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WATER NEEDS FOR ELECTRICAL ENERGY PRODUCTION IN IOWA

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GLOSSARY

boiler make-up water - water required to replace the loss of circulating water in the boiler system.

British thermal unit (Btu) - the standard unit for measurement of the amount of heat energy necessary to raise the temperature of one pound of water one degree Fahrenheit.

capacity factor (electric power) - the ratio of the average load on the generating plant for the period of time considered to the capacity rating of the plant.

condenser cooling water - water required to condense the steam after its passage from the steam turbine.

cooling water consumption (power) - the cooling water withdrawn from the source supplying a generating plant which is lost to the atmosphere. Caused primarily by evaporation due to the temperature rise in the cooling water as it passes through the condenser. The amount of consumption (loss) is dependent on the type of cooling employed; flow-through, cooling pond, or cooling tower.

cooling water load - heat energy dissipated by the cooling water.

cooling water required (power) - the amount of water needed to pass through the condensing unit in order to condense the steam to water. This amount is dependent on the type of cooling employed.

generator efficiency - the ratio of the power output of the generator to the power unit.

heat equivalent of electric generator output - the amount of heat energy equivalent to one kilowatt hour of electric energy. 3413 Btu is equal to one kilowatt hour of electric energy output of the generator.

heat loss from boiler furnace - heat energy loss from the combustion chamber through the stack. This energy is not part of the cooling water load.

heat loss from electric generator - heat loss in converting the mechanical turbine energy into generator electric energy. This heat is generally dissipated by a fluid flowing in a closed circuit which is cooled by water. Thus, it is a part of the cooling water load.

heat rate - a measure of the thermal efficiency of a generating station. It is computed by dividing the total Btu content of the fuel burned (or heat released from a nuclear reactor) by the gross energy generated, generally expressed as Btu per kilowatt hour.

kilowatt (kw) - the electrical unit of power or rate of doing work, which equals 1,000 watts or 1.341 horse power.

kilowatt hour (kwh) - the basic unit of electric energy. It equals one kilowatt of power applied steadily for one hour.

megawatt (mw) - one thousand kilowatts.

megawatt hour (mwh) - one thousand kilowatt hours.

net heat rate - a measure of the thermal efficiency of a generating stations including station use. It is computed by dividing the total Btu content of the fuel burned (or of heat released from a nuclear reactor) by the net energy generated, generally expressed as Btu per net kilowatt hour.

peak load (electric power) - the maximum load in a stated period of time. Usually it is the maximum integrated load over an interval on one hour which occurs during the year, month, week or day. It is used interchangeably with peak demand.

plant efficiency - the ratio of the energy delivered from the plant to the energy received by it under specified conditions.

reserve capacity (electric power) - the difference between the peak load and the generating capacity available.

thermal efficiency - the ratio of the amount of energy produced to the total Btu content of the fuel consumed, usually expressed as a heat rate (Btu per kwh).

ABBREVIATIONS

IELP	Iowa Electric Light and Power Company
IPL	Iowa Power and Light Company
IIGE	Iowa-Illinois Gas and Electric Company
IPS	Iowa Public Service
IPC	Interstate Power Company
ISU	Iowa Southern Utilities
CIPCO	Central Iowa Power Cooperative
CBPC	Corn Belt Power Cooperative
EILP	Eastern Iowa Light and Power Cooperative
MUNI	Municipally-owned utilities

INTRODUCTION

As the population of the United States continues to grow, the consumption of electrical energy is growing at an even faster pace. Some estimate our consumption to double every ten years, for an annual growth rate of 7.2% [1]. Even if one assumes a nearly zero population growth and a 50% reduction in the current growth rates of both individual wealth and power consumption in the next fifteen years, the consumption of electricity might still triple by 1990 [2]. This current national growth rate, which is greater than the growth rate of our nation's Gross National Product [3], is reflected also in the State of Iowa. In 1953, sales of electricity in Iowa amounted to approximately 4.675 billion kilowatt-hours (kwh), and in 1973 approximately 15.418 billion kwh were sold [4]. This represents a growth rate of over 6% per year. In 1973, about one-fourth of the total energy consumed in the State was used in the production of electrical energy, as shown in Figure 1.

Although logic would indicate that this exponential growth cannot continue indefinitely, there are indications that it will continue for at least the next ten to twenty years, as predicted by various utility

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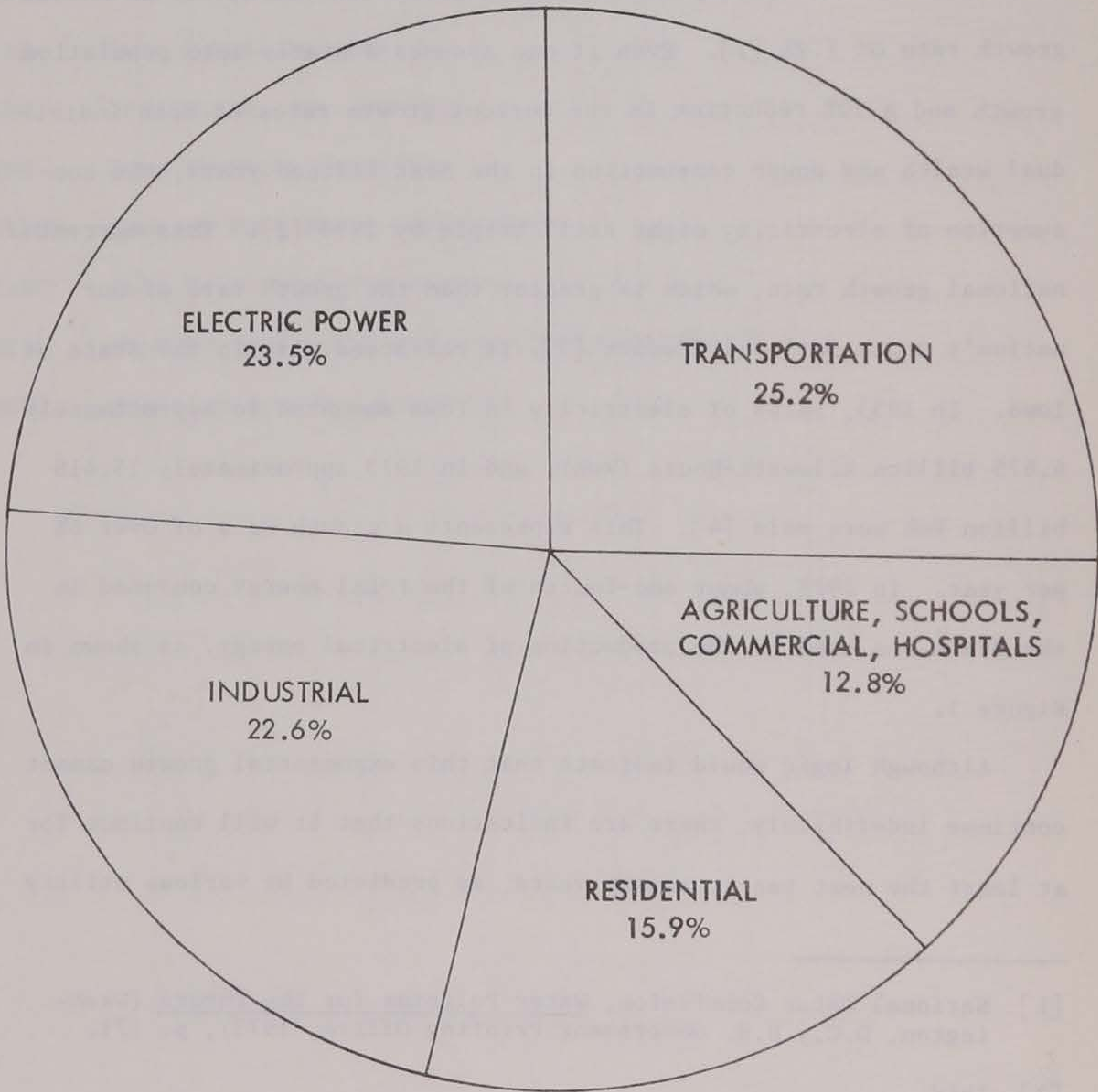
[1] National Water Commission, Water Policies for the Future (Washington, D.C., U.S. Government Printing Office, 1973), p. 171.

[2] Ibid.

[3] UMRCBS Coordinating Committee, Upper Mississippi River Comprehensive Basin Study, Appendix M: Power (Washington, D.C., 1970) p. M-43.

[4] Iowa Energy Policy Council, Energy: 1975, The First Annual Report of the Iowa Energy Policy Council (Des Moines, Iowa, 1975), p. 8.

Figure 1. Energy consumption by sector in Iowa.



companies in the upper midwest in Table 1. This increased demand must be met with the construction of new facilities, utilizing existing and new technologies. The generation capabilities of the United States were analyzed by the Federal Power Commission in their 1970 National Power Survey and estimates were made of the additional capacities needed to meet the increased demands. These estimates are shown in Table 2. Power companies in Iowa have also projected additional construction of generating plants in the Mid-continent Area Reliability Coordination Agreement (MARCA), which is shown in Table 3.

A consequence of the new construction will be the impact of these new facilities on the environment, including the demand for water. In the past, these environmental impacts have been largely ignored, for a variety of reasons. However, with increased public awareness of environmental issues, it is important that the problems related to the environmental impacts of power plants be analyzed and solved as quickly as possible in order to provide the consumer with the best alternative, in terms of economy, environment, and power availability.

In the past, utility companies have been able to provide large amounts of low-cost power to its consumers. Although low-cost power remains a goal of these companies, satisfying environmental concerns has also become a goal. The cost of environmental mitigations has in the past been a relatively small part of the overall project cost. Currently and more so in the future, these costs will become a substantial part of the project cost, or will affect the power plant operations in such a way as to cause increased consumer costs. It is therefore obvious that the so-called best alternative involves satisfying two conflicting goals. Because of the conflicting nature of

TABLE 1

Summary of Net Energy Requirements of Iowa Utilities
Annual - GWH

Owner	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
IPC	2978	3157	3346	3547	3760	3985	4224	4478	4746	5031	5333
IPS	2733	3106	3518	3908	4181	4474	4826	5204	5593	6030	6508
IPL	3986	4277	4601	4959	5315	5700	6122	6571	7016	7521	8056
IELP	4522	4802	5171	5533	5920	6336	6781	7260	7768	8366	8902
IIGE	3627	3920	4234	4572	4938	5333	5760	6221	6718	7256	7836
ISU	1409	1615	1808	1933	2063	2203	2353	2514	2687	2873	3073
CBPC	792	827	870	914	960	1008	1058	1111	1166	1225	1286
EILP	245	262	283	308	334	360	388	418	450	484	520

TABLE 2

Projected Utility Growth in the United States.

Type of Plant	1970 (actual) Capacity	1970 (actual) % of Total Generation	1980 Capacity	1980 % of Total Generation	1990 Capacity	1990 % of Total Generation
Hydroelectric-conventional	51.6	16.4	68	9.4	82	5.4
Hydroelectric-pumped storage	3.6	0.3	27	0.8	70	1
Fossil steam	259.1	80.5	390	60.9	558	43.5
Gas-turbine and diesel	19.2	1.4	40	0.9	75	0.8
Nuclear	6.5	1.4	140	28	475	49.3
TOTALS	340	100	665	100	1,260	100

Notes: (1) The projections are premised on an average gross reserve margin of 20%.
(2) Since different types of plants are operated at different capacity factors, this capacity breakdown is not directly representative of share of kilowatt-hour production. For example, since nuclear plants are customarily used in baseload service and therefore operate at comparatively high capacity factors, nuclear power's contribution to total electricity production would be higher than its capacity share.

Source: U.S. FEDERAL POWER COMMISSION (1972). The 1970 National Power Survey. U.S. Government Printing Office, Washington, D.C., pp. I-18-29.

TABLE 3

Added Capacities in Iowa Utilities by 1985
Mw.

Owner	Committed Additions			Proposed Additions		
	Fossil	Gas-Turbine	Nuclear	Fossil	Gas-Turbine	Nuclear
IPC	360	--	202			
IPS	579	60			65	150
IPL	533					335
IELP	50	29	22		250	500
IIGE	362	165				
ISU	470	100				
CBPC	53		2			
EILP	25					25

these goals, the solution of the environmental problems associated with the construction of power plants becomes even more complex.

Unfortunately, the conflicting nature of these goals also increases the complexity of the problem. Environmental impacts might be split into two main categories, including the direct impacts upon the human senses (sight, odor, noise, etc.) and the indirect impacts, such as the depletion of our natural resources [5]. There are many different subgroups within these two categories, such as radioactivity effects, land use effects, air pollution effects, and so on. Although it is not within the scope of this paper to examine or solve any of these problems, it will examine a very important issue in the environmental spectrum. This point is: How much water is used in the State of Iowa for the production of electricity?

Water is used for many different purposes in power plants. Depending upon the type of plant, there can be an appreciable change in the quality of the water used, or there can be an appreciable loss of water within the plant. The amounts of water used and lost can have an impact upon the other beneficial use groups in the water resource picture, such as municipal supply, irrigation, recreation, or water quality management. It shall be the purpose of this paper to determine how much water is used to produce power in Iowa, and to evaluate the future requirements of water to meet the increased demands.

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[5] Woodson, Riley D., "Logical Approaches to Power Supply and Environment," Journal of the Power Division, ASCE, Vol. 98, No. PO2, Proc. Paper 9257, October, 1972, p. 112.

METHODS OF PRODUCTION OF ELECTRIC POWER

To fully understand how water is used in the production of electric power, one must first understand the methods of production. As is shown in Table 2, there are three major processes used to generate electricity, including: 1) gas-turbine or diesel plants; 2) hydroelectirc plants; and 3) steam-electric plants, using either fossil fuels such as coal, gas, or oil, or nuclear fuels, such as uranium. Shown in Tables 4 and 5 are the contributions these processes make to generation of power in Iowa. Although the current capacity of gas-turbine and diesel units in Iowa does appear to be significant (12% and 8%, respectively), it can be seen that in terms of total generation, these plants contribute very little to Iowa. This is due to the fact that these plants are used for peaking purposes or to provide standby power, and therefore are not used continuously. The total water use in these plants is also very small. Therefore, this paper shall only consider hydroelectric plants and steam-electric plants, and their respective contribution to the water demand spectrum in the State of Iowa.

Hydroelectric Plants

The primary source of energy in a hydroelectric plant is the kinetic energy released from falling water. This is demonstrated in the following equation:

$$E = \frac{WQH}{550},$$

where E = energy produced, in horsepower, W = the unit weight of water,

TABLE 4

Available Production Capacity in Iowa, 1974, by Method of Production, in MW.

