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Water Usage and Power Production: The Electric Utility Industry is Dependent on Water Utilization

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WATER USAGE AND POWER PRODUCTION:

THE ELECTRIC UTILITY INDUSTRY IS DEPENDENT ON WATER UTILIZATION

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The utilization of water as a heat transfer fluid is essential for the production of economic electrical power. There are many types of cooling facilities; however, the most economical means of electrical power production requires very large quantities of water to serve as a low temperature heat sink. For this reason, the power industry has, when possible, located its facilities near large sources of cold water, such as the Missouri River. The Omaha Public Power District (OPPD) has utilized the Missouri River since the turn of the century, and continues to do so today.

The availability of water in the future will play an important part in determining the rates power consumers must pay. In the Missouri River Basin, electric power water withdrawals from streams are second only to irrigation in total volume (Missouri River Basin Study, 1969). It is estimated that electric power facilities will be responsible for 19 percent of all Missouri River Basin surface water withdrawals by 1980. But, electric power facilities are only borrowers of water and have a consumptive use lower than other principal users, including cattle feeders, irrigators, municipalities, and industries. Power facilities consume only 6 percent of the water they withdraw (Missouri River Basin Study, 1969).

Omaha Public Power District (OPPD) facilities, as well as the vast majority of other fossil fuel and nuclear electrical power plants, utilize the Rankine thermodynamic steam cycle. In these facilities, small volumes of water are generally utilized to produce steam to drive the turbines for power production. For a 560 megawatt fossil-fuel facility such as Nebraska City Unit 1, the maximum volume of makeup water required is approximately 225 gpm. This makeup will replenish water lost in pumps, glands, steam vents, boiler blowdown, and steam soot blowing. In contrast, the Nebraska City Station will utilize approximately 298,000 gpm of cooling water for condensing turbine-exhaust steam. (Environmental Assessment, 1975)

In general, the operating efficiency of power plants is determined in part by turbine-exhaust temperatures which vary from plant to plant, which in turn are dependent on the relative type and size of the condenser used and the temperature of the available cooling water (heat sink) (Harding, et al., 1973). In the thermodynamic cycle, maximum efficiency is achieved by rejecting heat at the lowest possible temperature to a heat sink (Budenholzer, et al., 1972). Thus, a low cooling water temperature will create a low condenser temperature and a resulting low turbine exhaust steam temperature. The greater the total temperature drop across the turbine, the greater the turbine shaft energy produced per unit of fuel burned. Total thermodynamic cycle efficiency can be referred to in terms of heat rate or the number of BTU's of fuel required to produce a kilowatt hour of electricity. The lower the heat rate, or the number of BTU's required per kilowatt hour of generation, the higher the total thermodynamic cycle efficiency. High thermodynamic cycle efficiencies will provide electrical power at the lowest fuel cost. Thus, system design and equipment selection, which affect plant efficiencies, are critical to the determination of final electrical power costs.

Depending on the availability of water and/or environmental considerations, different types of condenser cooling systems are selected for power plants. Of the systems available, once-through condenser cooling generally provides the most efficient and economical operation. This type of system is illustrated in Figure 1. With once-through cooling systems, water is pumped from a natural body of water, at temperatures normally below 75°F, through the condenser where it is warmed 15°F to 25°F before it is returned to the source. Use of this system results in turbine-exhaust pressures of 1.0 to 2.5 inches of Hg absolute (abs.), which corresponds to exhaust

*Deceased, February 21, 1979.

