34-45-31

VII-C-179

INLAND FLORIDA COOLING SYSTEMS

A. F. Dinsmore
Brown & Root, Inc.
Houston, Texas U.S.A.

ABSTRACT

A power station if located at an inland site in Florida must have an efficient means of disposing of waste heat.

In general, the regulatory authorities have been leaning towards the use of cooling towers for heat dissipation. The climatic conditions of Florida do not favor the use of dry or wet-dry towers and only wet towers can operate effectively.

To make use of cooling towers, an abundant source of water must be available to overcome evaporation and other losses. Hydrologic conditions do not permit, within inland Florida, the continuous withdrawal of water. In order for the cooling towers to properly function, a water supply reservoir is required in the cooling system.

If a water supply reservoir is required for successful cooling tower operation, why not use that water body for heat dissipation rather than storage.

This paper discusses how for a large steam electric generating station, if located within Florida, the preferred method of heat dissipation is the use of a cooling pond.

1.0 STEAM ELECTRIC GENERATING PLANT OPERATION

The basic components of a steam electric generating plant are illustrated in Figure 1. High temperature steam is produced in the steam generator and fed under high pressure to the turbine. This high pressure steam enters the turbine, nozzles accelerate the steam to a high velocity and direct it at an angle to a row (or rows) of turbine blades mounted on a shaft, and forces on the moving turbine blades are thus created. The force component in the direction of motion of the turbine blades maintains the rotation of the shaft, which turns a generator and produces electric power. Low pressure steam exits the turbine and enters the condenser where cooling water, circulating through the condenser, removes heat from the steam causing the steam to condense to liquid water. Since water occupies a smaller volume than the steam, a partial vacuum is created at the turbine exhaust. This partial vacuum in turn causes the incoming high pressure steam to deliver more energy to the turbine than if the steam were released directly to the atmosphere. Low temperature, low pressure water is exhausted from the condenser and pumped back to the steam generator and the process is repeated.

For a "closed cycle" power generation device such as discussed above, thermal efficiency of the cycle is defined as that fraction of the thermal energy input which is converted into net power output of the cycle. Thus:

$$\text{Thermal Efficiency} = \frac{\text{Net Energy Output as Power}}{\text{Thermal Energy Input}}$$

All "closed cycle" power generation devices are limited by the second law of thermodynamics to thermal efficiencies less than 100 percent. Thus, only a portion of the heat input to the cycle can be converted into power, and that portion of the heat input not converted into net power output must be rejected to the condenser cooling water and on to the environment as waste heat. The waste heat from a nuclear generating unit is approximately two-thirds of the heat input.

The cooling water circulating through the condenser must remove this waste heat from the steam and then safely dissipate it to the environment.

2.0 COOLING SYSTEM

2.1 General

The efficient operation of a steam-electric generating plant requires an adequate supply of cooling water to its condensers for the removal of waste heat. The amount of waste heat that is absorbed by the cooling water as it passes through the condenser is the product of the rate at which the cooling water circulates and temperature rise it undergoes in the condenser. The cooling system must be able to efficiently and safely transfer the heat load from the condenser to the cooling water and from the cooling water to the environment.

The transfer of heat from the cooling water to the environment for any cooling system will occur by one or more of the following heat transfer mechanisms: conduction, evaporation, radiation and convection. To maintain high efficiencies, large flow rates of cooling water are required to pass through the condenser. This water must be supplied from natural water bodies in either a once through system or a circulating water system in which heat is dissipated from the water to the atmosphere. The systems being evaluated consist of two that are primarily evaporative systems (mechanical draft wet cooling towers and natural draft wet cooling towers), two that are partially evaporative systems (wet/dry cooling towers and cooling ponds) and one in which the heat transfer is accomplished by transferring the sensible heat from the water directly to the air (dry cooling towers).