Owner	Fossil	Nuclear	Gas-Turbine	Diesel	Hydro	USBR Hydro	Total	%
IELP	429.8	565.7	-0-	42.6	1.8	8.9	1048.8	17
IPL	478.9	418.0	281.5	-0-	-0-	5.0	1183.4	20
IIGE	339.0	414.0	201.0	1.0	3.6	-0-	958.6	16
IPS	690.0	-0-	96.0	23.1	-0-	0.6	809.7	13
IPC	525.8	-0-	43.5	10.7	-0-	16.8	596.8	10
ISU	268.1	-0-	-0-	11.5	-0-	0.4	280.0	5
CIPCO	96.6	-0-	28.7	5.8	-0-	15.4	146.5	2
CBPC	87.8	-0-	-0-	17.6	-0-	18.0	123.4	2
EILP	63	-0-	-0-	-0-	-0-	-0-	63.0	1
MUNI	337	-0-	49	398	0.5	59.9	844.4	14
TOTAL	3316.0	1397.7	699.7	510.3	5.9	125	6054.6	100
%	55	23	12	8	--	2	100	

TABLE 5

Net Generation in Iowa, 1974, in MwH
by Method of Production

Owner	Fossil	Nuclear	Gas-Turbine	Diesel	Hydro	USBR Hydro	Total	%
IELP	1,807,566.3	930,890.3	-0-	9,059.5	7,164.7	77,891.0	2,832,571.8	14
IPL	2,073,712.4	884,484.0	159,284.6	-0-	-0-	43,783.0	3,161,264.0	16
IIGE	1,317,882.6	1,983,033.0	162,826.6	29.3	20,034.7	-0-	3,483,806.2	18
IPS	3,188,416.1	-0-	10,628.5	598.9	-0-	4,995.0	3,204,638.5	16
IPC	1,993,732.1	-0-	5,300.4	504.4	-0-	147,504.0	2,147,040.9	11
ISU	1,056,802.3	-0-	-0-	292.7	-0-	3,787.0	1,060,882.0	5
CIPCO	334,861.0	265,969.8	-0-	20,634.0	-0-	134,888.9	756,353.7	4
CBPC	345,558.8	-0-	-0-	595.3	-0-	157,897.0	504,051.3	3
EILP	248,210.0	-0-	-0-	-0-	-0-	-0-	248,210.0	1
MUNI	1,029,841.0	-0-	2.943.6	421,486.7	101.7	525,028.0	1,979,401.0	10
TOTAL	13,396,581.0	4,064,377.1	340,983.7	453,200.8	27,301.1	1,368,505.9*	19,650,947	98
%	68	21	2	2	--	7	100	

*Includes 272,732.0 MwH sold to L & O Power Coop. & Northwest Iowa Power Coop.

usually 62.4 lbs per cubic foot, Q = the amount of water flowing through the turbines, and H = the net difference in elevation between the water surface upstream of the plant and downstream of the plant, called "head." The energy produced may be converted to kilowatts by using the following equation:

$$E_{kw} = 0.746E_{hp}$$

where E_{kw} is the energy produced, in kilowatts. The kinetic energy released by the falling water as it flows through the turbines is utilized to generate electric power. There are three methods now used to generate hydropower, which include plants at conventional dams and reservoirs, pumped-storage plants, and run-of-the-river plants [6].

Conventional hydroelectric plants, such as those located at the main-stem dams on the Missouri River, utilize large amounts of storage and head upstream of the dam to provide a substantial amount of firm power which can be made available 100% of the time. The available storage should be sufficient to provide carry-over storage from the wet season through the dry season, thus providing a firm flow substantially higher than the natural flow of the river. Many large plants have the storage capacity to hold over the equivalent of two years of natural flow. The Missouri River main-stem system contains about three times the average annual runoff (75 million acre feet of storage compared to 25 million acre feet of annual runoff).

Pumped-storage plants, such as the Taum Sauk Plant operated by the Union Electric Company at St. Louis, Missouri, generate power for

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[6] Linsley, Ray K. and Franzini, Joseph B., Water Resources Engineering. (New York: McGraw-Hill Company), p. 473.

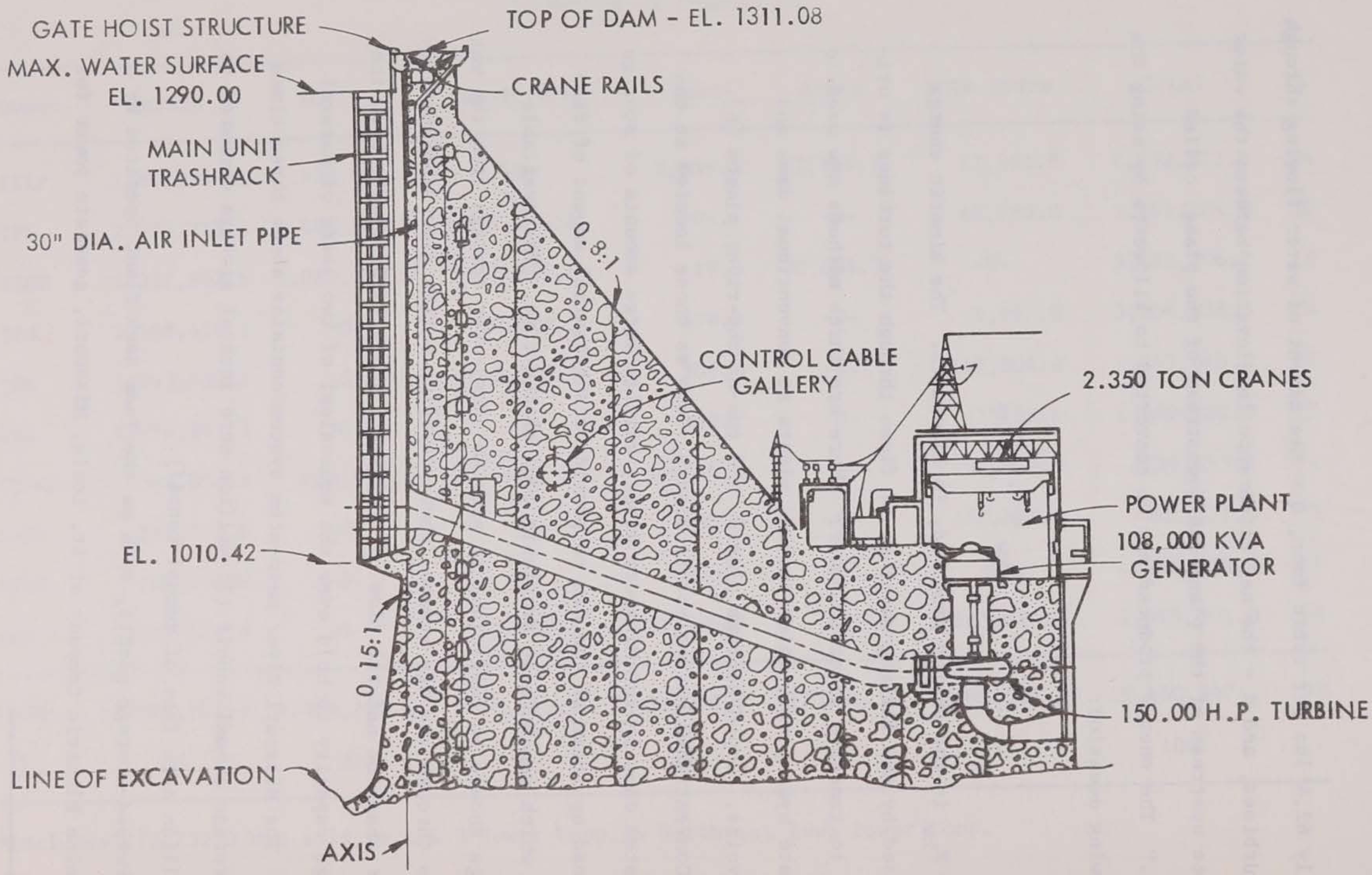

Figure 2. Conventional hydroelectric plant, Grand Coulee development, Columbia River, Washington, 823,000 KVA (1944), 330 ft head, live storage 5,350,000 acre-ft.

Source: Craeger and Justin, Hydroelectric Handbook, p. 200.

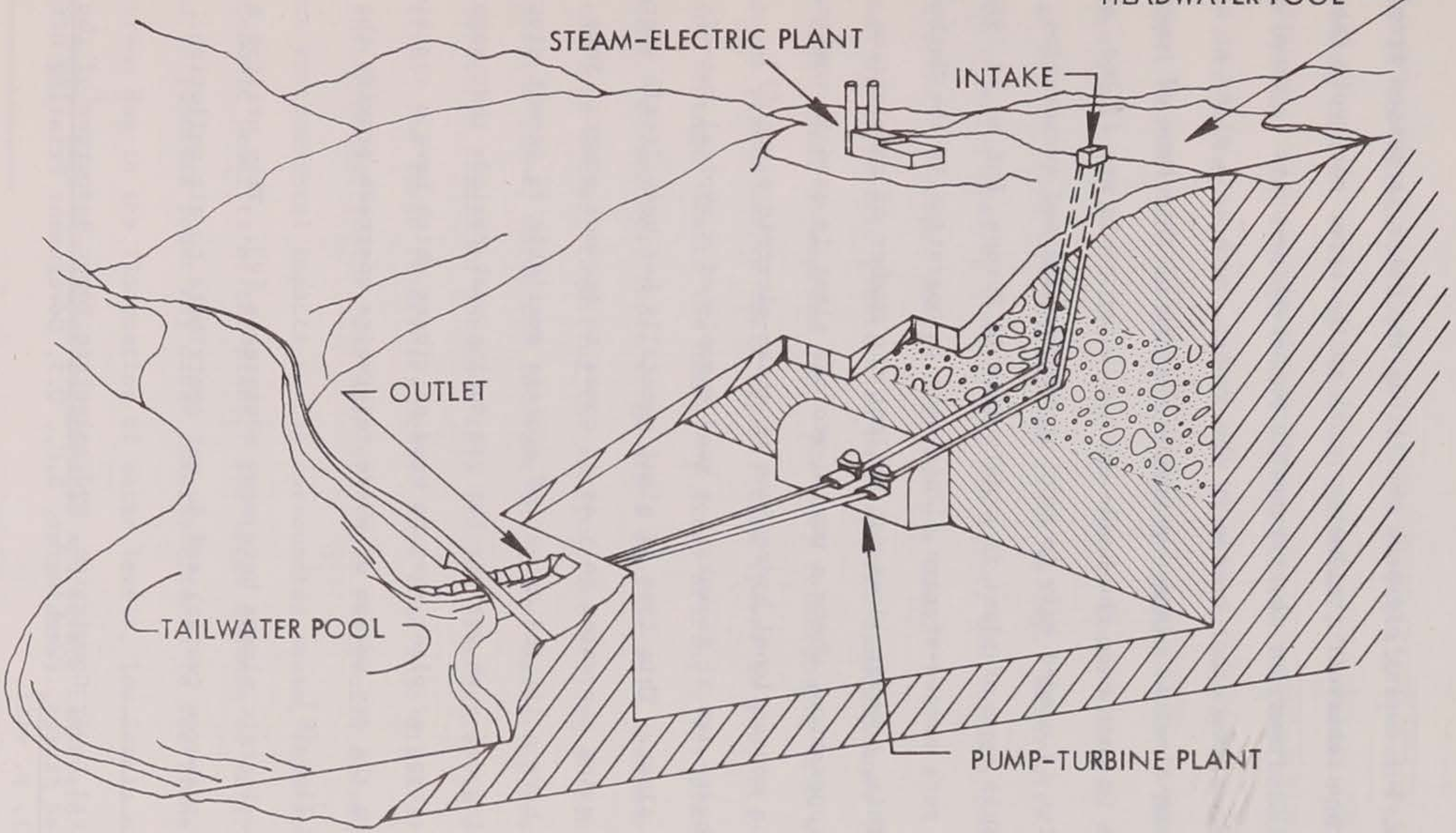

Figure 3. Pumped-storage plant.

Source: Heitz, The Potential for Nuclear and Geothermal Power Plant Siting in Idaho as Related to Water Resources, p. 25.

peak loads, but during off-peak conditions the water is pumped from the lower storage reservoir (tailwater pool) to the upper reservoir (headwater pool). Power for the reversible pump-turbine units is usually provided from some other source in the system, such as a plant at a dam or steam-electric plant. A unique feature of this type of power generation is that once the head- and tailwater pools are filled, additional water is needed only to make up for seepage and evaporation losses. This type of plant is widely used in Europe, but as of 1972 only nine pure pumped-storage plants were in operation in the United States. This, however, does not reflect the number of combination plants in operation, where a pumped-storage plant is used in combination with a conventional hydroplant or steam-electric plant [7].

The hydro dam at Keokuk is a good example of a typical run-of-the-river plant. This type of plant generally has very little storage capacity, using the water only as it comes to produce power. Some plants do have a limited amount of storage available to permit storing water during off-peak periods for use during peak periods that same day. This type of plant must be used on rivers which have a sustained flow during the dry season or where reservoirs upstream provide the necessary flow [8].

Hydroelectric plants have many advantages [9]. They utilize a renewable resource (water) and do not contribute to air pollution.

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[7] Federal Power Commission, Hydroelectric Power Resources of the United States, (Washington, D.C., U.S. Government Printing Office, 1972), p. viii.

[8] Linsley and Franzini, op. cit., p. 472.

[9] Federal Power Commission, op. cit., p. xii.

Because of low outage rates, they can add to overall system reliability, and provide instant start-up power in the event of a failure elsewhere in the system. The storage reservoir can provide recreational benefits to the surrounding region as well as a firm water supply for downstream municipal, industrial, navigational, and irrigation needs. The reservoir can also provide cooling water for nearby steam-electric plants, and can aid in flood control for the river valley. Reservoirs also can aid in water quality control for the river, and enhance local fish and wildlife, if proper design measures are used.

But hydroelectric plants also have several disadvantages [10] which limit their widespread use. The very relationship from which hydropower plants derive their capabilities (power is proportional to head and storage) limits the number of sites available for plant development. Oftentimes, these sites are a considerable distance away from the load center, requiring the construction of long distances of transmission lines, which can increase the annual operating costs. Steam-electric plants do not have this limited flexibility in site selection. The large reservoirs needed have come into disfavor with many environmental groups, who maintain these reservoirs cause many adverse environmental impacts to the surrounding areas, thus reducing the economic benefits of the plant. The large amounts of water released to generate power may cause adverse effects to the fishery downstream due to the fluctuation of water levels, low levels of dissolved oxygen from the deeper reservoirs, and severe temperature

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[10] Ibid.

differences. The resulting fluctuations of the reservoir can also inhibit the recreational value of the project. All of these impacts have been studied extensively in the Tennessee Valley Authority system.

Steam-electric Plants

In 1970, more than 80% of the electrical energy produced in the United States was generated in steam-electric plants, using either fossil fuels (80.5% of the total production) or nuclear fuels (1.4% of the total production). By 1990, the Federal Power Commission predicts that over 92% of the total production will come from steam electric plants (43.5% and 49.3%, respectively) as shown in Table 2 [11]. In 1974, fossil and nuclear plants provided 68% and 21% of Iowa's net generation.

Inherent with the increased production predicted for the future is the rising magnitude of the waste heat disposal problem, with its related increase in the withdrawal and consumptive use of water. Since the efficiencies of most modern plants are in the range of 30% to 40%, this means that 60% to 70% of the heat generated in a steam-electric plant must be wasted to either the air or, as is the case in most all plants, the cooling water.

A steam-electric plant operates through the thermodynamic process known as the Rankine Cycle [12]. In this cycle, steam, produced at high temperature and pressure, flows through a turbine, which converts

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[11] National Water Commission, op. cit., p. 172.

[12] Harding, Theodore P., and Dose, B. E., "Energy Production," from The Role of Water in the Energy Crisis (Lincoln: Nebraska Water Resources Research Institute, 1973), p. 74.