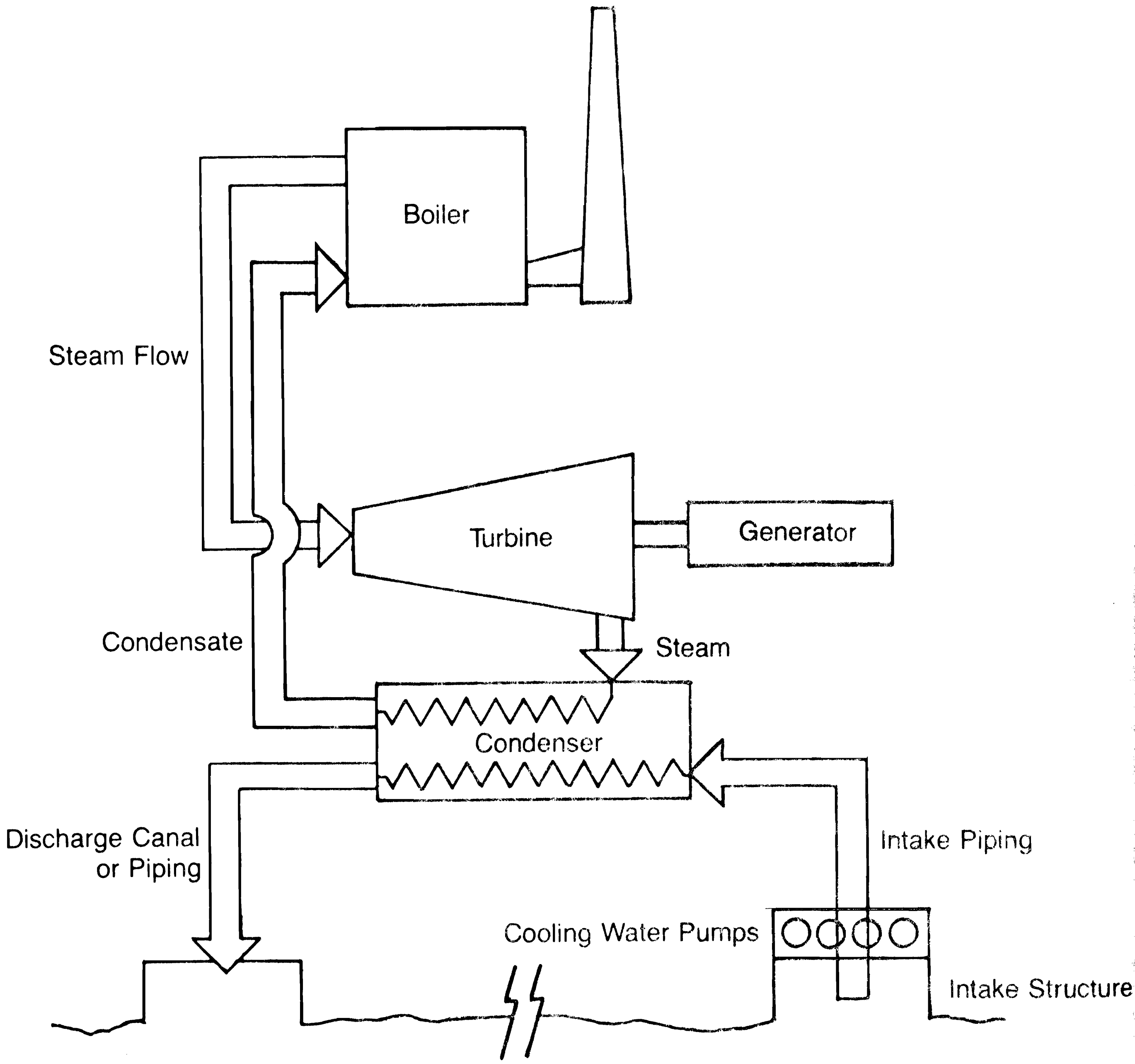

Figure 1. Once-Through Circulating Water System.

temperatures of 79°F to 109°F (Budenholzer, et al., 1972). All of the OPPD's current facilities, with the exception of its gas turbines, utilize the Rankine cycle with once-through cooling. The newest of these facilities, the Nebraska City Power Station, will operate at a calculated heat rate of approximately 9044 BTU/KWh. This heat rate is comparable to heat rates of other modern facilities in the United States of the same size using once-through cooling (Harding, et al., 1973).

Closely resembling once-through cooling is closed-cycle cooling. As can be seen in Figure 2, cooling water is recirculated between the lake and the plant, differentiating it from once-through cooling. Since cooling lakes are normally mu smaller than natural water bodies, rejected power plant he normally results in a buildup of lake temperature and, as result, warmer intake temperatures. For the Nebraska Ci Station, a cooling lake would have required a surface area about 1900 acres (Environmental Assessment, 1975). The systems typically operate with turbine-exhaust pressur slightly higher than once-through cooling and are commonly the range of 2.0 to 3.5 inches of Hg abs., or exhaust tempe tures of 101°F to 120°F. (Budenholzer, et al., 1972) This ri in pressure and resulting temperature increases the heat ra and cost of production. At the Nebraska City Station, use