2.2 Types of Cooling Systems

The types of cooling systems may be classified as follows:

1. Once-Through
2. Natural Draft or Mechanical Draft Wet Cooling Towers
3. Cooling Ponds
4. Dry Cooling Towers
5. Hybrid Wet/Dry Cooling Towers

A simple system for providing the condenser cooling water is the once-through cooling system. As the name implies, once-through cooling involves taking water from a river, an ocean, or large lake and routing it through the condenser once, then discharging the water (at an elevated temperature) back to the body of water. The points of intake and discharge should be sufficiently distant from one another to prevent recirculation of the heated cooling water. This method of heat dissipation is normally more economical and provides a more efficient steam-electric generating cycle than other systems, however, a suitable body of water is not available in inland Florida and consequently this evaluation is of the merits of the various types of cooling towers (mechanical or natural draft; wet/dry or dry mode) and of a cooling pond.

2.3 Makeup and Blowdown

In cooling systems where evaporation is the primary mechanism of heat transfer, it is necessary to periodically replace water lost from the system. This water loss is the result of two processes. First, there is direct evaporative loss of water and second, the release of a portion of the cooling water called blowdown. This blowdown is required to control the level of dissolved solids in the cooling system.

The acceptable level of dissolved solids in the system is controlled either by the tolerance levels of the cooling system and/or the limitation of dissolved solids of the receiving body of water to which the blowdown will be discharged.

The total makeup water requirements, therefore can be defined as the sum of the evaporative water loss, and the quantity of blowdown required to maintain an acceptable total dissolved solids concentration.

3.0 CLIMATOLOGY OF INLAND FLORIDA

The amount of heat transfer that occurs in a cooling system is a complex function of thermodynamic conditions existing at that point in time. The climatic conditions of a geographical area thus become one of the primary considerations in the selection of a cooling system. The climatology of inland Florida is summarized in this section.

Florida lies approximately between latitudes 25^{o} and 30^{o} north and is subjected to a mean cloud cover of 50%. The annual mean daily solar radiation is about 450 langleys which is only exceeded in the United States by several of the southwestern states and California. The average annual relative humidity exceeds 80 percent due to Florida's proximity to the Atlantic Ocean and the Gulf of Mexico. Maximum average monthly mean relative humidity values recorded at the Fort Myers and Tampa weather stations were 88% and 87% respectively with both stations recording a maximum monthly mean of 90% for one month. The average wet bulb temperature for Florida ranges from 74^{o} to 76^{o}F.

Mean annual temperatures range from the upper 60's in northern portions of the state to the middle 70's on the southern mainland, but reach 78^{o}F at Key West. Mean temperatures during the summer vary from 81^{o}F to 82^{o}F throughout the state. During June, July and August maximum temperatures exceed 90^{o}F about 2 days in 3 in all interior areas. In May and September 90^{o}F temperatures or higher can be expected about 1 day in 3 in the northern interior and 1 day in 2 in the southern interior. Average minimum temperatures during the coolest months range from the middle 40's in the north to the middle 50's in the south. The average annual wind speeds for Florida vary from approximately 9 miles per hour along the coasts to approximately 7 miles per hour inland, depending on the topography.

4.0 HYDROLOGY OF INLAND FLORIDA

4.1 General

Ground water is not considered in this report as the existing aquifers of good quality water are under stress from existing use. The use of the deeper more saline aquifers would pose problems with blowdown wastes. Ground water was not therefore concluded to be a sufficiently reliable source of makeup water and is not discussed. Due to natural fluctuations in flow, the rivers of central and southern Florida are incapable of consistently delivering a quantity of water sufficient to meet the requirements of a steam electric generating plant. The situation is further complicated by the inherent presence of poorer water quality during lower stream flows when the average stream water quality conditions will vary radically. The following discussion of the Peace River flow at Arcadia will serve to illustrate these points.

4.2 Peace River Flows

The main stem of the Peace River is a narrow and shallow watercourse having a relatively narrow floodplain with a steep slope. Historically, the Peace River has experienced a wide range of flows on both a seasonal basis and on a short-term basis. At the USGS gaging station located at Arcadia, Florida, the average flow is 1252 cfs (561,900 GPM) based on records from 1931 through 1970, while that at Zolfo Springs, approximately 20.8 miles upstream of the site, is 351.1 cfs or 157,750 GPM (USGS 1970). Mean monthly flows for this period are given in Table 1 for both the Arcadia and Zolfo Springs gaging stations together.

As may be seen in Table 1, May is historically the low-flow month of the Peace River followed in order by the months of December, November, January, April, February, and March.