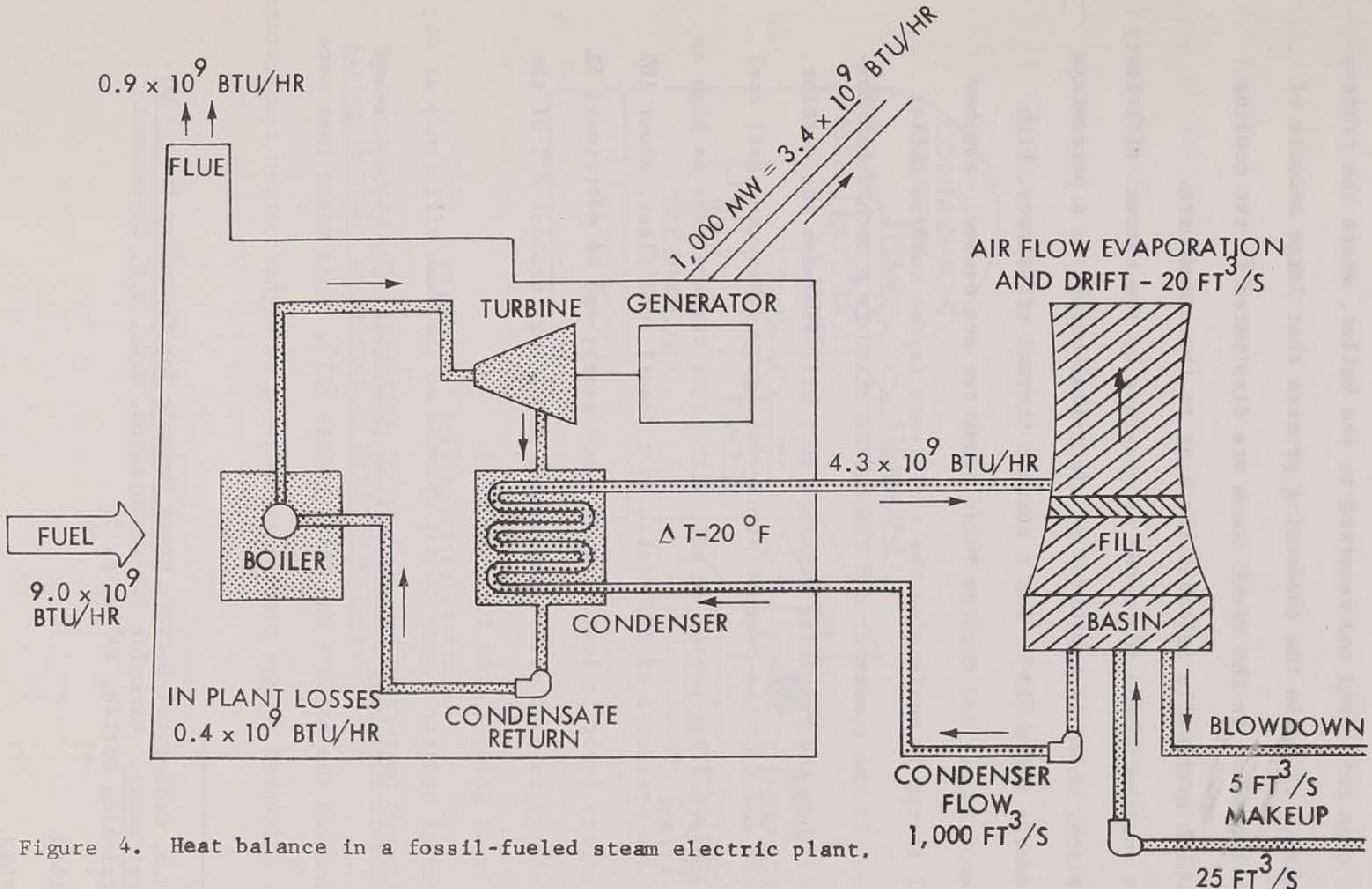

Figure 4. **Heat balance in a fossil-fueled steam electric plant.**

Source: U.S.G.S. Water Demands for Expanding Energy Development, Cir. # 703, Washington, D.C., p. 4.

the kinetic energy in the steam to electrical energy. The "spent" steam is then condensed and returned to the boiler, where the process is repeated. It is in the condensing process that large amounts of waste heat present in the spent steam are dissipated to the cooling water, which eventually releases the heat to the atmosphere.

The cooling demand for water is governed by the thermal efficiency of the plant, which is expressed as electrical output as a percentage of the energy input [13]. For a maximum thermal efficiency, high steam temperatures and turbine inlet pressures are needed. Another critical factor in maximizing the efficiency is the turbine outlet pressure. If the condenser can reduce the steam to a much lower temperature, then the resulting pressure drop will increase the turbine efficiency and thus the overall plant efficiency. Modern fossil fuel plants achieve efficiencies of 40%, with inlet temperatures as high as 1000 °F and pressures of 3500 psi. In a fossil fuel plant, about 10% of the energy input is lost through stack gases, and an additional 5% of the energy is used within the plant, resulting in about 85% of the energy input going to the turbines [14].

Present nuclear plants do not operate at the same efficiency as do modern fossil fuel plants because there is no heat loss through stack gases between the boilers and the turbines [15]. This means that more heat is delivered to the turbines, resulting in higher outlet temperatures

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[13] U.S. Geological Survey, Water Demands for Expanding Energy Development. Circular 703 (Washington, D.C., U.S. Government Printing Office, 1974), p. 5.

[14] Ibid.

[15] Ibid.

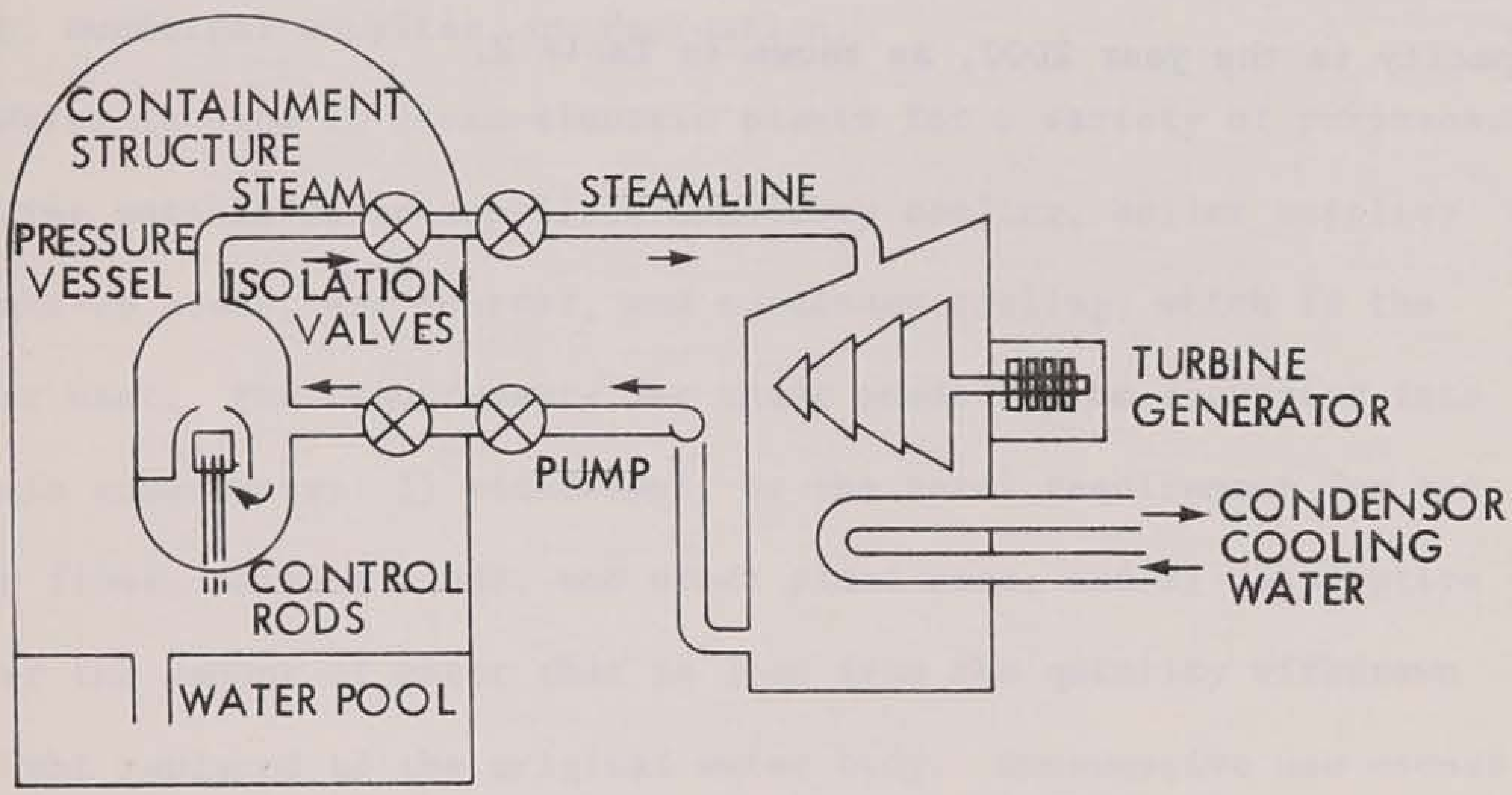

Figure 5. Boiling water reactor.

Source: Heitz, The Potential for Nuclear and Geothermal Power Plant Siting in Idaho as Related to Water Resources, p. 5.

in the spent steam and more heat for the condensers to absorb. Boiling water reactors, shown in Figure 5, usually achieve efficiencies of about 33%, dissipating almost 50% more heat to the cooling water than do fossil fuel plants of comparable capacity. The additional heat has a pronounced effect on the needed cooling water flow, although sources can not agree how much this effect is. However, it is agreed that nuclear plants do require more water than do fossil fuel plants, a factor which must be considered in light of the FPC's predictions of nuclear capacity in the year 2000, as shown in Table 2.

WATER USE IN POWER PLANTS: AN OVERVIEW

The volume of water needed for the production of electricity is dependent upon a number of factors which include the thermal efficiency, the type of plant, the type of cooling system, and the temperature rise across the condensers. Hydroelectric plants may use large quantities of water, but the water may also be used for a number of other beneficial uses at the same time, such as flood control, irrigation, municipal supplies, or recreation.

Water is used in steam-electric plants for a variety of purposes, including potable water supplies, auxiliary cooling, boiler supplies and make-up needs, ash control, and condenser cooling, which is the largest user. The requirements for these needs may be separated into two main components: 1) withdrawal, or the total requirement for condenser flows, make-up needs, and other plant uses, and 2) consumptive use, or the amount of water that is lost from the quantity withdrawn or is not replaced to the original water body. Consumptive use occurs when quantities of water are lost due to evaporation, drift, blowdown, etc. Withdrawals have increased in the past at a rate comparable to power consumption, and although there is some difference of opinion on this matter, they are expected to continue to increase. The consumptive use of water is also expected to increase, though at a more rapid pace than the withdrawal rate [16].

The effects of thermal efficiency and plant type on the water requirements for steam-electric plants have already been mentioned.

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[16] Ibid.

Another serious consideration in determining the water requirements is the method of cooling used to dissipate the waste heat from the spent steam to the atmosphere. Although other factors mentioned have a bearing in determining the total water needed, it is the method of cooling used that has the greatest impact on the consumptive loss of water.

Heretofore, waste heat was dissipated from power plants by merely returning the cooling water to the source directly from the condenser. This method, known as once-through cooling, is losing its popularity because of its impacts on the environment. Indeed, there is a definite trend away from once-through systems on a nationwide basis, as is indicated in Table 6. Once-through systems are being replaced by cooling ponds, spray ponds or canals, wet evaporative towers, dry radiation towers, or a combination of these methods [17].

Once-through Systems

In a once-through cooling system, water is taken from a suitable source, such as a river or lake, and passed through the condenser, where it absorbs the waste heat from the steam, and is returned to the source, where the heat is eventually dissipated through conduction and convection to the atmosphere. This method is the most economical to use if environmental or ecological damages are not included or can be avoided.

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[17] Croley, T. E., and Kennedy, J. F., "Research Needs Related to Heat Dissipating from Large Power Plants, from Proceedings of the Workshop on Research Needs Related to Water for Energy (Urbana, Illinois, University of Illinois, Water Resources Center, 1974), p.111.

TABLE 6

Percent Use of Cooling Systems.

Type of Cooling	Percent of Total Number of Plants			Percent of Total Installed Capacity		
	1969	1970	1971	1969	1970	1971
Once-Through, Fresh	49.8	49.4	48.1	50.5	50.1	47.7
Once-Through, Saline	18.9	18.5	18.1	23.5	22.8	21.5
Cooling Ponds	5.4	5.7	6.0	5.9	6.7	9.3
Cooling Towers	17.2	17.5	18.1	10.9	11.2	12.9
Combined Systems	8.7	8.9	9.7	9.2	9.2	10.6
	100.0	100.0	100.0	100.0	100.0	100.0

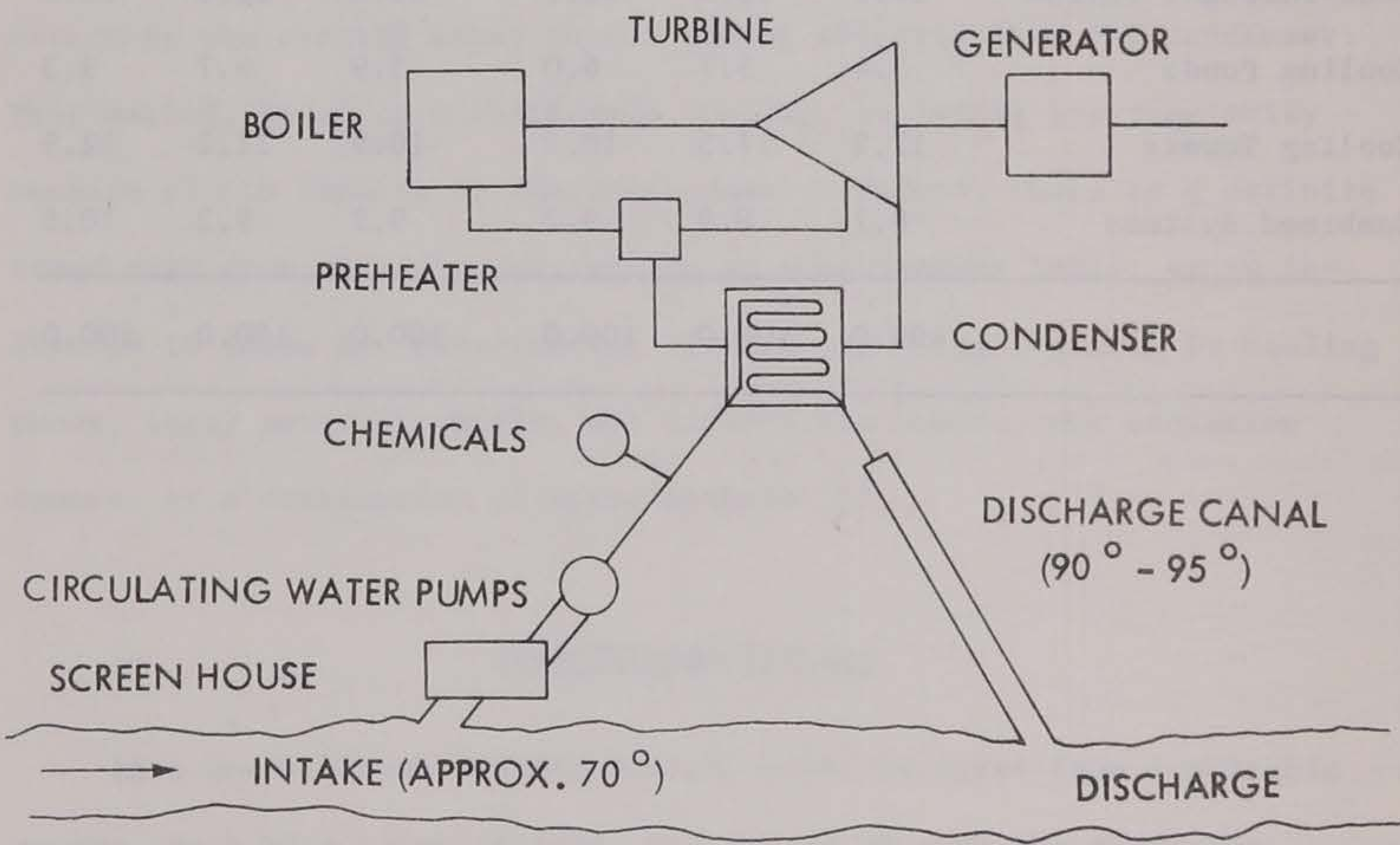

Figure 6. Typical layout of a once-through cooling system.

Source: Nebraska Water Resources Research Institute, The Role of Water in the Energy Crisis, p. 81.