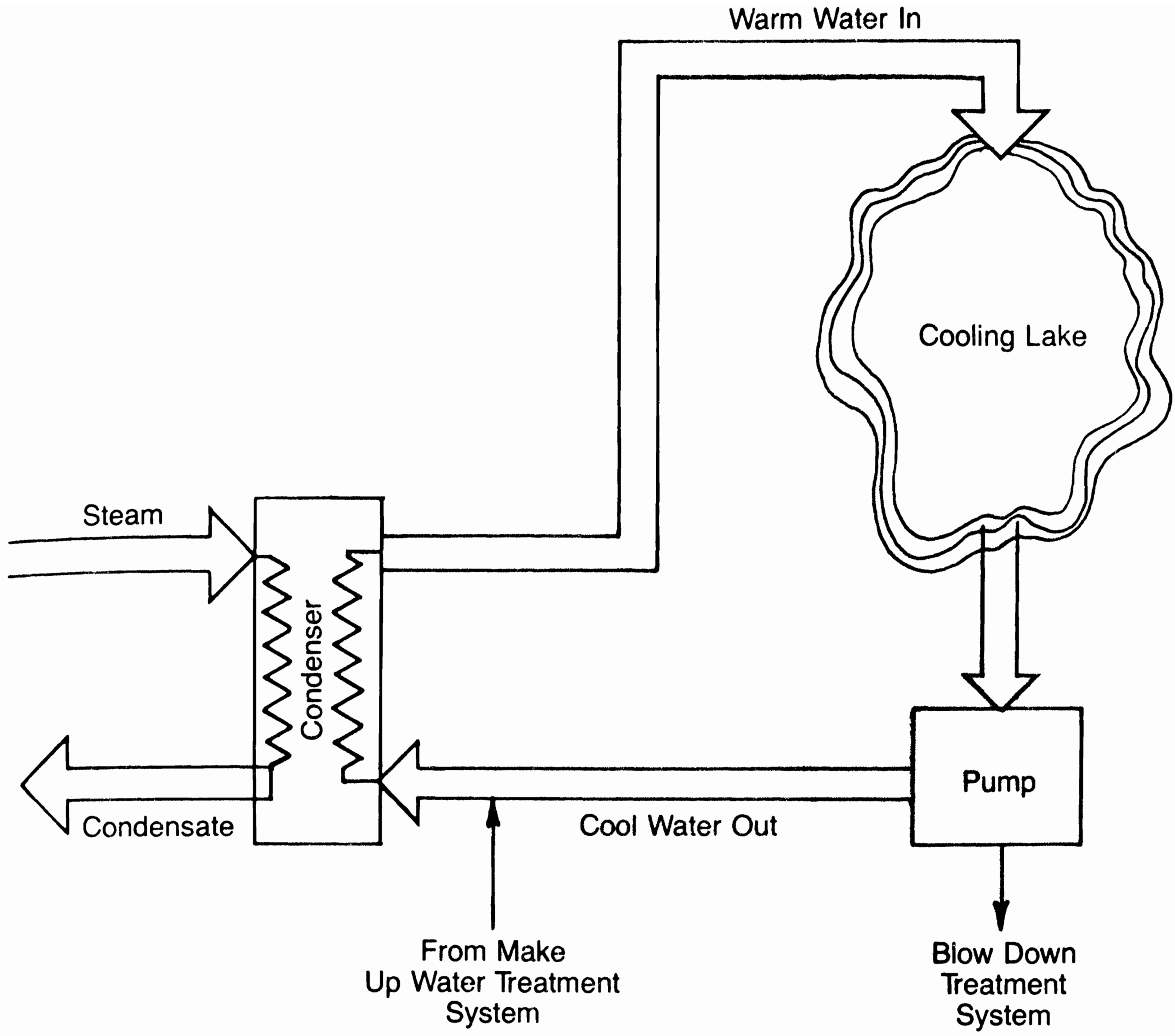

Figure 2. Closed Cycle Cooling Lake.

a cooling lake would have added about 3.6 percent to the total station production costs (Environmental Assessment, 1975).

As illustrated in Table I, the increased production costs are the costs necessary to cover capital expenses, operating expenses, capacity losses, and fuel costs. Each of the parameters involved differs, depending on the type of cooling alternative utilized. A comparison of these alternatives and their costs is summarized in Table II (Environmental Assessment, 1975). Capital cost, a major factor in production costs, consists of costs for the purchase and installation of equipment as well as land. Operating costs include pumping and fan power where appropriate, as well as water treatment, operating labor, and maintenance. In addition to higher auxiliary power requirements, the increased turbine-exhaust pressures and temperatures result in an additional loss of the plant's ability to

TABLE I

Factors Lending to the Additional Costs of Cooling Processes Other than Once-Through Cooling

1. **Increased Heat Rate**
   Higher Fuel Costs per Unit of Power Produced
2. **Increased Capital Cost**
   Land Purchases, Equipment Cost and Installation
3. **Increased Operating Costs**
   Fan and Pump Operation, Water Treatment and Maintenance
4. **Decreased Turbine Capability**
   Capacity Lost Must be Replaced

TABLE II

Estimated Percent Increases in Total Nebraska City Power Station Unit 1 Cost
for Various Cooling System Alternatives