4.3 Makeup Water Diversion Scheme

The following discussion of water availability from the Peace River near Arcadia will serve to illustrate the effect of a makeup water diversion scheme.

The assumption has been made that a diversion scheme similar to those previously accepted by water management districts, would also be permitted for the Peace River and water availability is evaluated on that basis. Using this assumed diversion scheme, a minimum bypass flow was determined for the Peace River for each of the twelve months of the year and a percentage diversion, which varies with the rate of flow in the river, was proposed for such periods of time as the rate of flow exceeds the minimum bypass flow. This diversion scheme is illustrated on Figure 2.

Figure 3 demonstrates the effect of the application of the diversion scheme by showing the periods of time during an actual one year of record when diversion would have been permitted by showing the volume of water which would have been diverted. It can be seen from Figures 2 and 3 that there will be many months when it would not be possible to divert water to meet the requirements of the plant.

4.4 Drought Period

The most severe low-flow sequence for the Peace River near Arcadia in the period 1931 through 1970 was between October 23, 1931, and May 22, 1932. During this 212-day period the Peace River flows never exceeded 330 cfs (148,100 GPM) past Arcadia. Flows in the river were below the minimum river bypass flow established on a monthly basis for the makeup water diversion scheme illustrated on Figure 2 and Figure 3. Thus, no water would have been available for power plant requirements during this entire period. Table 2 gives low flow data for the Peace River at Arcadia for the period of 1931-1965. Conditions therefore dictate that some provision be made to store water so as to maintain plant operation during such periods.

The following discussion will pertain to the four most widely used types of cooling towers. They are the mechanical draft wet tower, mechanical draft dry tower, wet-dry hybrid tower and natural draft wet tower.

5.0 COOLING TOWERS

5.1 General

Evaporative cooling towers remove heat from cooling water by a flow of air, developed either naturally or mechanically, delivered across or through the heated cooling water. Heat transfer to the atmospheric environment occurs primarily through evaporative cooling. To achieve heat removal, water is pumped to the top of the tower and contact with the air flow is made as the cooling water then falls down through the tower to the tower basin. Evaporative cooling accounts for most of the waste heat rejection with most of the remaining heat rejection (5-10% as an annual average) goes into heating the moist air flowing through the tower. This warming is in the form of sensible heat, observed as a direct temperature rise of the air.

Operation of evaporative cooling towers results in the phenomenon known as drift. When the cooling water is introduced at the top of the tower, droplets are formed by mechanical breakup at nozzles, in the fill, and on structural components of the towers. Some of these droplets will become entrained in the air flow and leave the tower. Some may fall out close to the tower and others at a distance dependent upon the actual climatic conditions.

It should be noted that in modern cooling towers, drift is largely, but not totally, eliminated by a low pressure drop filter system known as a "drift eliminator". In this, the air stream is forced to follow a curved path, and a portion of the drift droplets are removed by centrifugal impaction on the eliminator surfaces with subsequent drainage back into the tower basin and eventually into the recirculation loop. State-of-the-art drift eliminators, fully maintained and operating at design conditions, are capable of reducing the drift to 0.002 percent (or less) of the total water circulation rate. There is, however, a tradeoff between pressure drop across the eliminators (Which also affects tower size and cost) and the required eliminator efficiency. Drift does not, however, pose a serious problem in terms of the deposition of solids on terrain and vegetation due to recent advances in cooling tower technology.

5.2 Mechanical Draft Wet Cooling Tower

The term wet implies that the heated cooling water is exposed to direct contact with the flow of air. In this type of tower the cooling water is pumped to some elevation above the tower base where it falls through fill to a tower basin and is collected and recirculated through the condensers. Cooling is accomplished by evaporation and by sensible heat transfer as a mechanically induced air draft passes through the fill. The heated air-vapor mixture is then released to the atmosphere at the top of the tower.