In the past, rivers have been used extensively for cooling water purposes, as the flow of the river provides a natural conveyance for heated discharges. However, in view of the magnitude of flow needed for the larger plants projected for the future, it appears the number of sites available for once-through cooling systems will be considerably reduced. For example, it has been shown that a 4000 megawatt station with a designed temperature rise of 15 ^{o}F across the condenser would require a condenser flow of between 4,600 cfs and 7,000 cfs, depending upon the type of plant [18]. This condenser flow does not in itself present serious limitation. However, in order to meet existing water quality standards allowing a maximum 5 ^{o}F rise in the receiving stream, a minimum flow of between 14,000 cfs and 21,000 cfs would be needed. Few rivers in the country could meet this requirement. Most of the new nuclear plants located on Iowa's border streams have generating capacities of between 800-1600 mw, requiring 1,400 cfs to 2,100 cfs for once-through cooling systems.

Cooling Ponds

When adequate river capacity is not available, cooling ponds may be constructed if suitable sites are available. This type of system is similar to the once-through system, with the exception that it is a "closed" system, as the cooling water is recirculated between the condenser and the pond. Since heat dissipation is primarily a surface

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[18] Federal Power Commission, Problems in Disposal of Waste Heat from Steam-electric Plants (Washington, D.C., U.S. Government Printing Office, 1969), p. 4.

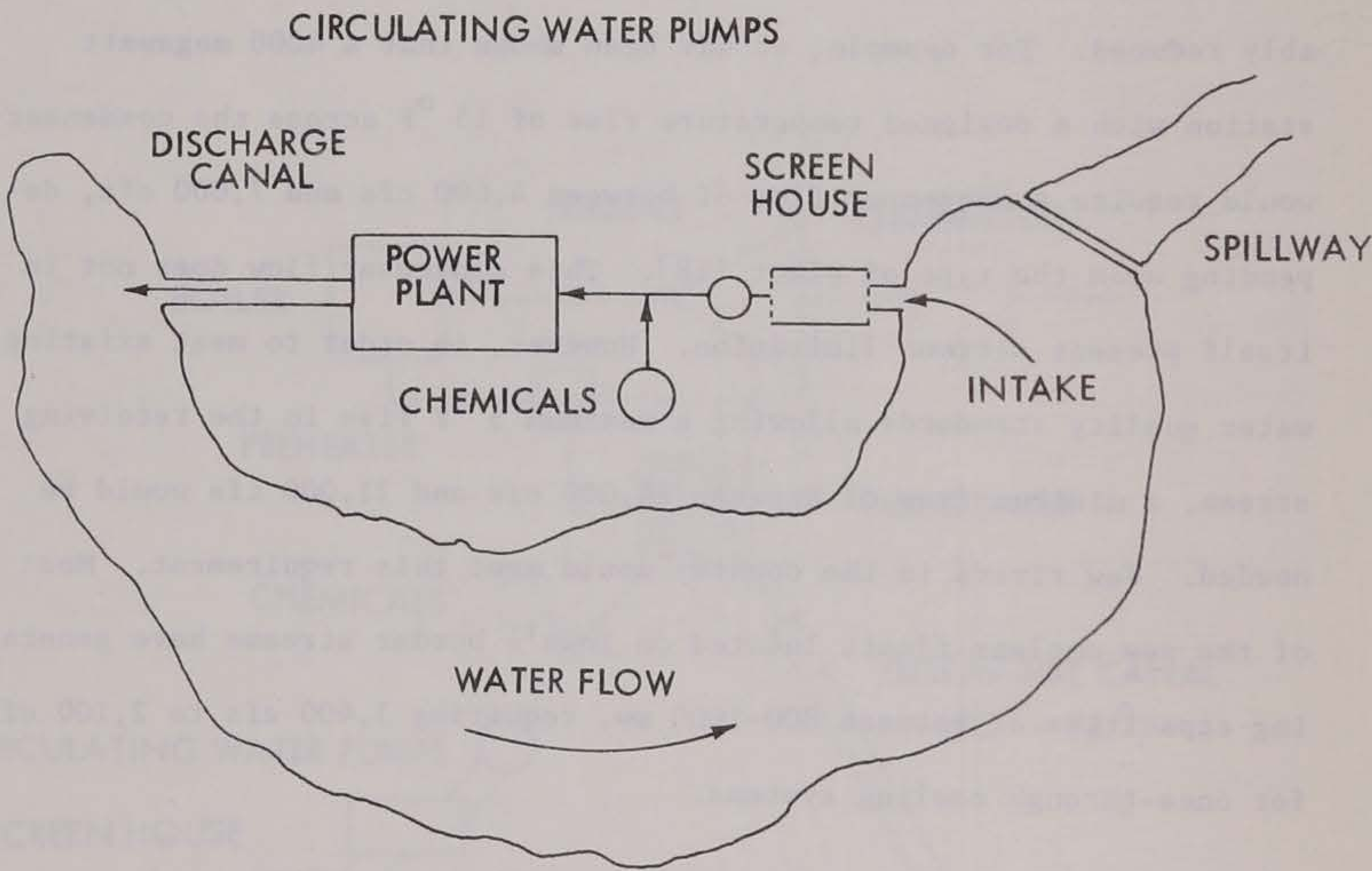

Figure 7. Typical layout of a cooling pond system.

Source: Nebraska Water Resources Research Institute, The Role of Water in the Energy Crisis, p. 81.

phenomenon, this type of cooling is ideal where economic and physical conditions are favorable, as cooling ponds provide large amounts of surface area. Generally, a pond size of one to two acres of surface area per megawatt capacity is needed for adequate cooling, depending upon the type of plant [19].

Spray Ponds and Canals

The primary disadvantages to cooling ponds are the large amounts of land needed for the pond, and the lack of flexibility in cooling capacity if the plant requires expansion. Spray ponds, which are essentially a cross between cooling ponds and wet towers, offer an alternative which eliminates these problems.

The basic concept of spray pond operation is very simple. The heated water is sprayed into the air to increase the surface area exposed to the air and to increase the relative velocity between the air and the water. In a well-designed spray pond, a twenty-fold increase in the heat transfer coefficient can be realized, as compared to the coefficient of a cooling pond. In "conventional" systems, the heated water is discharged into pipes which spray the water into the air. This system is relatively inexpensive. Recent innovations have produced a "powered" system, which has attracted considerable interest. In the powered system, the heated water is discharged into a canal, where it is sprayed and resprayed into the air by floating spray modules which are independently moored to the shore [20].

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[19] Croley, T. E., and Kennedy, J. F., op. cit., p. 115.

[20] Ibid., p. 118.

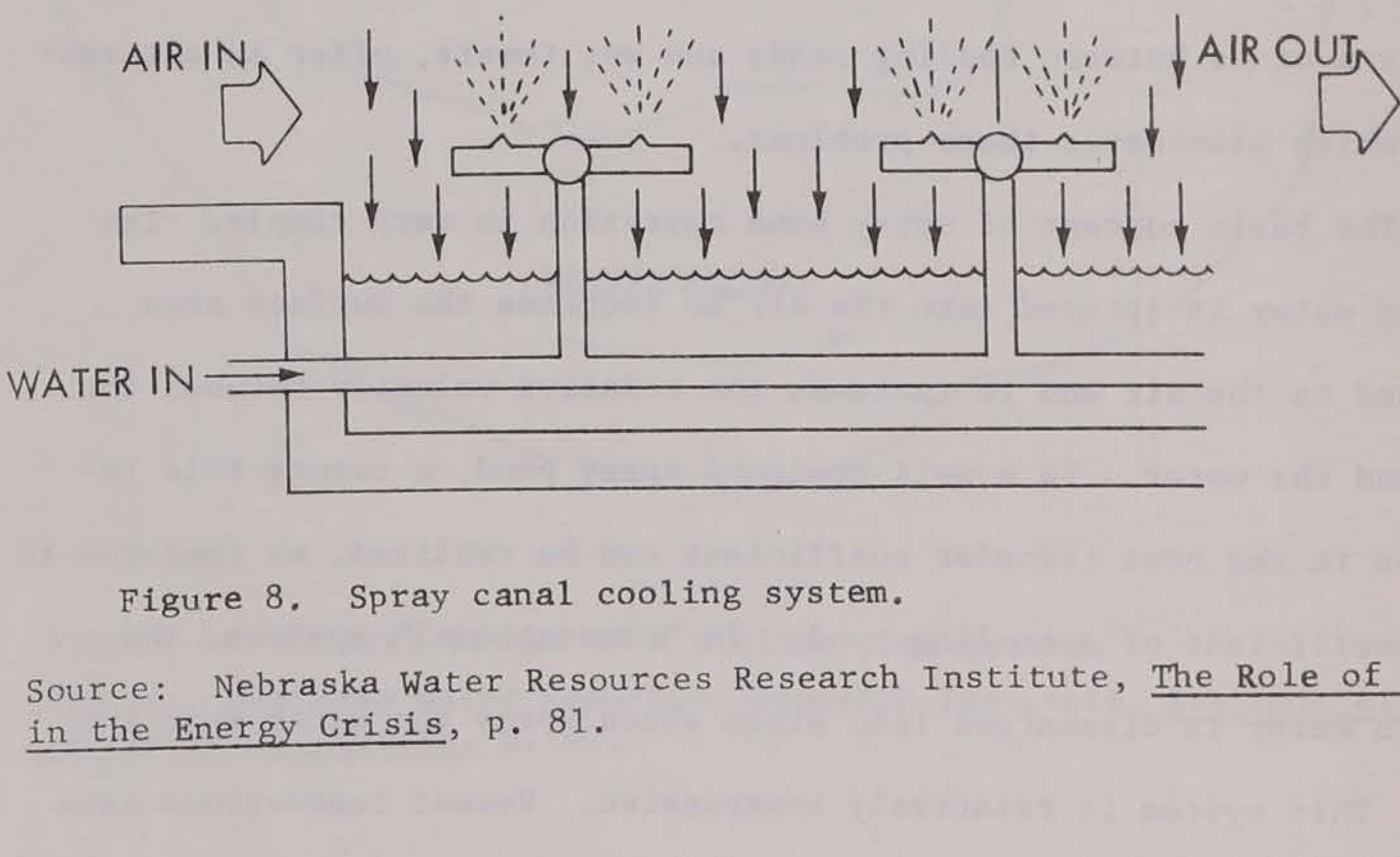

Figure 8. Spray canal cooling system.

Source: Nebraska Water Resources Research Institute, <u>The Role of Water in the Energy Crisis</u>, p. 81.

Spray ponds have low environmental impacts and high flexibility in operation and alteration. They require less than 5% of the land area of a cooling pond with comparable heat loads, and provide a greater contact area and air volume than cooling towers of comparable heat loads.

However, recent evaluations indicate that the total cost of spray ponds is considerably greater than cooling towers because of low reliability and high maintenance. Energy costs for spray pond operation are also higher than other systems of cooling. These factors have forced some plants to consider other cooling systems. Since the performance of a spray pond is a function of the nozzle design on the sprayer, a poorly designed spray system will require higher pressures for efficient operation, and may not mix the air and water efficiently. Water use in a poorly designed system can also be very high, due to drift and evaporative losses.

Although they have become very popular with environmental groups desiring to eliminate or reduce the impact of once-through cooling, very little is known at this time about the detailed performance of powered spray systems, since they are relatively new. Currently, a powered spray system is in use at Commonwealth Edison's Quad Cities Plant near Davenport, and much research has been made on the overall performance of this system. Preliminary results would indicate that the costs of the system may be prohibitive and may not be competitive in the future with alternative cooling systems. The poor performance of this system, coupled with the fact that powered systems are new, places the designer in the awkward position of relying on the manufacturer's guarantees, the reliability of which is difficult to establish [21].

Wet Towers

In a "wet" cooling tower, the cooling water is brought into direct contact with a flow of air, provided by either mechanical means or a natural draft, where the heat is transferred to the air by evaporation. Thus, the limiting temperature for effective cooling becomes the wet-bulb temperature of the ambient air. As the temperature of the heated water approaches the wet-bulb temperature, a larger tower is needed for effective cooling. A cooling tower must accomplish three basic functions: 1) they must generate a continuous flow of air; 2) they must convey the water through the heat exchange pile in such a way as to provide a large ratio of surface area to volume, and 3) they must bring the airstream into direct or indirect contact with the water [22]. With the increasing emphasis on environmental protection, there has been an increasing trend toward the use of cooling towers as opposed to any other method of cooling.

The operation of a cooling tower is not as simple as that of a spray pond or canal. As the heated water enters the tower, it may be sprayed into the air or allowed to flow onto a lattice network inside the tower. This lattice network, called "fill," breaks the water into droplets, which increases the heat transfer process. The cooling water is then collected under the fill in a basin and returned to the condenser,

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[21] Ibid., p. 121.

[22] Ibid., p. 123.

where the cycle is repeated. The tower fill may be constructed so as to create a thin film of water to be exposed to the air, which is effective in reducing "windage," or loss of the water droplets to the wind. This can become a critical factor when the cooling water contains high amounts of salts or other chemicals.

Until recently, most wet towers constructed were of the mechanical-draft type, shown in Figure 9. This type of tower is designed to use a forced draft of air created by fans located at the air intakes. This draft may be either counterflow, where the air is flowing upward to meet the downward flow of water, or crossflow, where the air is flowing horizontally across the downward flow of water.

Mechanical draft towers have several advantages. They provide a positive control over the air supply, and a close control over the cooling water temperature. The land requirement is not nearly as large as is needed for a cooling pond, and they have a lower capital cost than natural draft towers. They operate against a low pumping head, which reduces the in-plant power use [23].

However, because the tower draft is supplied by mechanical means, the tower is subject to mechanical failure. Under certain wind conditions, the tower will be subject to recirculation of the humid exhaust air, thus reducing the effectiveness of the tower. Also under certain wind conditions, a possible mixing of exhaust air from the tower with the stack gases from the plant could cause severe air pollution problems. Other meterology impacts include local icing and fogging conditions [24].

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[23] Harding, T. P., op. cit., p. 80.

[24] Ibid., p. 80.