Additional Cost Criteria	Once-Through	Cooling Lake	Spray Pond	Wet Tower: Mechanical Draft	Wet Tower: Natural Draft	Dry Tow
1. Increased Heat Rate	base	1.6	1.0	.3	.7	N.A.
2. Capital Cost	base	2.8	2.1	2.4	4.6	N.A.
3. Operating Cost	base	- .8	3.8	5.4	2.4	N.A.
4. Decreased Turbine Capability	base	- .01	.5	.6	.3	N.A.
5. Total	base	3.6	7.4	8.7	8.0	32[6]

N.A.–Not Available

deliver electric power. This loss must be replaced by additional plant capacity, which results in higher capital costs.

Figure 4 illustrates a modification of the cooling lake concept. This system is called a spray pond. Spray modules are used to increase convective and evaporative heat transfer. This option utilizes a smaller pond area and is of interest where space is a consideration. The Nebraska City Station would have required a 120-acre pond with about 140 spray modules if once-through cooling was not utilized. Such a system has performance characteristics more similar to those of a wet-cooling tower than to those of a cooling lake.

Spray-pond cooling is dependent on the wet bulb temperature. The wet-bulb temperature is the lower limiting temperature for the cooling process and is an indicator of the air's ability to absorb heat. Turbine exhaust pressures with a spray pond normally range from 2.5 to 4.5 inches of Hg abs., which corresponds to exhaust temperatures of 109°F to 130°F (Budenholzer, et al., 1972). This option would have resulted in an additional total Nebraska City Station production expense of about 7.4 percent (Environmental Assessment, 1975).

Wet-cooling towers illustrated in Figure 3 are also closed cooling systems. A wet tower is a direct-contact evaporative cooling device. Cooling water pumped from the condenser into the top of the tower cascades through the tower, passing over baffle plates which break the flow into drops. Air is drawn through the water droplets, cooling them by evaporation. As with the spray pond, the extent of cooling is limited by the wet bulb temperature. The cooled water is then pumped back to the condenser.

Air flow in the tower may be created by fans (mechanical draft) or by a tall shell in which heated air rises in a chimn effect (natural draft). With a mechanical-draft system, induc draft or forced-draft fans may be utilized. For the Nebras City Station, forced-draft fans were not considered, due to distribution problems which led to a lower cooling efficien An induced-draft tower which would have operated with exhaust pressure of 2.5 to 4.5 inches of Hg abs., and exha temperatures of 109°F to 130°F (Budenholzer, et al., 19 would have resulted in a total increase of station costs about 8.7 percent (Environmental Assessment, 1975).

Because the air flow in a natural-draft tower depends the temperature difference between the air inside the sh and the ambient air, higher temperatures are normally countered in natural-draft towers than in mechanical-dr towers. Natural-draft towers are not generally conside suitable for hot climates, in which the difference obtainal between inside and outside temperatures would at times too small for proper operation. These conditions would duce the cooling efficiency of the natural-draft towers dur the hot, humid months of the year, when the towers needed the most. Because of atmospheric conditions, the n ural-draft wet-cooling tower was considered to be a margina practical cooling system alternative for the Nebraska C Station. If this system was used, total station cost would h been elevated by about 8 percent (Environmental Assessme 1975).

Figure 5 illustrates the dry-cooling tower option. The type of cooling tower has either air-cooled condensers or cooled heat exchangers, and there is no contact between and water. As with the wet tower, both the mechanical natural-draft options are available. For economic reasons, dry-cooling towers were not considered for the Nebraska C Station. With heat transfer dependent entirely on convecti

