gallons per ton sinter	900 - 1,000 gallons per ton sinter	200 gallons per ton sinter	2.2 MM BTU/ton sinter	80%
Blast Furnace	100 - 200 gallons per ton molten iron	800 - 1,000 gallons per ton molten iron	2,500 - 3,000 gallons per ton molten iron	15.48 MM BTU/ton molten iron	90%
Boilers for Converting Blast Furnace Gas			20,000 - 60,000 gallons per ton molten iron	3.2 MM BTU/ton molten iron exported in the form of blast furnace gas	Varies depending on the age of the boilers
Basic Oxygen Furnace	100 - 200 gallons per ton liquid steel	800 - 1,000 gallons per ton liquid steel	2,500 - 3,000 gallons per ton liquid steel	1.17 MM BTU/ton liquid steel	50%
Direct Reduced Iron Processes	70 - 80 gallons per ton iron	negligible	200 - 250 gallons per ton iron	8.3 MM BTU/ton iron	~80%
Electric Arc Furnace	negligible	negligible	2,000 - 2,500 gallons per ton liquid steel	5.65 MM BTU/ ton liquid steel	80%
Continuous Caster	negligible	negligible	3,000 - 3,500 gallons per ton cast product	0.15 MM BTU/ton cast steel	70%
Plate Mill	1,000 - 2,000 gallons per ton plate	negligible	7,000 - 8,000 gallons per ton plate	3.0 MM BTU/ton plate product	30%
Hot Strip Mill	400 - 600 gallons per ton hot rolled strip	negligible	7,000 - 8,000 gallons per ton hot-rolled strip	2.2 MM BTU/ton hot-rolled strip	60%
Pickling	30 - 40 gallons per ton steel pickled	80 - 100 gallons per ton steel pickled	20 - 30 gallons per ton steel pickled	0.20 MM BTU/ton steel pickled	70%
Cold Rolling	50 - 100 gallons per ton cold-rolled strip	negligible	2,500 - 3,000 gallons per ton cold-rolled strip	4.2 MM BTU/ton cold-rolled strip	90%
Coating	60 - 70 gallons per ton coated steel	1 - 10 gallons per ton coated steel	1,200 - 1,800 gallons per ton coated steel	5 - 8 MM BTU/ton coated steel, depending on process and product	80%

MM BTU/ton = million British thermal units per ton.

Source: Compiled CH2M HILL client project data

Overall, approximately 12 percent of the water use is for material conditioning, 13 percent is for air pollution control, and 75 percent is for

heat transfer, which does not include the water requirements for the boilers. The fraction of the water recycled varies from operation to op-

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eration, but it may be as much as 90 percent for some operations.

Not all integrated mills have all of the operations listed in Table 8.1-1; for instance, sinter plants have been disappearing for economic reasons.

Coke ovens produce by-product gas and liquids from the destructive distillation of coal. These by-products have considerable energy value. The liquids used to have considerable value as chemical products or raw materials for pharmaceuticals, dyestuffs, or resins. The market for the coal tars and light oils has been overtaken by the production of similar products from oil refineries (AISI, 2001). The production of coke will require that the by-products be treated or consumed as raw materials and not released to the environment. For the purposes of this study, it is assumed that the by-products are consumed in boilers for the production of electric power or steam. Similarly, blast furnaces produce a by-product gas that must be treated or consumed and not released untreated to the atmosphere. For the purposes of this study, it is assumed that this gas stream is used as low-heating value fuel in heat recovery boilers for the production of electric power or steam. This is a simplified view of energy use and recovery practices that have been at the heart of integrated steelmaking for the past 100 years.

### **Steel Manufacturing Processes**

Figure 8.1-1 provides a graphical overview of steel manufacturing processes:

#### **Consumptive Uses**

##### **Evaporative Losses**

Water is consumed in operations where the water is evaporated. These operations include slag quenching at blast furnaces and basic oxygen furnaces, coke quenching in coke ovens, spray chamber cooling at casters, and evaporation in cooling towers.