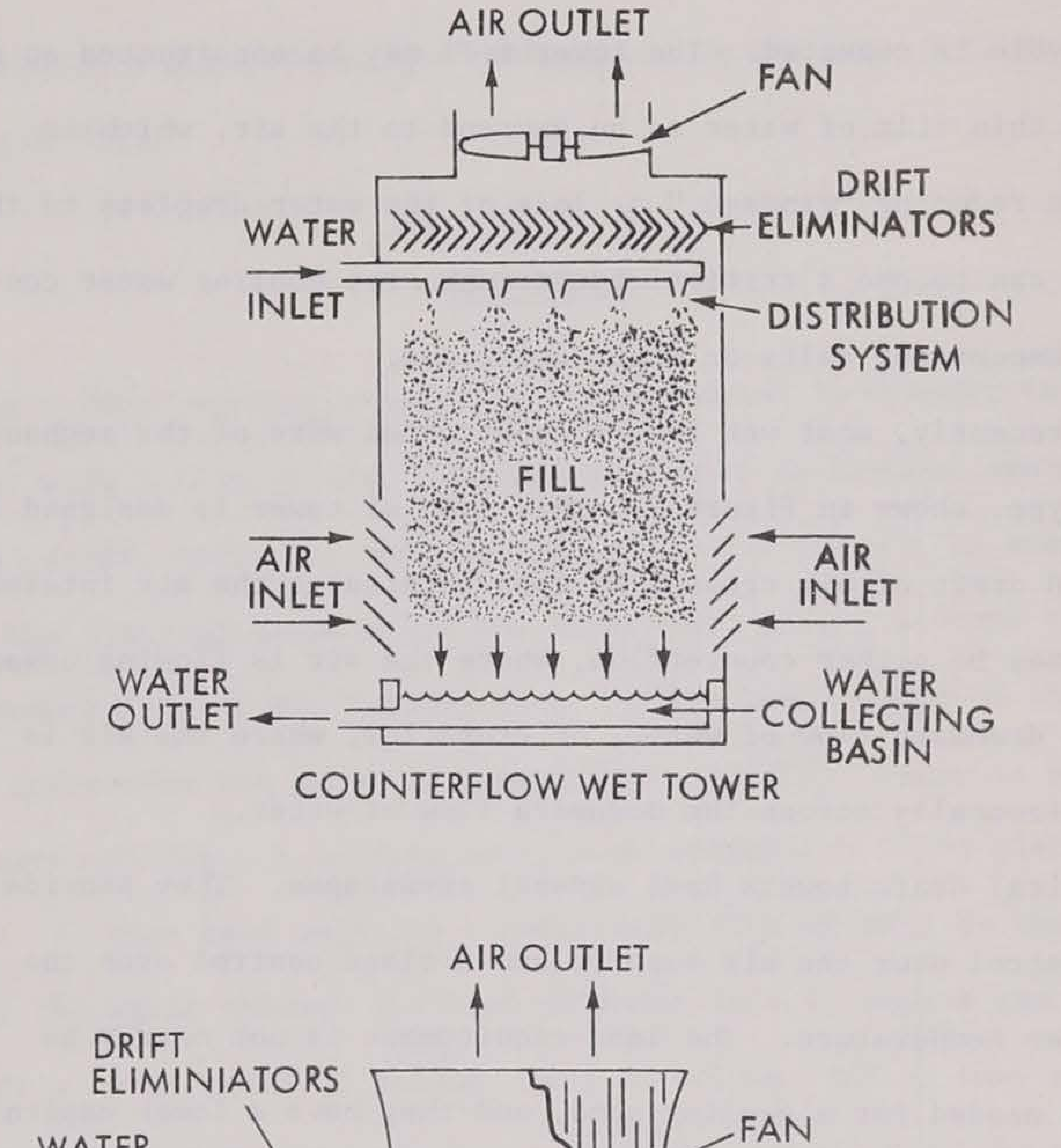

Figure 9. Wet evaporative cooling tower, mechanical draft.

Source: Liptak, Bela G., Environmental Engineers Handbook, Chap. 5.11, "Cooling Towers - Their Design and Application to ... Thermal Pollution." p. 801.

Another means of providing air flow are natural-draft towers, which also utilize evaporation to dissipate waste heat. In this type of tower, the flow of air is created by the natural chimney effect created by the height of the tower. Natural draft towers now in use range in size from 250 to 400 feet in diameter at the base, and from 325 to nearly 500 feet high. They can be designed to provide either crossflow or counterflow, although the most efficient heat transfer occurs with a counterflow design. Natural draft towers are most efficient in areas where the ambient relative humidity is high, such as the northeastern United States. Used extensively in Europe, they have only recently appeared in the U.S., the first installed in Kentucky in 1962 [25].

The primary advantage to natural draft towers is that because there are few mechanical or electrical components within the tower, a mechanical failure or power outage in the system will not have serious consequences on the overall cooling system. Another advantage is created by the height of the tower, which causes a substantial reduction in local icing or fogging conditions as is experienced with mechanical towers [26].

However, the capital costs of natural draft towers are much higher than mechanical draft towers. The great height necessary to produce the draft may cause the towers to be aesthetically undesirable in some areas. The exact control of outlet temperature of the cooling water

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[25] F. P. C., Problems in Disposal of Waste Heat from Steam-electric Plants (Washington, D.C., U.S. Government Printing Office, 1969), p. 12.

[26] Harding, T. P., op. cit., p. 81.

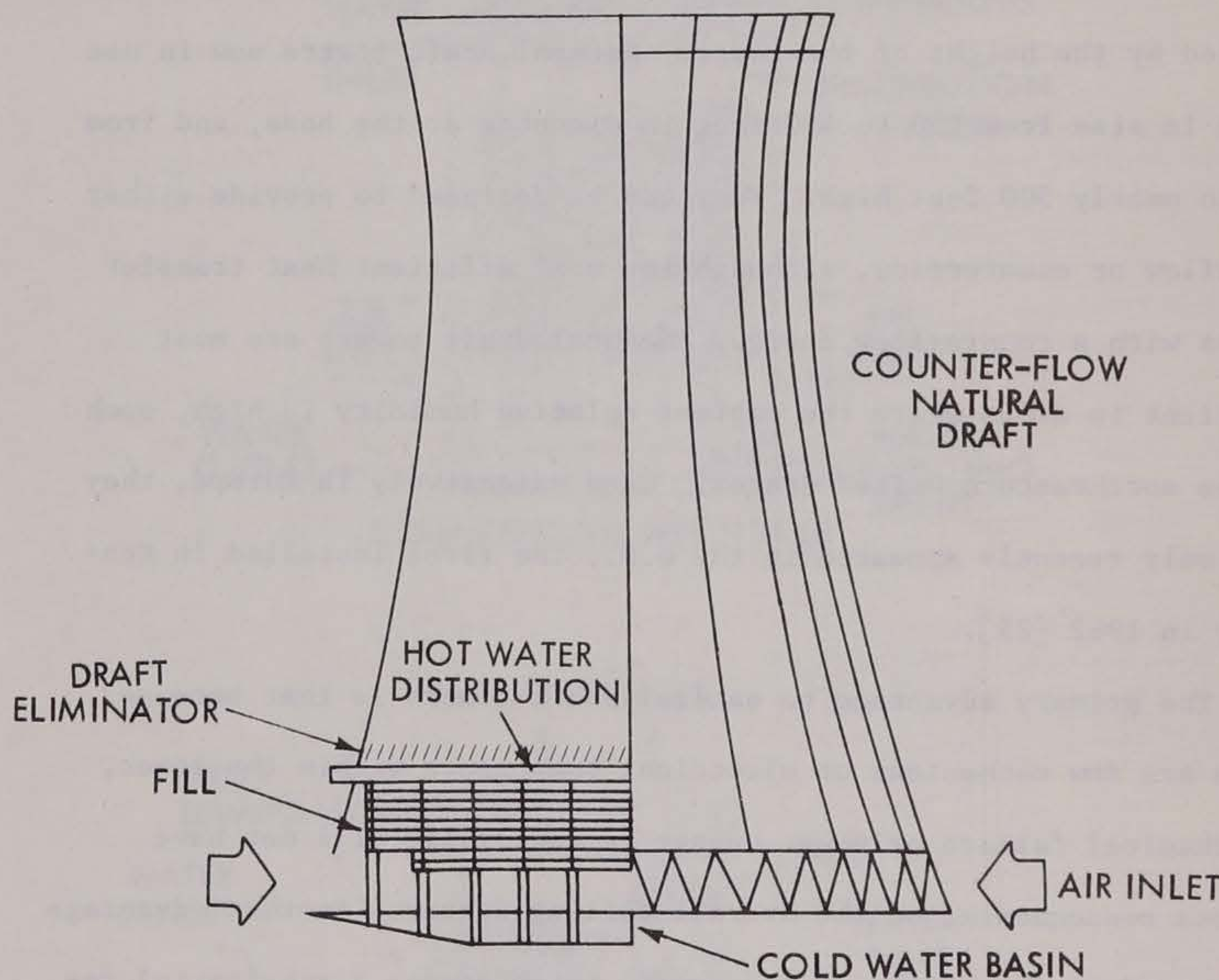

Figure 10. Natural draft cooling tower.

Source: Nebraska Water Resources Research Institute, <u>The Role of Water in the Energy Crisis</u>, p. 81.

is difficult to maintain, and the troublesome mixing of stack gases with tower vapors can also occur [27].

Dry Towers

In a "dry" cooling tower, heat is transferred to the air by conduction and convection, rather than by evaporation, in much the same manner as an automobile engine is cooled. Because there is no direct contact between the air and water, there are no consumptive uses of water [28], but a much greater air movement is needed for proper cooling. Again, air flow can be provided by either mechanical means or natural draft.

By the very nature of the operation in a dry tower, the design will eliminate problems of water availability, evaporative losses, blowdown needs, and thermal pollution. They can also avoid problems of icing or fogging. Until recently, the capital costs of dry towers have been considered to be prohibitively high when compared to a wet tower or spray pond system. However, recent research [29] indicates that a dry tower working in combination with a wet tower may provide adequate cooling at a competitive operating cost.

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[27] Ibid.

[28] Ibid.

[29] Croley, T. E., Patel, V. C., and Cheng, Mow-Soung, The Water and Total Optimizations of Wet and Dry-Wet Cooling Towers for Electric Power Plants, University of Iowa, Iowa Institute of Hydraulic Research, 1975.

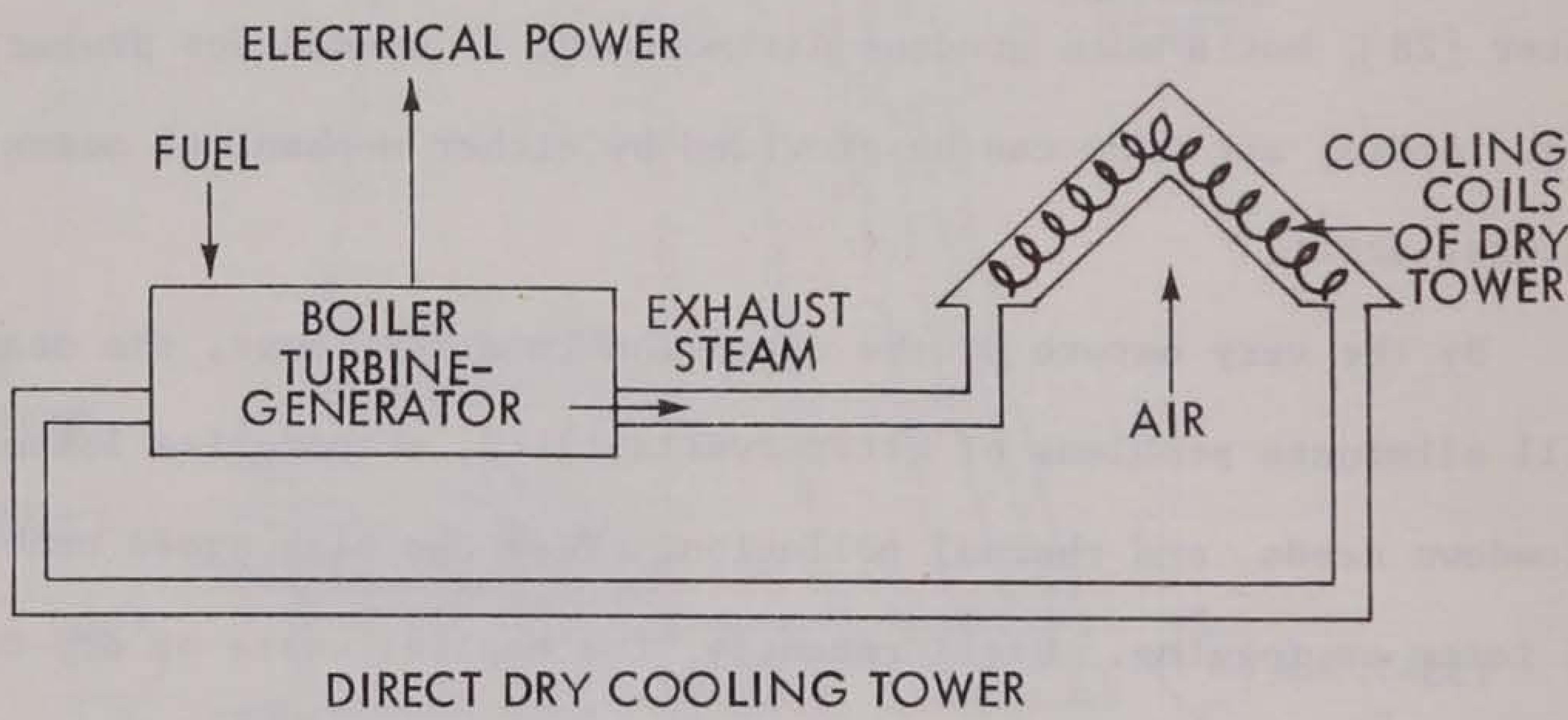

Figure 11. Simplified Schematic of Power Plant and Direct, Dry Cooling System.

Source: Croley, T. E., et.al, <u>The Water and Total Optimizations of Wet and Dry-Wet Cooling Towers for Electric Power Plants</u>, Iowa Institute of Hydraulic Research, IIHR Report No. 163, p. 12.

COOLING SYSTEM IMPACT ON WATER USE

As noted previously, there are many needs for water in a steam-electric plant, the largest of which is the cooling system. Although it is generally agreed that the cooling system also has the largest impact on the consumptive use in a steam plant, expert opinion differs as to the amounts of consumptive use. Cootner and Löf [30] suggest there is little difference in consumptive loss regardless of the method of cooling used, whereas the National Water Commission feels the consumptive losses in wet tower cooling systems to be twice as great as those in once-through systems [31]. Other estimates generally lie within this range, as shown in Table 7.

The wide range in values is a result of a general lack of information on evaporation from open water bodies. For example, the Upper Mississippi River Basin Commission (UMRBC) estimates the evaporative loss in a once-through system to be approximately 0.30 gallons per kilowatt hour [32]. However, Cootner and Löf [33] compute these losses to be approximately 0.59 gallons per kilowatt hour.

It is important to note that the consumptive losses in both of the above systems are based on the kilowatt hours generated. This basis can provide meaningful results, as it accounts for the effects of plant efficiency. However, it can also provide misleading results

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[30] Cootner, R. H., and Löf, G. O., Water Demand for Steam Electric Generation (Boston, Mass., Resources for the Future, 1965), p. 58.

[31] National Water Commission, op. cit., p. 173.

[32] UMRCBS, op. cit., p. M-44.

[33] Cootner, R. H., and Löf, G. O., p. 74.

TABLE 7

Consumptive Loss, Gal/kwh from a 1000 Kw Plant,
Heat Rate, 9500 Btu/kwh,
Temp. Rise Across Condensers 18 °F

Source	Fossil Fuel			Nuclear Fuel		
	Once-Through	Cooling Pond	Wet Tower	Once-Through	Cooling Pond	Wet Tower
Upper Mississippi River Commission Basin Study	0.300	0.358	0.479	0.358	0.430	0.573
Thompson & Young	0.340	0.670	0.517	0.425	0.843	0.646
National Water Commission	0.331	0.497	0.663	0.531	0.797	1.064
Davis & Wood (USGS)	NA	NA	0.500	NA	NA	0.800

if the plant is inefficient or is operated only partially during the year. The National Water Commission [34] uses the design condenser flow as a basis for consumptive losses, a value which is not affected by plant efficiency calculations. The Commission estimates that the consumptive losses in a once-through system to be approximately one percent of the condenser flow, one and one-half percent in a cooling pond, and two percent of the condenser flow in wet towers. These gross estimates are valid, however, only if the condenser is operating at full design capacity at all times the plant is operating, or if accurate records of the condenser flows are kept, which is usually not the case.

All of these sources of information place much emphasis on the consumptive losses in once-through systems. Although most of the plants now in operation use once-through systems, it is felt that by monitoring the consumptive losses in wet towers, a more realistic basis for estimating losses in once-through systems may be obtained. The consumptive losses in wet towers are relatively easy to measure, simply by recording the daily make-up flows into the tower. The make-up flows essentially represent the consumptive loss, although not all of the water is lost to evaporation since blowdown is also included in consumptive losses. By metering the make-up flows, good estimates can be made of the consumptive losses. Thus, the relationship between consumptive loss and condenser flow, net generation, or load factor. This relationship can in turn be applied to once-through systems.

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[34] National Water Commission, op. cit., p. 173.