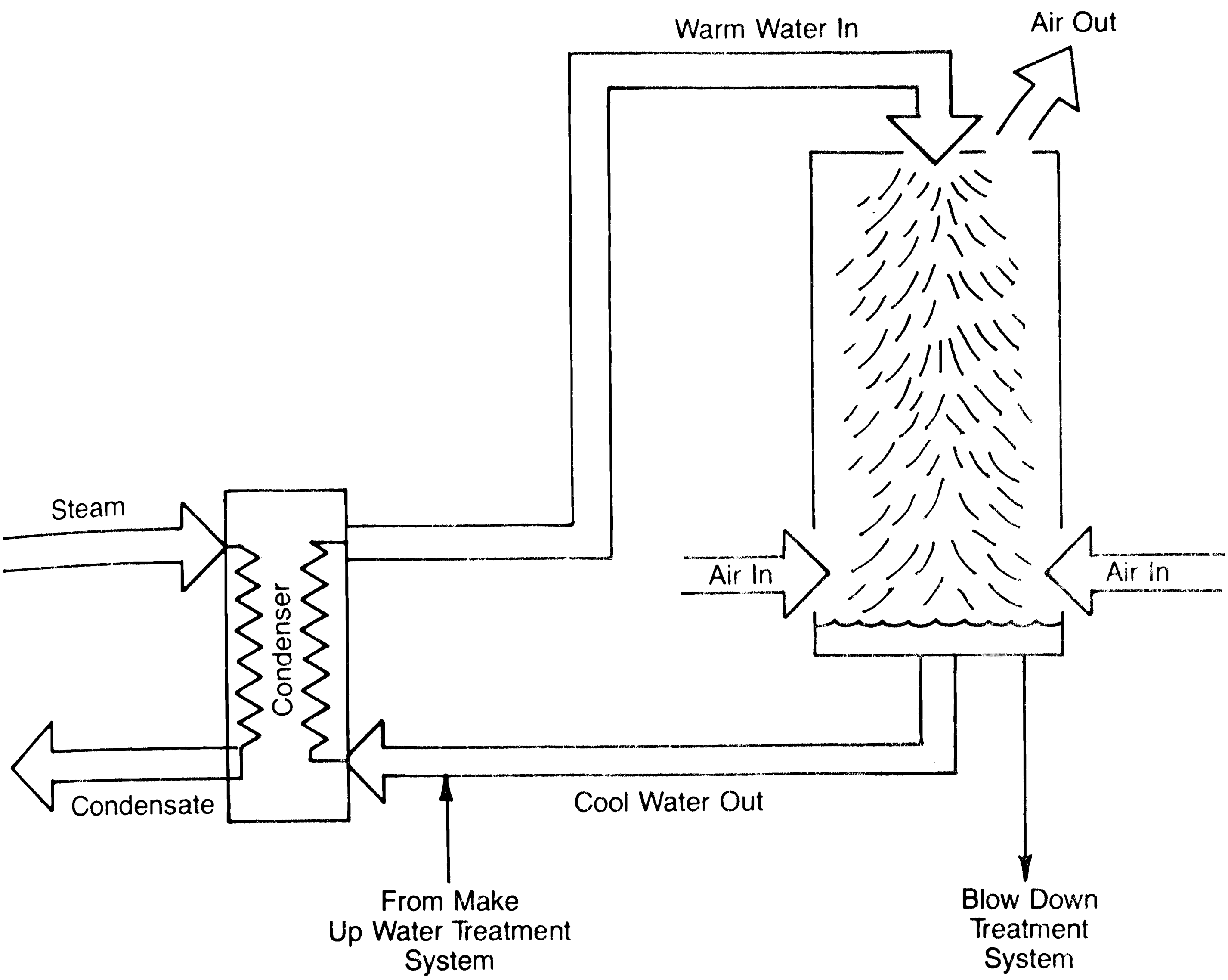

Figure 3. Wet Cooling Tower Natural or Mechanical Draft.

the ambient dry-bulb temperature is the lowest temperature to which the water could be cooled. In these systems, turbine-exhaust pressures in excess of 6 to 8 inches Hg abs., and temperatures of 149°F to 152° are common (Budenholzer, et al., 1972). It is estimated that this cooling alternative would have elevated the total station production cost by about 32 percent (Hauser, 1969).

Each cooling system has its own environmental pros and cons that need to be considered in system selection. Thermal pollution has attracted major interest (Merriman, et al., 1976). Obviously, thermal effects on natural bodies of water are a major consideration with open-cycle systems such as once-through cooling, where heated water is returned to the natural water source. When these effects are detrimental, closed-loop cooling systems afford the only alternative which eliminates completely the thermal discharge to streams. This is of major importance in power plant design, when one considers that any alternative to once-through cooling will result in higher total production costs. However, in comparing once-through and closed-loop systems in general, the overall effects on water and air quality must be carefully considered.

Wet-cooling towers evaporate large quantities of water. This evaporation results in concentrating the dissolved solids in the systems. The dissolved-solid concentrations are controlled, below the point where they would precipitate, by blowing down and/or chemical additions. The effects of cooling tower blowdown on natural water bodies must be evaluated and controlled with adequate treatment. Fogging effects due to cooling towers, cooling lakes, and spray ponds must also be considered in any environmental evaluation of closed-loop systems. Other problems with certain closed-loop systems are related to noise levels and the high consumption of water.