#### **Water in Products**

Water is not a part of steel products. Water is sold or transferred with spent pickle liquors.

#### **Return-Flow Uses**

Water is supplied to the unit operations in steel plants and recycled or treated and discharged. Water supply comes from surface water sources, groundwater sources, and--in one case--as treated water from a municipal sewage treatment plant. Water is used for heat transfer from the processes, for treating and washing product, and as a solvent for electrolytic plating operations.

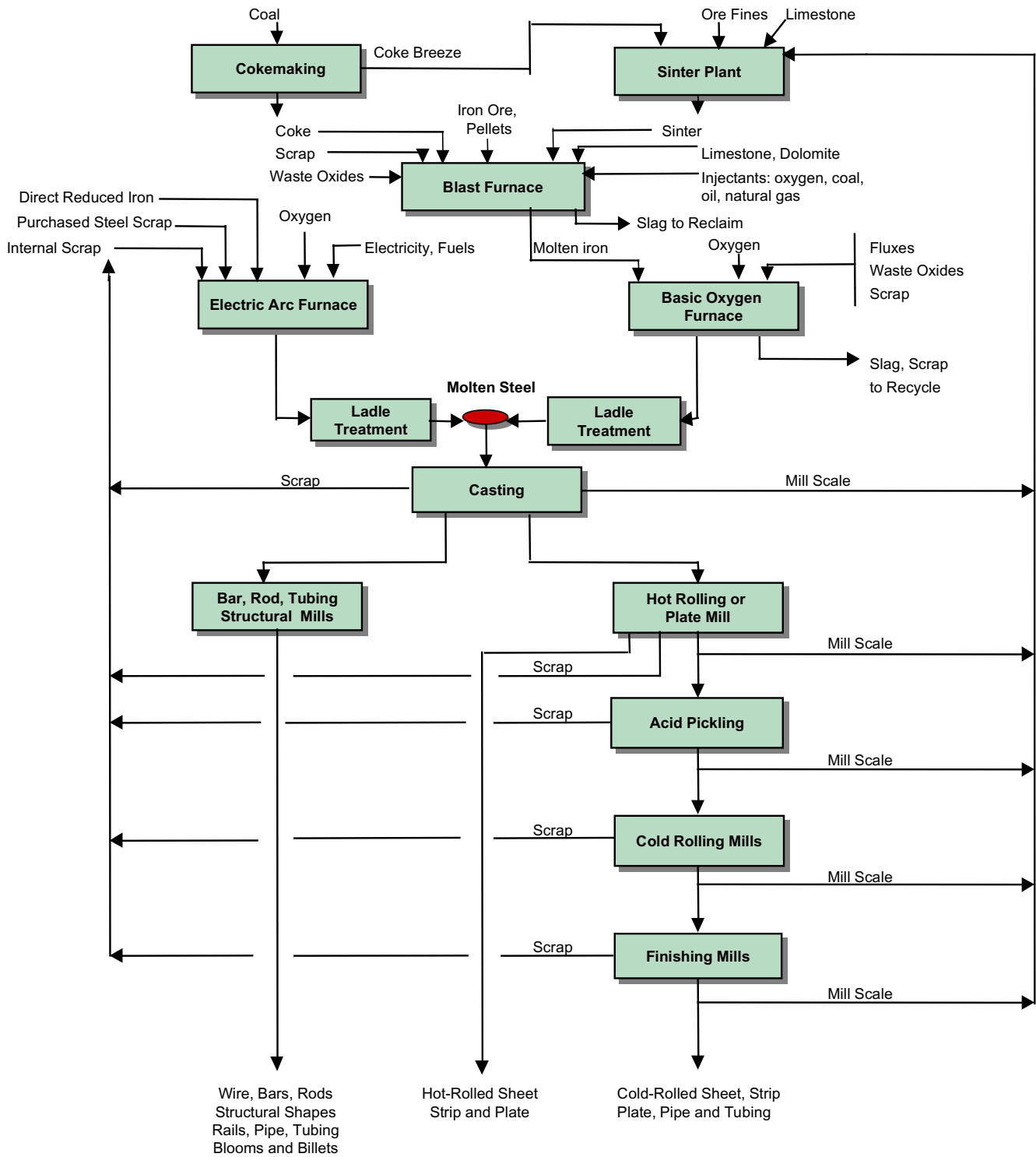
#### **Contact Water**

Water is used for contact cooling (quenching) in coke oven gas treatment, slag handling in basic oxygen furnaces, electric arc furnaces, continuous casters, scale breaking in hot-rolling operations, acid pickling, cold-rolling operations, caustic washing for coating lines, and to make up electrolytic solutions in tin-coating and chrome-coating lines. Water is also used in wet scrubbers for air pollution control in coke oven gas treatment, sinter plants, blast furnace gas treatment, basic oxygen furnaces, acid pickling, and coating operations.

#### **Noncontact Water**

Water is used in a series of heat exchangers in coke oven gas treatment, blast furnaces, basic oxygen furnaces, electric arc furnaces, hot-rolling operations, cold-rolling operations, boilers, annealing furnaces, and coating lines. This noncontact water is generally discharged separately from the process waters. Process waters require treatment before being discharged to receiving waters.

Table 8.1-2 shows a breakdown of contact and noncontact discharges and evaporative losses for steel-making operations



**Source:**

Adapted from U.S. Council on Wage and Price Stability, Report to the President on Prices and Costs in the United States Steel Industry, 1977 (COWPS, October 1977)

Reported in the Steel Industry Technology Roadmap, AISI, December 2001

FIGURE 8.1-1  
Overview of Steelmaking Processing

**TABLE 8.1-2**  
Evaporation losses and discharges for various steel-making operations

Process Area	Makeup Water	Evaporation	Process Contact Water Discharge	Noncontact Water Discharge	Recycle Rate