WATER USE IN POWER PLANTS: IOWA'S EXPERIENCE

Currently, Iowa is served by seven investor-owned utility companies, which own 81% of the available generating capacity, and contributed 80% of the electricity (kwh) used by Iowans in 1974. Municipalities own 14% of the available generating capacity, but contributed only 10% of the net generation in 1974. The difference is due to the fact that many of the municipal plants were used only on a stand-by basis, and some were not operated at all in 1974. Generating and transmitting cooperatives provided the remaining 10% of electricity in 1974, although they own only 5% of the available generating capacity. Much of the power sold by these cooperatives was purchased either from utilities within the state, or outside sources such as the U.S. Bureau of Reclamation. A complete breakdown of capacities and generations is shown in Tables 4 and 5.

Steam-electric Plants in Iowa

Of Iowa's total net generation in 1974, 78% was produced in steam-electric plants. Over 92% of these plants are owned and operated by investor-owned utilities or cooperatives. Using Federal Power Commission Form #67, it is possible to estimate the water use in these plants. This form, entitled "Steam-electric Plant Air and Water Quality Control Data," is completed annually and filed with the Federal Power Commission, for plants having an installed capacity greater than 25 Mw. Listed in Table 8 are those plants in Iowa with a capacity of more than 25 Mw, and some important information about these plants.

TABLE 8

Plant Data for Selected Iowa Power Plants with Capacity Greater than 25 Mw.

	PLANT DATA					SYSTEMS DATA			
1	2	3	4	5	6	7	8	9	10
Name	Owner	Capacity Mw A	Generation kwh B	Type C	Source	Flow cfs	g/kwh D	Hours Connected to Load	Capacity Factor
M. L. Kapp	IPC	238.5	1,042,978,320	OTF	R	253	56.35	8627	.507
Dubuque	IPC	80	375,271,690	OTF	R	220	137.6	8717	.538
Lansing	IPC	62	246,335,800	OTF	R	134	113.8	7770	.511
Fox Lake	IPC	108	299,863,300	OTF	R	147	115.6	8760	.317
Moline	IIGE	90	172,864,600	OTF	R	275.7	208.3	4850	.396
Riverside	IIGE	249	1,145,018,000	OTF	R	381.8	78.7	8760	.525
Fair	EILP	63	248,210,000	OTF	R	109	103.6	8760	.450
Burlington	ISU	207	867,583,000	OTF	R	180	44.7	7999.5	.524
Bridgeport	ISU	61.1	189,219,300	WCT	R	124	148.7	8427	.367
Des Moines #2	IPL	340.3	1,280,511,700	CB	R	626	115.3	8760	.430
Council Bluffs	IPL	138.6	793,200,730	OTF	R	173.4	50.8	8624	.664

[A] MARCA 4-hour credited capacity.

[B] 1974 Data from FPC Form #1.

[C] OTF - Once-Through-Fresh
WCT - Wet Cooling Tower
CB - Combination
CP - Cooling Pond

[D] Gallons per kilowatt-hour, calculated by:

$$\frac{\text{Col. 7} \times \text{Col. 9}}{\text{Col. 4}} \times \text{conversion}$$

TABLE 8 (cont.)

	PLANT DATA				SYSTEMS DATA				
1	2	3	4	5	6	7	8	9	10
Name	Owner	Capacity Mw	Generation kwh	Type	Source	Flow cfs	g/kwh	Hours Connected to Load	Capacity Factor
Duane Arnold	IE	550	930,890,313	WCT	R	632.4	71.6	3912	.433
Boone	IE	29.8	123,526,000	WCT	City	86.9	165.9	8760	.473
Sutherland	IE	149.5	980,131,700	WCT	GW	220	52.9	8760	.748
Prairie Creek 1,2,3	IE & CIPCO	96.5	326,117,320	OTF	R	163	117.9	8760	.386
Prairie Creek 4	IE	138.5	516,255,000	OTF	R	157	56.9	6945	.537
Sixth St.	IE	102	165,500,760	CP	RO	31.9	45.4	8760	.189
Humboldt	CBPC	49.75	170,847,700	OTF	R	26.3	36.3	8760	.392
Wisdom	CBPC	38	174,693,100	WCT	GW	66.8	73.0	7086	.648
Quad Cities	IIGE	1656	1,983,033,000	CB	R	2100		8250	.879
	Com Ed		5,922,114,000						
			7,905,147,000				59.0		
Cooper	NPPD & IPL	836	1,740,474,000	OTF	R	1405	87.8	4039.6	.515
Big Sioux	IPS	47	41,145,300	OTF	R	164.3	201.9	1878	.466
Maynard	IPS	104	360,849,000	OTF	R	138.9	82.2	7928	.396
Neal	IPS	477	2,701,947,500	OTF	R	502	78.3	15651	.647

The information contained in Table 8 is readily available in the Federal Power Commission data. However, the information contained in columns 8 and 10 is not listed in any FPC data, and therefore was computed for this report. Column 8 represents the amount of cooling water used for the production of one kilowatt hour of electricity, and was computed using the design condenser flow (col. 7), the net generation in 1974 (col. 4), and the capacity factor (col. 10). The reader will note the wide ranges of values contained in column 8, with the Wisdom Station near Spencer having the lowest value, and Iowa-Illinois Gas and Electric's Moline station using the most water for production. Theoretical values for the cooling requirement should be in the range of between 30 and 60 gallons per kilowatt-hour, depending upon the type of plant [35]. The wider ranges shown in Table 8 are due to either inadequate data, or possibly to the use of high condenser flows during partial load operations.

All steam-electric plants use at least two pumps to move the water through the condenser, and some of the larger plants, such as Cooper Nuclear Station or Quad Cities Nuclear Station, have three or four pumps on the condenser. During the course of normal operations, a plant does not operate at full capacity at all times, and may have only one pump operating. Thus, the plant is operating, but only using half as much water or less, since the plant is not fully loaded. These pumping rates are not reflected in any FPC data, or any other related water-use data forms. By using the capacity factor, an average water

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[35] UMRCBS, op. cit., p. M-44.

use for a yearly period can be approximated, although it does not indicate what the water use might be during peak load periods.

The problems related to lack of data are exemplified further when examining the consumptive uses of water in these plants. Shown in Table 9 are calculated values of consumptive loss using three methods of calculation. Upon close examination, it can be seen that there is a similar wide range of values, although the values obtained from Cootner and Löf's equation [36] seem to be consistently high. The UMRBC and NWC values are in fairly close agreement, although in some plants there is a wider range.

Again, it is felt that the reasons for the wide differences are due primarily to the lack of meaningful data. In those plants which use wet tower cooling systems, it is possible to compare the computed values against actual observed values, as the make-up water for these towers is generally metered. Unfortunately, only six plants in Iowa use wet tower cooling systems, the rest using once-through systems or cooling ponds, where make-up water (consumptive loss) is not measured.

It can be seen from Table 9 that the consumptive losses from Iowa plants do not constitute a major portion of the river flow. During periods of low flow, however, when the water lost from the plants is in severe competition with other beneficial uses, the consumptive use can become critical. Perhaps even more critical, however, is the condenser requirement needed for cooling during the low-flow periods. Low-flow conditions usually occur during the winter, when the stream is ice-covered, or during the late summer. It is during both of these

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[36] Cootner, R. H., and Löf, G. O., p. 74.

TABLE 9

Calculated Consumptive Losses in Iowa Power Plants
Using Three Sources in Acre-Ft/Year

Plant Name	Capacity, Mw[A]	Eff.[B] %	Dis.[C]	Source UMRBC	NWC	Cootner & Löf
Big Sioux	47	19	1	70	120	180
Neal 1 & 2	477	35	1	2,560	2,350	5,080
Council Bluffs	138.6	31	1	850	820	1,810
Cooper	836	27	1	2,515	2,420	4,860
Wisdom	38	27	1	340	510	490
Humboldt	50	23	3	250	80	600
Boone	29.8	23	3	210	600	430
Des Moines	340.3	26	3	2,570	3,900	3,770
Bridgeport	61.1	22	3	460	630	700
Sutherland	149.5	29	5	1,770	1,510	2,470
Duane Arnold	565	31	5	1,750	1,770	2,120
Sixth Street	102	14	5	460	70	1,080
Prairie Creek 1-3	96.5	26	5	410	460	960
Prairie Creek 4	138.5	32	5	540	480	1,120
Maynard	104	27	5	440	360	1,010
Burlington	207	33	5	880	620	1,800
Lansing	62	26	6	310	440	730
Dubuque	80	24	6	510	530	1,240
M. L. Kapp	238.5	33	6	1,050	910	2,160
Quad Cities	1656	30	6	9,550	7,430	18,920
Riverside	249	29	6	1,300	1,450	2,880
Moline	90	24	6	230	330	570
Fair	63		6	NA	360	NA
TOTAL				29,925	28,150	54,980

periods that peak demands would occur, due to either extreme cold or heat. Therefore, the design condenser flow becomes an important criterion in determining the optimum site location for new power plants. The condenser flows of the 23 plants studied in Iowa are listed in Table 10, along with the low-flow characteristics of the receiving stream.

Hydroelectric Power in Iowa

The largest portion of hydropower used in Iowa is supplied from the U.S. Bureau of Reclamation, and is generated in plants located in North and South Dakota, Montana, and Wyoming. Therefore, the water uses at these plants do not present a problem to the State of Iowa. Currently, there are several run-of-the-river plants in operation in Iowa, the largest of which is located on the Mississippi River at Keokuk. This plant, operated by the Union Electric Company of St. Louis, has an installed capacity of 131.3 Mw, and serves the Keokuk area. Other run-of-the-river plants are quite small in comparison to the Keokuk plant, and are used sparingly during the year. These plants, as well as the overall potential for hydropower in Iowa, are shown in Table 11. The overall potential shall be discussed in a later section.

TABLE 10

Existing Plant Requirements vs. Low Flow Characteristics of Receiving Stream

Plant Name	On River	Cond. Flow[A] cfs	Cal. Cons. Loss[B] cfs	Q_{AVG} cfs	7-day, 10 Year Low cfs	Q_{90} cfs
Big Sioux	Big Sioux	164.3	0.1-0.3	Not Availalbe (NA)		
Neal 1 & 2	Missouri[C]	502	3.3-7.0	31,900	5,780	NA
Council Bluffs	Missouri[C]	173.4	1.1-2.5	28,700	3,326	NA
Cooper	Missouri[C]	1405	3.3-6.7	37,880	6,473	NA
Wisdom[D]	Groundwater	66.8	--	--	--	--
Humboldt	Des Moines	26.4	0.1-0.8	460	9.2	20
Boone[D]	Des Moines	86.9	0.3-0.8	1,658	41	110
Des Moines[D]	Des Moines	626	3.5-5.4	1,983	47	130
Bridgeport[D]	Des Moines	124	0.6-1.0	4,768	100	397
Maynard	Cedar	138.9	0.5-1.4	2,554	240	380
Duane Arnold[D]	Cedar	632.4	2.4-2.9	3,094	310	620
Sixth Street[D]	Cedar	31.9	0.1-1.5	3,094	310	620
Prairie Creek 1-3	Cedar	163	0.6-1.3	3,094	310	620
Prairie Creek 4	Cedar	157	0.7-1.5	3,094	310	620
Lansing	Mississippi	134	0.4-1.0	33,090	8,644	NA
Dubuque	Mississippi	220	0.7-1.7	33,090	8,644	NA
M. L. Kapp	Mississippi	263	1.3-3.0	47,030	9,794	NA
Quad Cities[D]	Mississippi	2100	13. - 26.	47,030	9,794	NA
Riverside	Mississippi	381.8	1.8-4.0	47,030	9,794	NA
Moline	Mississippi	275.7	0.3-0.8	47,030	9,794	NA
Fair	Mississippi	109	0.5	47,030	9,794	NA
Burlington	Mississippi	180	0.9-2.5	61,520	11,673	NA
Sutherland[D]	Groundwater	220	--	--	--	--

[A]Design condenser flow taken from FPC #67, p. 16, line 14.

[B]From Table 9.

[C]Missouri River now regulated to 10,000 cfs low flow.

[D]Plant has cooling system other than once-through.

TABLE 11

Hydroelectric Potential of Iowa, 1972, Developed and Undeveloped.[A]

Site	Owner	River	Developed: Installed Cap., Kw	Developed: Average Ann. Gen., MwH	Undeveloped: Installed Cap., Kw	Undeveloped: Average Ann. Gen., MwH	Usable Stor.[B] 1,000 AF	Gross Static Head, Ft.
Ottumwa	Municipal	Des Moines	3,000	11,000			U	15
Red Rock	Corps of Engr.	Des Moines			17,200	103,600		
Hydro	Fort Dodge	Des Moines	800	3,500			NA	17
Keokuk	Union Electric	Mississippi	124,800	775,000	30,400		128	36
Rochester		Cedar			28,000	85,000	220	55
Cedar Rapids		Cedar			9,600	44,000	170	45
Project 13A		Cedar			11,200	40,000	U	38
Cedar Falls		Cedar			25,000	70,000	NA	11
Waverly	Municipal	Cedar	495	1,700			U	13
Amana	Amana Woolen Mills	Iowa	300	900			NA	24
Iowa Falls	IELP	Iowa	580	1,000			NA	25
Muscatine[C]	First Iowa Hydro. Coop.	Geneva Cr.			25,000	194,800	NA	105
Maquoketa	IELP	Maquoketa	1,200	5,000			NA	25
Delhi	IPC	Maquoketa	750	1,750			U	35
Nebr. City to Sioux City[D]		Missouri			200,000	1,100,000	NA	195
	TOTAL		131,925	799,850	346,400	1,637,400		

[A]Source: Federal Power Commission,"Hydroelectric Potential in the United States, Developed and Undeveloped," 1972, Table 5, p. .

[B]U - under 5,000 acre-ft.
NA - Not available

[C]Pumped Storage

[D]Block of usable capacity between designated points.