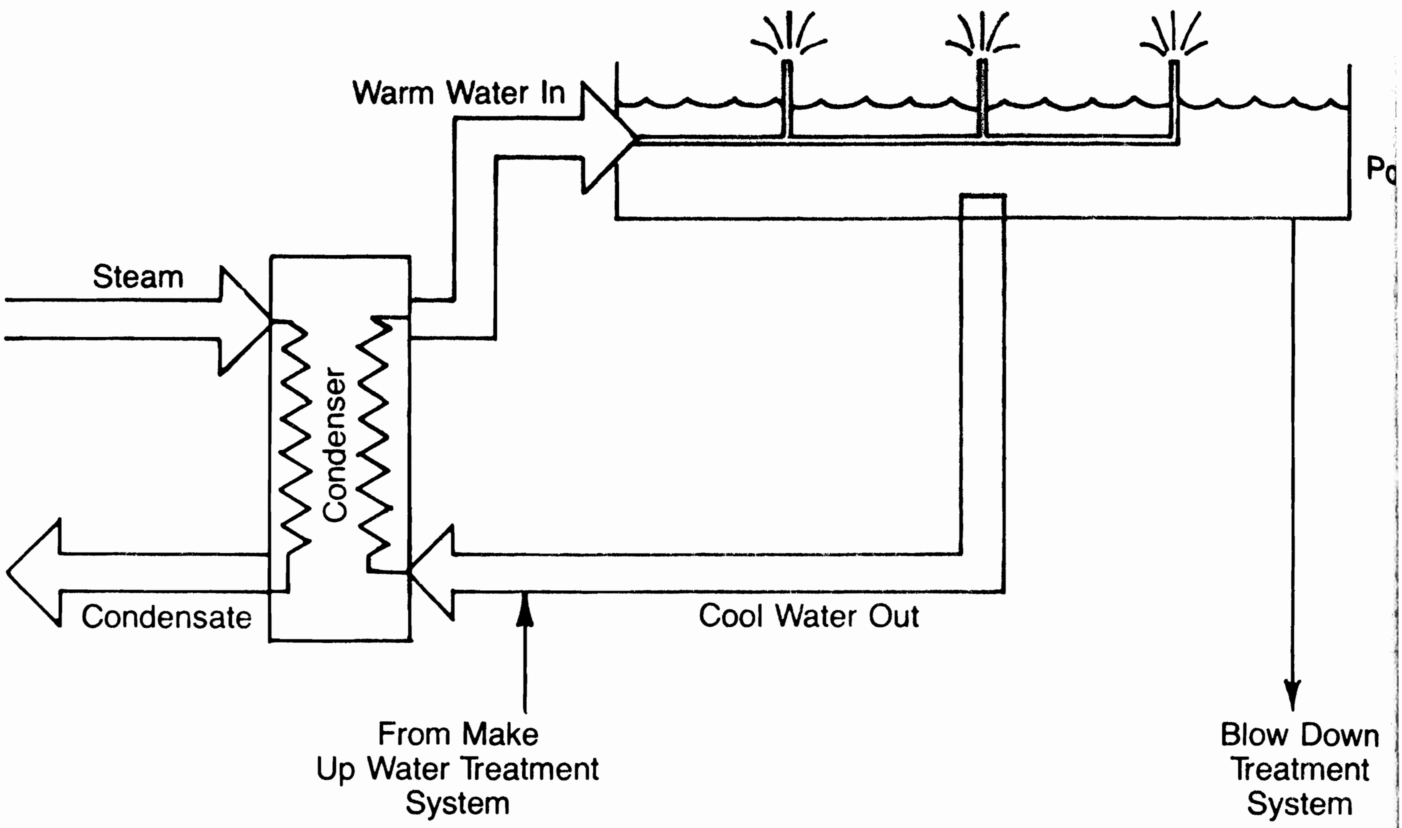

Figure 4. Spray Pond.