Cokemaking	8,800 gallons per ton coke	230 gallons per ton coke	260 gallons per ton coke	8,310 gallons per ton coke	Negligible to significant, depending on the age of the plant
Sinter Plant	240 gallons per ton sinter	100 gallons per ton sinter	140 gallons per ton sinter	negligible	1,000 gallons per ton sinter
Blast Furnace	350 gallons per ton molten iron	70 gallons per ton molten iron	25 gallons per ton molten iron	260 gallons per ton molten iron	3,500 gallons per ton molten iron
Basic Oxygen Furnace	2,100 gallons per ton steel	120 gallons per ton liquid steel	140 gallons per ton liquid steel	1,840 gallons per ton liquid steel	2,050 gallons per ton liquid steel
Direct Reduced Iron Processes	290 gallons per ton iron	20 gallons per ton iron	negligible	270 gallons per ton iron	~1,000 gallons per ton iron
Electric Arc Furnace	250 gallons per ton steel	negligible	negligible	250 gallons per ton steel	2,000 gallons per ton steel
Continuous Caster	1,000 gallons per ton cast steel	10 gallons per ton cast steel	10 gallons per ton cast steel	980 gallons per ton cast steel	2,200 gallons per ton cast steel
Plate Mill	6,700 gallons per ton plate	30 gallons per ton plate	2,300 gallons per ton plate	3,000 gallons per ton plate	2,700 gallons per ton plate
Hot Strip Mill	3,100 gallons per ton hot-rolled strip	30 gallons per ton hot-rolled strip	1,750 gallons per ton hot-rolled strip	15 gallons per ton hot-rolled strip	4,700 gallons per ton hot-rolled strip
Pickling	60 gallons per ton steel pickled	15 gallons per ton steel pickled	15 gallons per ton steel pickled	30 gallons per ton steel pickled	120 gallons per ton steel pickled
Cold Rolling	80 gallons per ton cold-rolled strip	4 gallons per ton cold-rolled strip	1 gallon per ton cold-rolled strip	75 gallons per ton cold-rolled strip	3,000 gallons per ton cold-rolled strip
Coating	250 gallons per ton coated steel	10 gallons per ton coated steel	60 gallons per ton coated steel	180 gallons per ton coated steel	1,400 gallons per ton coated steel

Source: Compiled CH2M HILL client project data

### Water Use by Facility Type

The integrated mills use more water than the other facility types, minimills and finishing mills. This is because integrated mills start with the most basic raw materials (ore, coal, and limestone) and convert them to steel that is then processed into products.