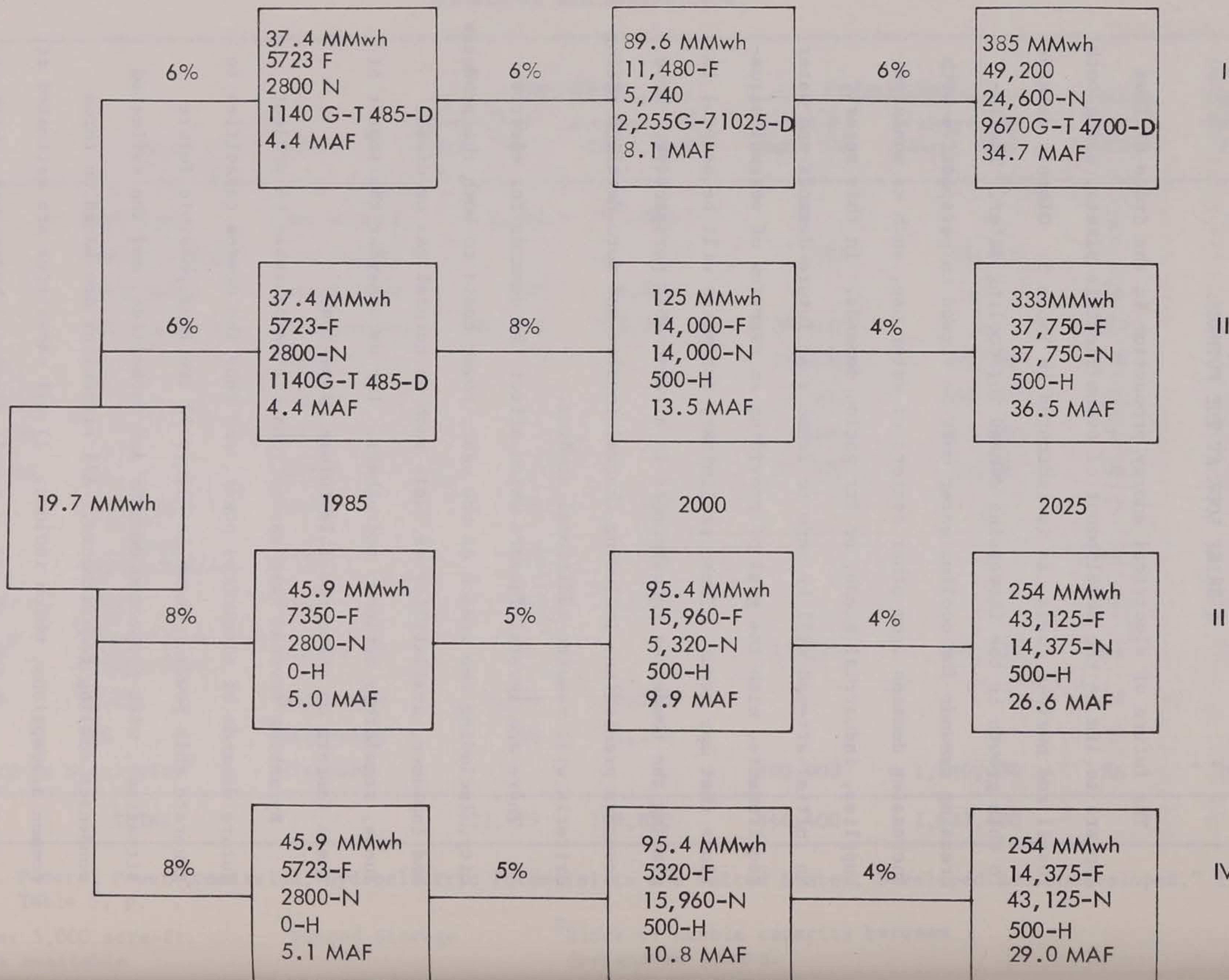
A BRIEF LOOK AT THE FUTURE

The future of electrical energy production in the State of Iowa appears to lie in the development of steam-electric plants, using both fossil and nuclear fuels, as is indicated in Table 3. Closely related to this growth is the increasing demand for cooling water. The increasing demands for cooling water must be viewed in perspective with increasing demands from other sectors of water use, such as municipal supplies, industrial needs, or irrigation demands. In this report, an initial attempt will be made to frame some future demands and water requirements, with the goal of providing an overview of several situations that may occur. These preliminary estimates will be helpful in placing the condenser requirements in a reasonable perspective. More accurate predictions including thermal impacts and more detailed siting criteria will require additional studies.

There are several factors which affect the demands for electricity, including the season of the year, power costs to both the producer and consumer, availability of fuels such as natural gas or diesel fuels, regulatory actions, and others. Let us consider the impact of these factors on three possible future situations.

By making several base assumptions, it is possible to project future demands of electrical power, and thus the needed capacities to generate this power. Shown in Figure 12 are four possible future situations, with projected demands and capacities, and the estimated condenser cooling requirements. All situations are based on three common assumptions, which include: 1) all capacities are estimated at a load factor of 50%; 2) all of Iowa's potential hydropower, which is

Figure 12. Preliminary estimates of future cooling requirements for selected energy growth trends.



approximately 500 Mw, is in operation by January 1, 1986; and 3) there will be no technological advances in water use in steam-electric plants, or in power generation techniques.

The primary variables used in estimating the cooling requirements shown in Figure 12 are the estimated annual rate of growth, the availability of fuel supplies, and the proportions of generating capacity by type of plant. Condition I was established to serve as a basis for other projections. In Condition I, it was assumed that the present growth rate of roughly 6% would continue for the next fifty years, and that during this time the fuel supplies needed for gas-turbine and diesel plants would be readily available. It was also assumed that the additional capacities needed would be added in the same proportions as now exist, shown in Table 4. The estimated cooling water requirements are based upon a demand of 550 gallons per megawatt (36% efficiency) in fossil fuel plants, and 650 gallons per minute per megawatt in nuclear plants (32% efficiency) [37].

In Condition II, it was assumed that present growth would continue until 1985, and that fuel supplies for gas-turbine and diesel plants would be available until 1985. It was also assumed that the additional construction shown in Table 3 would be available January 1, 1985. However, after 1985, it was assumed that all natural gas supplies for Iowa would be discontinued. This would have the effect of increasing the annual growth rate, as there would be a conversion of many homes and industries from natural gas to electricity. This increased growth rate was estimated to be 8% per year until the year 2000. After the

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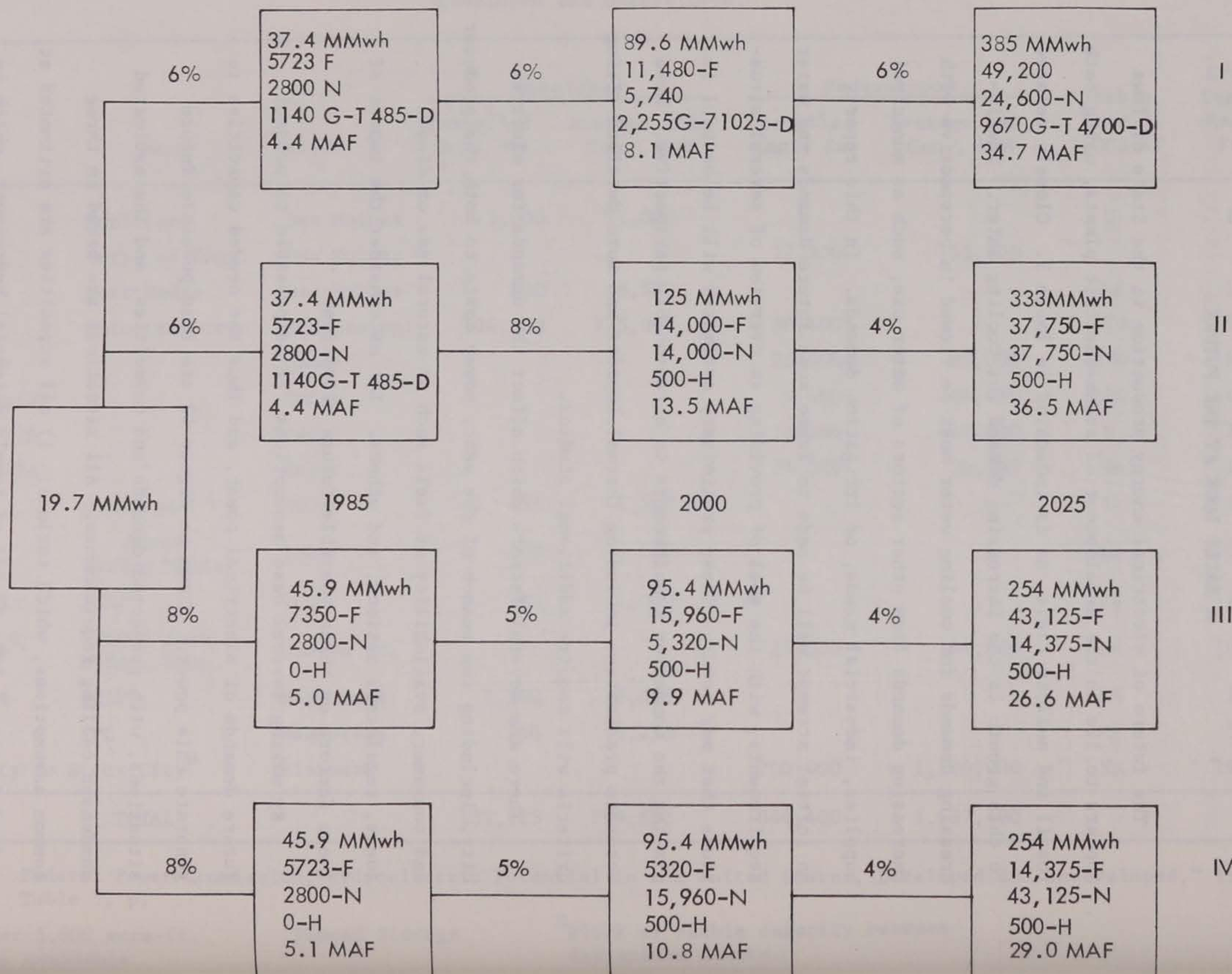
[37] UMRCBS, op. cit., p. M-43.

Figure 12. Preliminary estimates of future cooling requirements for selected energy growth trends.



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[37] UMRCBS, op. cit., p. M-43.

year 2000, the growth would slow to 4%, as it is estimated that the shift from natural gas to electricity would be nearly complete. The loss of natural gas would also force utility companies to add new plants to make up for the lost capacity of gas-turbine units, we well as the increased demand. It was assumed that the added capacity would be equally divided between nuclear and fossil fueled plants throughout the study period of 50 years.

In Conditions III and IV, it was assumed that the natural gas and diesel supplies would be discontinued after 1975 instead of 1985, resulting in an annual growth rate of 8% until 1985, for reasons mentioned above. The growth rate after 1985 would slow to about 5% due to the impacts of energy conservation, and because the shift from natural gas would be nearly complete. The 5% growth rate would continue until the year 2000, and decline to 4% after the year 2000. The proportions of additional construction were assumed to be 75% fossil and 25% nuclear in Condition III, and vice versa in Condition IV.

The values shown in Figure 12 for the estimated cooling requirements might be compared to approximate amount of water that flows past or through Iowa in an average year. The average annual runoff from Iowa's interior streams, such as the Des Moines or Cedar Rivers, is about 18 million acre feet per year [38]. It can be seen from Figure 12 that the estimated condenser requirements are considerably higher than the amount provided by these interior streams. However, the annual yield of the Missouri River at Rulo, Nebraska, located near the southwest

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[38] Wiitila, Sulo W., "Surface Waters of Iowa," Water Resources of Iowa (Cedar Falls, Iowa, Iowa Academy of Science), p. 17.

corner of Iowa, is over 26 million acre-feet [39], and the annual yield of the Mississippi River at Keokuk is over 44 million acre-feet [40]. Thus it can be seen that the border streams will play an important role in meeting Iowa's future power needs.

It is important to remember, however, that the condenser requirements shown in Figure 12 do not represent the actual consumptive use of water. Using the National Water Commission and UMBRC methods, the consumptive use of these estimated cooling requirements were calculated, and are shown in Table 10.

Future Generating Techniques

It should be pointed out here that the estimates shown in Figure 12 and Table 10 are not sacrosanct, and that several factors could alter the power demand picture. A principal factor which could affect both the needed steam capacity and the estimated water requirements is the impact of future research on alternate methods of generation. Three of the most promising techniques now being developed are nuclear breeder reactors, fuel cells, and magnetohydrohynamics.

Nuclear breeder reactors are the second generation of the reactors now in commercial use [41]. By using a more enriched fuel, breeder reactors produce additional fuel in the form of plutonium, a radioactive

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[39] U.S. Department of Interior, Water Resources Data for Iowa (Washington, D.C., U.S. Government Printing Office, 1972), p. 147.

[40] Ibid., p. 85.

[41] Iowa Energy Policy Council, Nuclear Energy - 1975 (Des Moines, 1975), Appendix A, p. 35.

TABLE 12

Estimated Consumptive Losses in Power Plants for Selected Energy Growth Trends in Million Acre-feet per Year

Condition	Source[A]	1985		2000		2025	
		Once-Thru	Wet Tower	Once-Thru	Wet Tower	Once-Thru	Wet Tower
I	NWC	.045	.090	.091	.184	.394	.798
	UMRBC	.036	.057	.074	.125	.316	.505
II	NWC	.045	.090	.162	.334	.436	.872
	UMRBC	.036	.057	.123	.198	.332	.532
III	NWC	.053	.106	.109	.218	.294	.588
	UMRBC	.043	.069	.090	.144	.243	.389
IV	NWC	.064	.128	.138	.276	.372	.744
	UMRBC	.046	.074	.065	.157	.266	.425

[A] National Water Commission Formula
Upper Mississippi River Basin Commission Formula

element which can be used for fuel in other reactors. Breeder reactors also operate at higher efficiencies (42%), thus lowering the water requirements. However, the fuel generated in these reactors is extremely toxic, requiring stricter safety measures. The safety measures required, along with other environmental hazards could inhibit the development of breeder reactors. For a more thorough discussion on breeder reactors, the reader is referred to Appendix "A" of Nuclear Energy - 1975, a report published by the Energy Policy Council.

A disadvantage to steam-electric power plants is that electricity is produced indirectly. Heat energy is released from coal or uranium, converted to mechanical energy in the turbine, and then to electircal energy. Fuel cells produce electricity directly from a chemical reaction. This direct conversion indicates a much higher efficiency can be obtained. In fact, fuel cells operate at about 60% efficiency, which is much higher than is possible with today's steam plants. Fuel cell generation also does not require a large central station for energy production, thus offering the alternative of locating stations immediately next to the load center, which eliminates transmission costs. Fuel cells require no water for cooling or power generation [42].

Magnetohydrodynamics (MHD), another alternative for power generation, is direct conversion. The principle of MHD is based on the fact that when an electrically conductive fluid is passed through an electromagnetic field, a current is produced. In MHD generation, the fluid is an ionized gas which is at a very high temperature. When this gas is passed through an electromagnetic field, large amounts of current

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[42] National Water Commission, op. cit., p. 179.

ELECTRICAL POWER GENERATING TECHNOLOGIES

Method of Generation	Fuel Used	Average Thermal Efficiency of Plants Built in 1990-2000 Period[1]	Heat Discharge to Condenser Cooling Water BTU/KWH	Date First Major Unit Could Be in Operation: Present R&D Funding	Date First Major Unit Could Be in Operation: Accelerated R&D Funding	Expected % of Total Capacity Year 2000
TABLE 13						
PRESENT SYSTEMS						
Hydroelectric (Conventional & pumped storage)	Water	--	-0-	SOA		5
Fossil Fuel[2]	Coal, Oil, Gas	~42%	3,900	SOA		10-20
Shale Oil, Coal Gasification & Coal Liquification (new fossil fuel)	Oil & Gas	42%	3,900	1995	1985	10-15
Internal Comb. Eng.	Oil	25-35%	-0-	SOA		<1
Gas Turbine	Gas, Oil	20-30%	-0-	SOA		<1
Topping G.T. w/Waste Heat Boiler	Gas, Oil	40%		SOA		<1
Light Water Reactors	Uranium & Thorium	~33%	6,600	SOA		30-40
TABLE 14						
DEVELOPING SYSTEMS FOR THE SHORT TERM (1970-2000)						
Gas Cooled Reactors	Uranium & Thorium	~40%	4,800	SOA		10-20

SOA - State of the Art

[1] Where SOA, the efficiency given reflects the Panel's estimate of improvements in state of the art technology.

[2] Conventional fossil fuel, excluding shale oil, coal liquification and gasification.

Source: KRENKEL, Peter A. et al. (May 1972). The Water Use and Management Aspects of Steam Electric Power Generation, prepared for the National Water Commission by the Commission's Consulting Panel on Waste Heat. National Technical Information Service, Springfield, Va., Accession No. PB 210 355, p. 25.

Method of Generation	Fuel Used	Average Thermal Efficiency of Plants Built in 1990-2000 Period[1]	Heat Discharge to Condenser Cooling Water BTU/KWH	Date First Major Unit Could be in Operation: Present R&D Funding	Date First Major Unit Could be in Operation: Accelerated R&D Funding	Expected % of Total Capacity Year 2000
TABLE 14 (cont.)						
Nuclear Breeders	Uranium & Thorium	38-42%	4,500	1900	1985	10-20
Fuel Cells[3]	Partially Oxidized Coal, Oil & Gas	60%	-0-	1985	1980	<5
EGD (Electrogasdynamics)	Nat. or Manu. Gas	40-55%	-0-	Never	1990	
MHD	Fossil or Nuclear	55%	-0-	Never	1990	<5
MHD Topping Cycles	Fossil or Nuclear	60%	1,700	Never	1990	
Geothermal	Geothermal Energy	20-30%		SOA		<1
TABLE 15						
DEVELOPING SYSTEMS FOR THE LONG TERM						
Thermoelectricity	Any Heat	10-15%		Indefinite		0
Thermionic	Any Heat	10-30%		Indefinite		0
Fusion	Hydrogen or Helium (seawater)	75-95%	Small	Never	2010	0
Solar	Sun's Energy	14-25%		Never	1990	<1

[3] Not Central Station.

are produced. Heretofore, the high temperatures needed for MHD generation were too prohibitive for economic production. However, ceramic research done for the space program produced materials which are capable of withstanding the high temperatures. MHD plants require little or no water for operation [43].