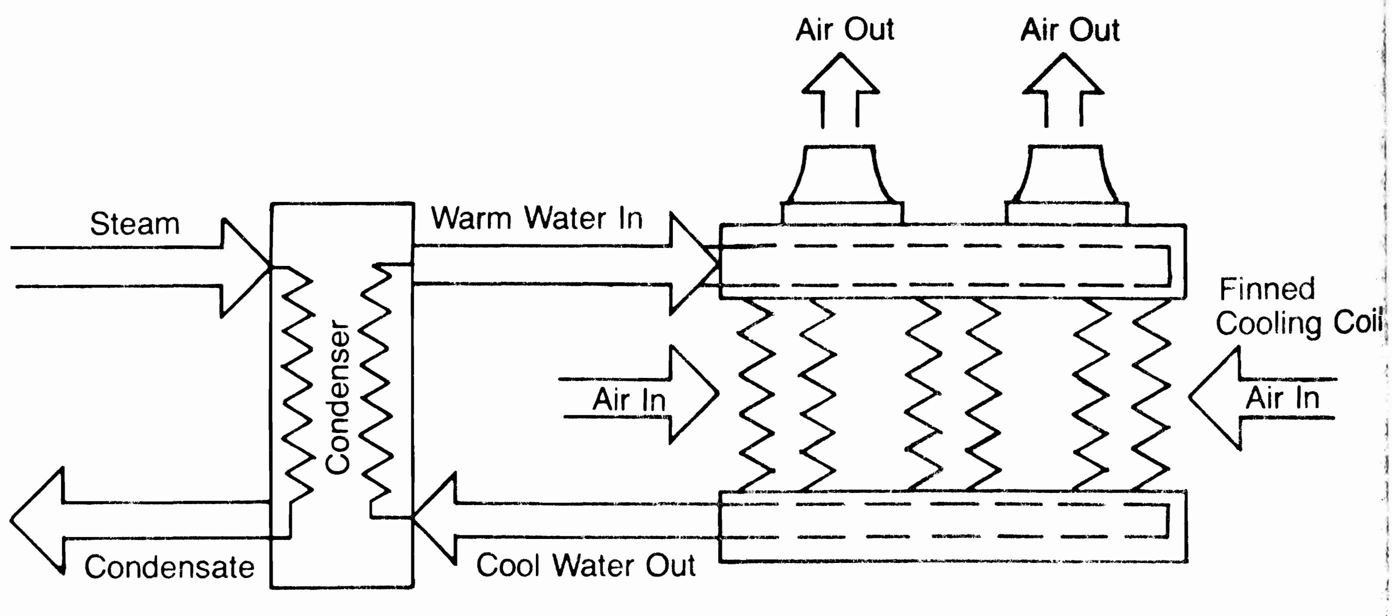

Figure 5. Dry Cooling Tower Natural or Mechanical Draft.

As demonstrated by Hauser and Oleson (1970), the cooling system that has the best water rate, or lowest consumption of water, is the once-through natural-cooling lake or river. If this system is not available for use, the next best water rate is produced by cooling towers or spray ponds, depending on site conditions. Cooling lakes have the highest consumptive water rate. For a 1,150-MW nuclear facility, it is estimated that a wet mechanical draft tower would have a total consumptive requirement of 14,400 gpm, whereas the total consumption with once-through cooling would be approximately 4,800 gpm (Environmental Report, 1976). In this case, once-through cooling has an evaporative loss of about one-third that of a cooling tower. Figure 6 delineates heat transfer mechanisms and relative consumption of water for each of the alternative cooling systems (Development Document, 1974).

Over the years, the OPPD has been aware of the water-consumptive and economic advantages of once-through cooling. In an effort to continue with the utilization of this mode of cooling, we have undertaken many studies to determine the level of biological effect of our thermal effluents. Since 1972, a comprehensive program of study has been conducted at the Fort Calhoun Nuclear Generating Station. These programs have been aimed at the study of all aspects of the once-through cooling operation. The effect of the interface of the cooling system and the biological communities of the Missouri River was of great concern in licensing the operation of Fort Calhoun in 1973. Since this time, a federal regulation has been passed that makes the discharge of thermal effluents to a natural river or lake illegal. At the present time, a waiver must be obtained to discharge heat. Such a waiver was obtained for the operation of the Nebraska City Unit 1; data generated at the Fort Calhoun Station were instrumental in obtaining this waiver.

Biologically, the District has developed into a leader in conducting Missouri River study programs. We have demonstrated that the effects are minimal on planktonic organisms in the Missouri River water in passing through a power-plant condenser of the design of Fort Calhoun Unit 1 (Kline, et al., 1977). At a maximum, there has been a reduction of only 5 percent in the population of the most fragile planktonic group: the larval fishes (King, 1977). This is a reduction in the total population of larval fishes passing the stations at any given instant. Similarly, other District programs have found that power plant cooling in the Missouri River can co-exist with a balanced biological community.

Future water availability, as well as power loading, has a direct influence on the continued use of once-through cooling on the Missouri River. Power loads have increased rapidly during the past and are anticipated to continue in the future. The Missouri Basin Interagency Committee (Missouri River Basin Study, 1969) estimates that power requirements in the Middle Missouri will increase by about 280 percent by the year 2000. During this same time, it is estimated that Missouri River flows will decrease due to increased upstream water withdrawals. Expected uses which will reduce flows include coal gasification, recreation, increased irrigation, and additional municipal and industrial utilization. It is estimated that Missouri River Basin stream flows will decrease by 38 percent by the year 2000 (Missouri River Basin Study, 1969).