Minimills use more water than finishing mills do because minimills start with scrap steel and convert it into steel to be processed into inter-

mediate and final products. The amount of water will depend on the specific mill and capacity.

Finishing mills tend to use less water than either integrated mills or minimills because (1) the technology for recycling water is more amenable to the finishing mills and (2) the finishing mills start with an intermediate product that needs processing only into a specific shape or finish for the market.

## Unit Operations That Use the Most Water

Figure 8.1-2 shows a breakdown of water use in the various steel-making unit operations that use the most water.

Steel industry operations tend to fall into three ranges for water use:

- Hot rolling (plate and strip) and cokemaking use water in the range of 7,000 to 9,000 gallons per ton of product, including both makeup water and recycled water.
- Blast furnaces, basic oxygen furnaces, electric arc furnaces, casters, and cold rolling use water in the range of 2,500 to 4,000 gallons per ton of product, including both makeup water and recycled water.
- Pickling, coating, and sintering use water in the range of 200 to 1,800 gallons per ton of product, including both makeup water and recycled water.

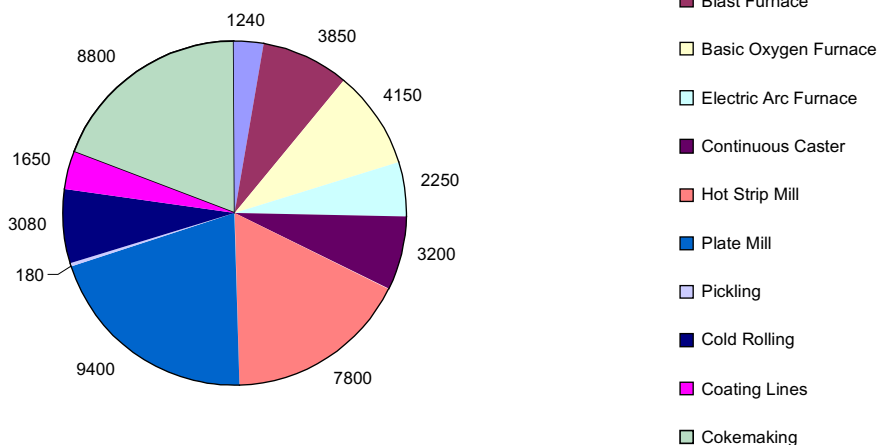


FIGURE 8.1-2 Water Use By Operation, Gallons per Ton of Production

experiences occur with the blast furnaces as more cooling is added to the shell of the blast furnace to extend the life of the linings at the same time that incremental improvements are

made to the energy balance with coal injection, heat recovery, oxygen addition, and burden management to increase yields.

In the transition from blast furnace and basic oxygen furnace combinations to electric arc furnaces with high scrap and supplemental supplies, the net energy and water consumption will decrease. The blast furnace - basic oxygen furnace combinations require a net use of approximately 2,400 gallons of water and 17 MM BTU/ton steel produced. The use of scrap steel in place of hot metal as feed to the basic oxygen furnace would reduce these ratios. If a direct reduced iron plant and electric arc furnace were coupled together with no scrap steel feed, the similar net usage rates would be approximately 550 gallons of water and 14 MM BTU/ton steel produced. The use of scrap steel as feed to the electric arc furnace would reduce these ratios.