Hydroelectric Power Potential in Iowa

A secondary factor which will affect the needed steam capacity for the future is the potential for hydroelectric plants in Iowa. Currently, there are very few plants in operation in Iowa, and most of the hydropower Iowa uses is generated in the main-stem plants along the Missouri River. Union Electric Company, which serves a small portion of southeast Iowa, also supplies hydropower to Iowa from the run-of-the-river plants along the Mississippi, and from several storage plants in Missouri.

According to the Federal Power Commission, the total hydropower potential in Iowa is about 478 Mw, of which 132 Mw is now developed, as is shown in Table 11 [44]. A large portion of the undeveloped potential is the reach of the Missouri River between Sioux City and Nebraska City, Nebraska. Because most of the floodway is now developed, it is unlikely that this source will be developed in the near future [45].

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[43] Ibid.

[44] Federal Power Commission, Hydroelectric Power Resources of the United States (Washington, D.C., U.S. Government Printing Office, 1972), p. viii.

[45] Personal conversation with Mr. Nels Carlson, Operations Engineer, U.S. Army Corps of Engineers, Omaha, Nebraska, July 1975.

Coal Conversion Processes

Two processes using coal, liquefaction and gasification, offer yet another alternative for future power production. In these processes, coal is converted into synthetic fuel oil or synthetic gas, which may be used for fuels in either industry, such as power plants, or in the home. Water requirements for these processes are estimated to range between 5 and 50 cubic feet per second, depending upon the type of process, as shown in Table 15.

The Bureau of Mines estimates that between 180 million and 1 billion tons of "strippable" coal remain in Iowa [46], most of which lies in the south central portion of the state. It is estimated that over 20 times this amount lies in deeper deposits in southwestern Iowa, shown in Figure 13, although these reserves are unproven. Although the amounts of proven reserves seem to be sufficient to justify construction of coal conversion facilities in Iowa, there are two major problems which must be resolved before any large scale plants can be built.

In 1973, Iowa coal was mined at the rate of about 2200 tons per day [47], whereas it can be seen in Table 16 that much larger amounts of coal are needed. More efficient and environmentally safe methods of strip mining must be developed before the coal requirements for conversion can be reached.

Iowa coal is high in sulfur content, which increases the water requirements for conversion, as well as greatly increases sulfur

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[46] Energy and Mineral Resources Research Institute, Iowa Coal Research Project Progress Report, Iowa State University, Ames, Iowa, 1975.

[47] Ibid.

TABLE 16

Coal and Water Requirements for Coal Conversion Facilities.

TYPE OF PLANT	THERMAL EFF.*(%)	COAL		WATER		
		Tons/Day†	Tons/10^6 BTU	cfs	Tons/Day	Tons/10^6 BTU
Electricity 1000 MW (8.19×10^{10} BTU/day)	35	9000 - 14700	1.11×10^{-1} - 1.78×10^{-1}	92.5[g]	249000	3.08
High BTU Gas[a] 250×10^6 scfd	65	13400 - 21600	6×10^{-2} - 9.3×10^{-2}	11.4 - 49	30600 - 132000	1.36×10^{-1} - 5.85×10^{-1}
Low BTU Gas[b] 525×10^6 scfd	72	3120 - 5010	5.31×10^{-2} - 8.6×10^{-2}	5.2	14100	2.42×10^{-1}
Low BTU Gas[c] 290×10^6 scfd	72	4680 - 7700	5.31×10^{-2} - 8.6×10^{-2}	7.0	18900	2.15×10^{-1}
Synthetic Crude Oil[d,e] 26×10^3 bbls/day + + Low BTU Gas[f] 1.33×10^9 scfd	72	23500 - 37550	5.31×10^{-2} - 8.6×10^{-2}	28.2	75800	1.74×10^{-1}

*A typical value for thermal efficiency is assigned.

†Knowing the produce (in terms of BTU/day), coal requirements are calculated based on 8000 BTU/lb and 13000 BTU/lb coals.

[a] quality of gas - 950 BTU/scf

[b] quality of gas - 110 BTU/scf (using air)

[c] quality of gas - 303 BTU/scf (using oxygen)

[d] based on COED process

[e] quality of crude - 5.8×10^6 BTU/bbl.

[f] quality of gas - 215 BTU/scf (pyrolysis, off-gas of 510 Btu/scf is combined with 120 BTU/scf gas from char gasification).

[g] based on an increase of 15 °F for cooling water discharge (34).

Source: "Water Requirements for Coal Conversion Facilities," from Proceedings of the Workshop on Research Needs Related to Water for Energy, University of Illinois, Water Resources Center, p. 59.

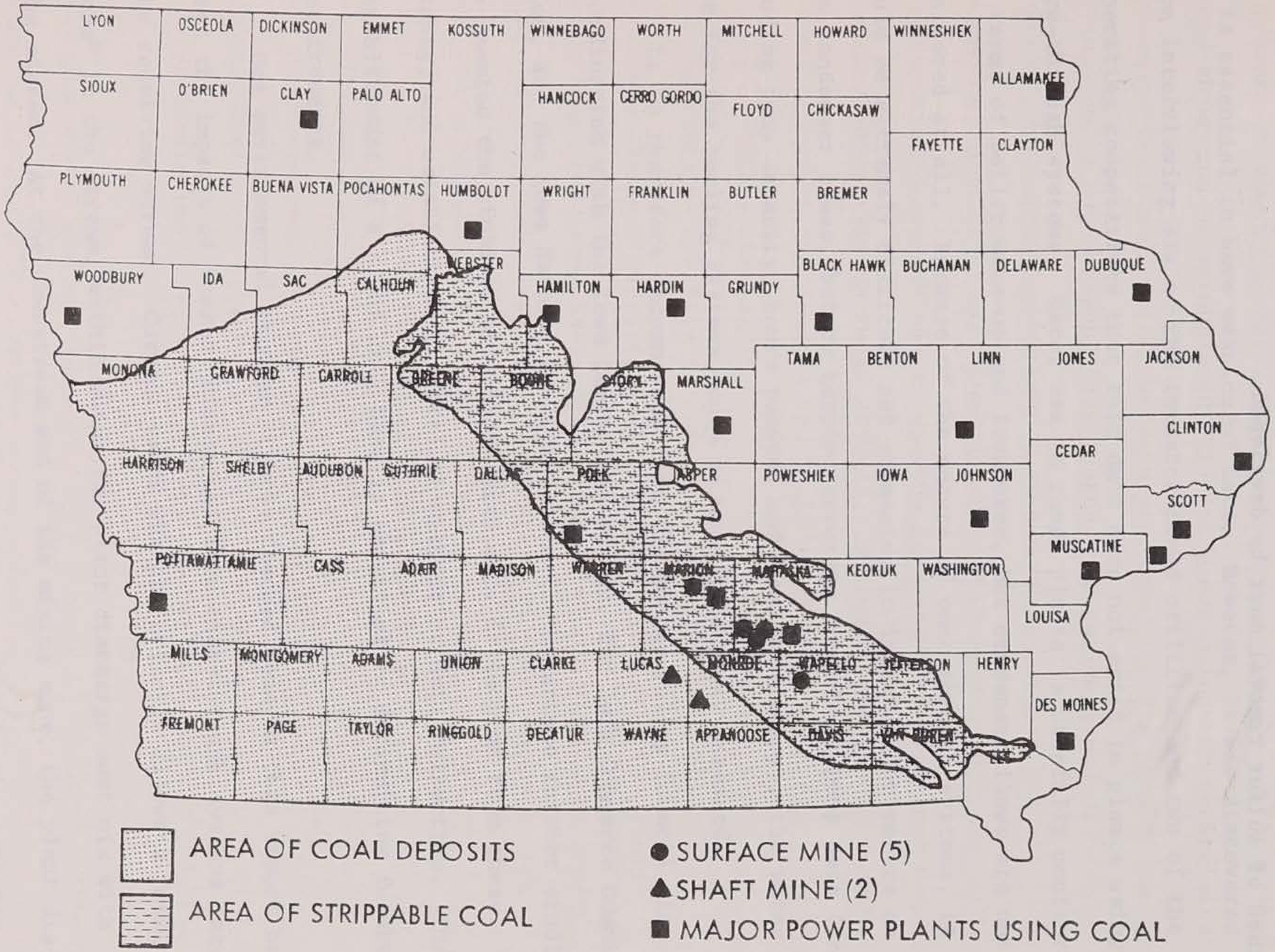

Figure 13. Iowa coal deposits and existing mines.

Source: Energy and Mineral Resources Research Institute, Iowa Coal Research Project: Progress Report, Iowa State University, Ames, 1975.

contents in stack gas emissions from plants using Iowa coal. Before large quantities of Iowa coal may be used for conversion, an economical method of sulfur removal must be developed.

RECOMMENDATIONS AND CONCLUSIONS

In determining the water requirements for steam-electric plants, it is essential to have meaningful data. However, it was discovered upon interviewing six of the investor-owned utilities and two of the generating cooperatives that this data does not exist in plants using once-through systems. Water use in these plants is carefully monitored in terms of boiler make-up and feedwater, but condenser flows are not monitored at all. Because of the nature of once-through systems, it would be extremely difficult and expensive to install flow meters on the condenser lines, but by keeping accurate records of pump data (including pump capacity, hours pumped, and pump efficiency), the water use for the cooling systems could be more accurately assessed.

It is therefore recommended that the Energy Policy Council, in coordination with the Iowa Geological Survey, the Iowa Commerce Commission, and the Iowa Natural Resources Council, undertake further studies to examine the problems associated with data collection from these plants, and establish more efficient methods of data collection. The establishment of a sound data base is essential in determining future requirements.

One environmental problem lightly touched upon in this report has been the impacts of thermal discharges from once-through systems into the receiving stream. Current water quality criteria allows a "mixing zone" in the stream, within which the plant discharge must mix with the stream. At the downstream end of the mixing zone, the plant discharge must be entirely mixed with the stream, that is the temperature at the lower limit of the mixing zone must be equal to the temperature

Allowable increase — not no increase — ffe

of the stream prior to entry into the plant. If the temperatures are not equal, the plant is in violation of water quality standards, and limits on the amount of water discharged from the plant may be established which could seriously curtail the plant output of electricity. This will effectively force the plant to use alternate methods of cooling, which may substantially increase operational costs.

It is therefore recommended that the Energy Policy Council study the thermal impacts of once-through systems on Iowa's interior streams, and determine if sufficient streamflow exists to allow further use of once-through systems on these streams. Thermal impacts on the border streams are now being studied at the Iowa Institute of Hydraulic Research, University of Iowa.

Plant siting criteria is now becoming an important aspect to water- and land-use planners. Water availability at a particular location is an important variable in site selection along with geological conditions, distance from load centers, and others. The Iowa Geological Survey is currently determining the water availability for Iowa as part of the Framework Study for the State Water Plan.

It is therefore recommended that the Energy Policy Council and the Iowa Geological Survey study and determine adequate site selection criteria, and integrate this study with the studies associated with the proposed State Land Use Policy legislation now being considered by the Iowa General Assembly.

As has been pointed out, there is a wide variance in the estimates of consumptive losses in steam-electric plants. Calculations of these losses in Iowa plants were shown in Table 9. Although data collection is a serious problem, there are some plants in Iowa which do have excellent data available on consumptive losses within the plant. These plants include Iowa Electric's Sutherland, Boone, and Duane Arnold Stations, Iowa Southern's Bridgeport Station, and Corn Belt Power's Wisdom Station. Also, two municipal power plants, Pella and Ames, have metered data available. It is felt that if these data were compared and analyzed with computed values, much could be learned about consumptive losses in steam plants in the State of Iowa.

It is therefore recommended that the Energy Policy Council conduct a study to analyze and compare these data with data derived from existing methods of computing consumptive losses, to determine the accuracy of these methods.

REFERENCES

1. Barrows, H. K. Water Power Engineering. New York: McGraw Hill, 1943.

2. Bessey, Roy F. Discussion on "Logical Approaches to Power Supply in Environment." ASCE Power Div., 99: PO1 (May 1973), pp. 261-263.

3. Coombe, R. A. Magnetohydrodynamic Generation of Electric Power. New York: Reinhold, 1964.

4. Cootner, R. H., and Löf, G. O. Water Demands for Steam Electric Generation. Boston: Resources for the Future, 1965.

5. Croley, T. E., and Kennedy, J. F., "Research Needs Related to Heat Dissipation from Large Power Plants," Proceedings of the Workshop on Research Needs Related to Water for Energy. University of Illinois, Water Resources Center, 1974.

6. Croley, T. E., Patel, V. C., and Cheng, Mow-Soung. The Water and Total Optimizations of Wet- and Dry-Wet Cooling Towers for Electric Power Plants. University of Iowa, Iowa Institute of Hydraulic Research, 1975.

7. Davis, G. H. , and Woods, L. A. "Water Demands for Expanding Energy Development," U.S. Geological Survey Circular 703. Washington, D.C.: U.S. Government Printing Office, 1974.

8. Federal Power Commission. 1970 National Power Survey. Washington, D.C.: U.S. Government Printing Office, 1970.

9. Federal Power Commission. Hydroelectric Power Resources of the United States: Developed and Undeveloped, 1972. Washington, D.C.: U.S. Government Printing Office, 1972.

10. Federal Power Commission. Problems in Disposal of Waste Heat from Steam-electric Plants. Washington, D.C.: U.S. Government Printing Office, 1969.

11. Federal Power Commission. Steam-electric Plant Air and Water Quality Control Data, 1971. Washington, D.C.: U.S. Government Printing Office, 1974.

12. Harding, Theodore P., and Dose, B. E. "Energy Production," The Role of Water in the Energy Crisis. Lincoln: Nebraska Water Resources Research Institute, 1973.

13. Heitz, Leroy F. The Potential for Nuclear and Geothermal Power Plant Siting in Idaho as Related to Water Resources. Moscow, Idaho, Water Resources Research Institute, University of Idaho, 1975.

14. Hottel and Howard, New Energy Technology - Some Facts and Assessments. Boston: MIT Press, 1971.

15. Iowa Energy Policy Council. First Annual Report. Des Moines, Iowa, 1975.

16. Iowa Energy Policy Council. Nuclear Energy 1975. Des Moines, Iowa, 1975.

17. Iowa Natural Resources Council. Iowa's Water Resources Program Progress and Needs. Des Moines: State of Iowa, 1973.

18. Iowa Natural Resources Council. Low-Flow Characteristics of Iowa Streams Through 1966. Des Moines: State of Iowa, 1970.

19. Kinsman, George, "Power Plant Cooling Systems," ASCE Power Div., 98: PO2 (October 1972), Proc. Paper 9231, pp. 247-252.

20. Linsley, Ray K., and Franzini, Joseph B. Water Resources Engineering, 2nd Ed. New York: McGraw-Hill, 1972.

21. Liptak, Bela G. Chapter 5.11, Environment Engineers Handbook, Vol. III, Land Pollution. Radnor, Penn.: Chilton, 1974, pp. 799-821.

22. Thompson and Young. "Forecasting Water Use for Electric Power Generation," Water Resources Research. American Geophysical Union, August 1975.

23. U.S. National Water Commission. Water Policies for the Future, Final Report. Washington, D.C.: U.S. Government Printing Office, 1973.

24. U.S. Water Resources Council. The Nation's Water Resources, the First National Assessment. Washington, D.C.: U.S. Government Printing Office, 1968.