Water Usage—Who Cares? The Omaha Public Power District is deeply concerned about water usage. Power production costs are directly related to water availability and, more recently, to minimizing adverse biological effects because of water use. It is the District's goal to continue to use once-through cooling in its future facilities. Our ability to accomplish this goal is largely in the hands of water resource planners who will determine how water will be utilized, and power district consumers who will determine the rate at which additional facilities must be constructed to meet power demands. Environmental considerations will also be extremely important in determining the mode of water use. It is the District's challenge to determine, through appropriate study, the extent to which once-through cooling may safely be utilized to insure a balanced biological community.

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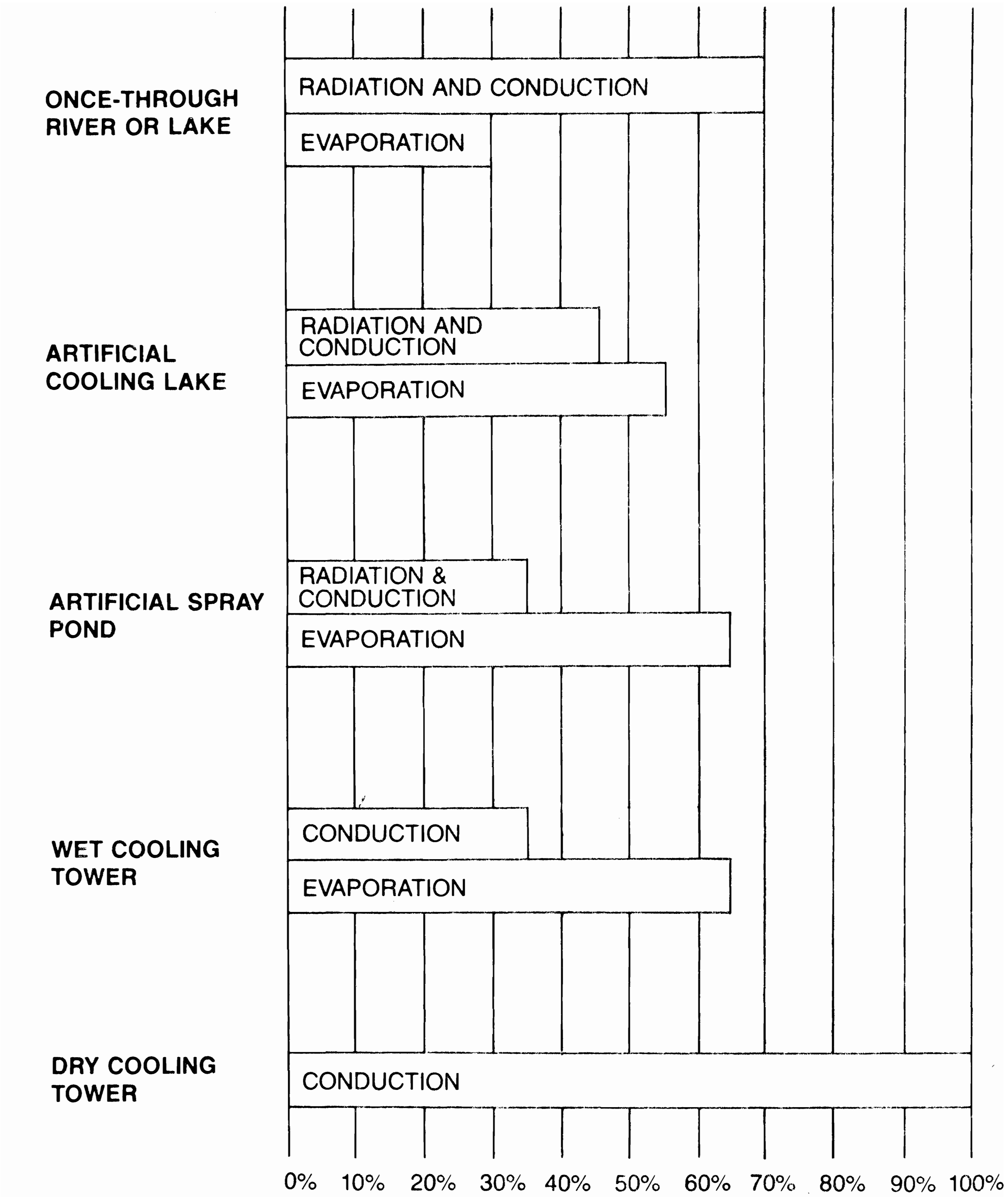

Figure 6. Heat Transfer Mechanisms with Alternative Cooling Systems.

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