The path to energy and water conservation in the steel industry is transformational in changing processes and not incremental in im-

### 8.1.2 Relationship of Water to Energy

Each unit operation in the steel-making process exhibits a different relationship between water use and energy consumption. In some cases, there is actually an inverse relationship. For instance, reheat furnaces for hot strip mills have progressed from three-zone furnaces with a heat rate of 5 million British thermal units per ton (MM BTU/ton) of steel heated to eight-zone furnaces with a heat rate of 1.4 MM BTU/ton. The cooling requirements increase with each zone added, however, in order to protect the internal components of the furnace. In this particular example, the energy required now is only 28 percent of the 1980 requirement, but the cooling water requirement is 230 percent of the 1980 requirement. Similar

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proving existing processes. This transformation is impeded by the current (calendar year 2002) worldwide over-capacity in steel production.

### 8.1.3 Water Reuse Practices and Challenges in the Steel Industry

#### Overview of Water Reduction and Reuse Practices and Challenges

In the steel industry, water is used primarily for heat transfer. Cooling towers minimize this water use. In some cases, closed-loop cooling systems have been used for heat removal from the process. Water has been supplied from a combination of surface water and groundwater withdrawal.

Future water supply may be in jeopardy from population pressures and competing demands. This situation may be mitigated by water reuse from treated municipal effluent or by increased internal treatment and recycling.

Process changes in steel production will reduce water demand; an example of such a change would be replacement of the cokemaking – sintering - blast furnace method with direct reduced iron processes for making iron as a raw material. Continuing replacement of the basic oxygen furnaces with electric arc furnaces has the potential to reduce water demand in the industry. This will be offset, however, by the water required for the alternative iron processes that will replace the blast furnaces and extend the scrap steel supply. Currently, the scrap steel supply is adequate for supplying minimills. This is likely to change in the future as blast furnaces are taken offline and not re-lined for economic reasons. Then an alternative iron supply will be required to supply the minimills.

#### Case Study Outline

Around 1950, the Sparrows Point Plant of the Bethlehem Steel Corporation was facing a shortage of water to support plant expansions to meet increasing market demands. The plant

is located on a developed peninsula at the mouth of the Patapsco River east of Baltimore, Maryland. Water supply had been provided by a combination of groundwater wells and surface water withdrawal. The increased demands for cooling water and process water supply also required closer control of the quality and reliability of water supplied. Dissolved solids in the cooling water for new blast furnaces and hot strip mill reheat furnaces were becoming stringent limitations as these units operated hotter and with higher heat fluxes, making scale formation a more significant impediment to productivity. Increasing demand for cleanliness on the finished product as the product mix shifted from plate to hot- and cold-rolled flat, thin-section, strip was another market criterion that made dissolved solids and salts in the process water an increasing concern. The flows in the Patapsco River and Old Road Bay were not sufficient to support the increased demands for water, especially during dry years. The water from the Chesapeake Bay is brackish, with relatively high salt and carbonate concentrations. The next best choice appeared to be taking water from the rivers to the north of Baltimore, but the only river that appeared to have the capacity to supply the plant was the Susquehanna, which was also being developed for the Baltimore Department of Public Works as a drinking water supply for the expanding population of Baltimore City and Baltimore County.

Simultaneously, the Baltimore Department of Public Works was increasing treatment of the municipal water discharge plant at the Back River Waste Water Treatment Plant. The water discharge quality as designed was sufficient to provide a relatively low dissolved solids concentration. The discharged waters were filtered and disinfected sufficiently to make this water a potential source for heat transfer in the more demanding processes that were being developed at the time. The requirement for clean water for processes could be met by a combination of the effluent discharge and the treated

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potable water from the Baltimore Department of Public Works.

The final resolution was that the Sparrows Point Plant contracted for 160 million gallons per day of treated effluent from the Back River Waste Water Treatment Plant as a new industrial water supply. This water is monitored to meet the wastewater discharge criteria set by permits for the wastewater treatment plant. The water is delivered by pipeline to a pond where the water is inventoried and pumped to

the users in the plant. Facilities are provided at the pond for bleach treatment (previously chlorine treatment) for algae control in the in-plant distribution system. This solution avoided the necessity of laying 60 miles of pipeline from the Susquehanna River and allocating water from the river, which has become a primary water supply for Maryland and Pennsylvania communities in the river basin (Mendelson and Hanson, 1996)

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