5.3 Natural Draft Cooling Tower

The natural draft cooling tower is essentially a wet tower incorporating a hyperbolic shell into the design and employing the principles of thermodynamics. The flow of air through the tower is primarily the result of the density difference between the external air and the internal air when it is heated by the cooling water and mixed with water vapor. Natural draft towers are designed to be several hundred feet tall in order to enhance the natural draft characteristics, and also to place the plume exit plane as high as possible above the terrain. For structural reasons the towers are constructed as hyperbolic shells with a base diameter 60-70 percent of the tower height. When considering this type of tower for an area, local climatic conditions must be such as to maintain the required air flow while overcoming pressure losses caused by the flow of air through the structure. It must be kept in mind that thermal performance of the tower will always be subject to weather conditions over which there is no control.

It should be noted that a wet cooling tower utilizing a naturally developed draft evaporates approximately the same amount of water as a mechanical draft wet cooling tower.

5.4 Mechanical Draft Dry Cooling Tower

There are two types of dry cooling towers; the indirect system and the direct system. In the indirect system, heat is transferred from the steam to the cooling water in the condenser. The heated cooling water is then pumped from the condenser through a tubing network in the cooling tower and back to the condensers. Cooling is accomplished as air passes over the tubing by heat conduction through the tubing walls and by heat convection at finned tube surfaces or similar heat transfer surfaces. The heated air is then released to the atmosphere at the top of the tower.

In the direct system steam flows directly to the cooling tower, in the same way as the heated cooling water is pumped in the indirect system, and cooling is accomplished in the tower as previously discussed. Thus, in the direct system the cooling tower performs the function of the condenser as well.

In the dry tower, the back pressure in the turbine and in turn its effect on power output, is related to the ambient dry bulb temperature. As the dry bulb temperature is always considerably higher than the wet bulb temperature, the cooled water leaves the dry tower at a higher temperature than would be obtained with a wet tower where the wet bulb temperature controls. Therefore, plant efficiencies are much lower with this type (dry) cooling tower. Dry cooling towers are not efficient in geographical areas with high dry bulb temperatures as in Florida, and are presently considered unsuitable to use in Florida.

5.5 Wet-Dry (Hybrid) Cooling Tower

Wet-dry cooling towers consist of a combination of evaporative cooling sections and dry cooling sections. The towers are designed and used for the elimination of cooling tower induced fogs and plumes. Having a portion of the cooling done in the dry section of the tower reduces the amount of water required for makeup. Passing a portion of the thermal effluent through finned tube heat exchangers, located at the top of the tower, lowers the relative humidity of the exiting air-water vapor thus reducing visible vapor plume.

A door like air flow restrictor, called the damper, is located in the heated dry air stream between the air cooled heat exchangers and the fan. During periods of high ambient dry bulb air temperatures, when the efficiency of wet cooling increases and that of dry cooling decreases, the damper is adjusted to reduce the air flow rate through the dry air stream, thus increasing the air flow rate in the wet stream. The evaporative section thermal performance is therefore used more effectively during periods of high ambient air temperature. During these periods of high usage of the wet section of the cooling tower, the evaporative losses of water are approximately equivalent to that which would occur in a standard wet cooling tower. It should be noted that on wet-dry cooling towers, it is normal to discontinue the use of the dry section at temperatures ranging from 35°F to 65°F. Therefore, in Florida the dry section of the cooling tower would be virtually useless.

5.6 Effect of Climate on Cooling Tower Operation

Cooling in a wet tower primarily takes place by evaporation and thus is influenced by temperature, relative humidity and the draft induced in the tower. The means by which the draft is developed has little effect on the amount of evaporation which takes place.

The loss of water by evaporation also requires that additional water be released as blowdown to prevent solids concentration. For an average monthly maximum total dissolved solids concentration of 500 mg per liter permitted in the receiving body of water and an existing concentration of 190 mg per liter in that body of water, the concentration ratio is approximately 2.6. For the climatic conditions of Florida, a 1200 MW(e) unit would evaporate approximately 14,000 GPM (all operating conditions being equal). With blowdown being 8800 GPM for the concentration ratio of 2.6. The makeup water requirement for one 1200 MW(e) unit would be 22,800 GPM or a total makeup water requirement of 228,000 GPM for a 12000 MW(e) power plant. Neither of the water requirements can be met by the Peace River for the greater part of the year as illustrated in Figure 3 and Table 1. These set of circumstances necessitate the incorporation of a water supply reservoir into the cooling tower system that would contain a sufficient volume of water to meet losses due to forced evaporation, seepage and blowdown.

5.7 Conclusions

From consideration of the effects of the climate of inland Florida, it can be concluded that the wet mechanical draft cooling tower is a more suitable option than natural draft cooling towers, dry cooling towers, or wet-dry towers and this type is discussed further.

6.0 EFFECT OF HYDROLOGY ON COOLING TOWER OPERATION

Due to the fluctuations of streamflow in Florida and the inherent presence of poorer water quality associated with lower streamflows, average stream water quality conditions will vary and the concentration of dissolved solids in a cooling tower system could often exceed the state water quality discharge standard (maximum monthly average allowable) of five hundred (500) mg per liter total dissolved solids. A tower system without any storage or blowdown flexibility could not in general operate at or above 2.5 cooling cycles and be capable of discharging to the stream at any time that the stream total dissolved solids level rose above 200 mg per liter. In order to meet these stream standards, constantly changing modes of tower operation would be required as the incoming water quality, quantity and blowdown quality varied. Additionally, blowdown to freshwater streams normally becomes economically prohibitive at cooling cycles of 4 or less due to the large volumes of makeup water and the large volumes that must be released to the stream to preserve environmental qualities.

A prolonged period below minimum makeup conditions would make it infeasible for a mechanical draft wet cooling tower to operate continuously and in turn the plant would be forced to close down. As stated earlier, the effects of climate and hydrology require the incorporation of a water supply reservoir into the cooling tower system in order to permit the cooling towers to operate.

Such a cooling system is illustrated in Figure 4.

6.1 Storage Reservoir Characteristics

The required reservoir volume to maintain operation during a drought must be such that (1) the volume of water is sufficient to maintain plant operation for a period equal to the period of the longest drought of record (see Section 5.3) and (2) a 6-month carry- over storage allocation which is based on the assumption that the maximum probable drought is yet to occur and consequently, some safety factor in the form of additional storage is required. Reservoir surface areas and embankment heights, which allowed for flood storage and wave runup, were computed and an economic comparison was made which considered the dollar value of land each reservoir would occupy and the respective capital costs of construction. The most economic reservoir, for a 12,000 MW(e) power plant using mechanical draft cooling towers, was found to have a 35,000 acre surface area with an embankment height averaging approximately 48 feet.

Water requirements were computed for the station based on full development of nuclear generating capacity (12,000 MW(e)) and a constant "load factor" of 80% of maximum capacity. Water supply for a system consisting of wet mechanical draft cooling towers and a water supply reservoir must meet the following demands: natural reservoir evaporation (net), drift and forced evaporation from the cooling towers, seepage from the reservoir, blowdown releases from the reservoir, and any additional outside demand.

Natural evaporation is influenced by wind speed and the difference between the saturated water vapor pressure at the surface of the water body and the water vapor pressure in the air. Water vapor pressure difference is, in turn, influenced by air and water temperature and humidity. For a water supply reservoir surface area of 35,000 acres, the average annual evaporation, based on computed monthly evaporation rates, is 92,200 GPM.

Net natural evaporation is simply the difference between natural evaporation and direct precipitation onto the reservoir surface. Based on computed monthly rainfall in the vicinity of Arcadia, the average annual rainfall onto a 35,000 acre water supply reservoir is 100,200 GPM. Hence the net natural evaporation (natural evaporation minus rainfall) averages (-) 8,000 GPM. The negative value indicates a surplus of rainfall over evaporation in this region of Florida.

Forced evaporation from cooling towers is a function of the wet bulb temperature of the air, relative humidity, cloud cover, wind speed, and range of cooling and heat losses by other mechanisms. For a site in West Florida, forced evaporation was estimated, for a 15°F approach to wet bulb, to be approximately 111,900 GPM.

Drift is the entrained water (water droplets) carried from the tower by the discharged air. For a site in West Florida, drift loss would be approximately 200 GPM for a 12,000 MW(e) plant based on 0.002% of condenser flow as drift.

Seepage from a water supply reservoir is dependent upon the foundation conditions underlying the reservoir and the material composition of the reservoir embankment. The seepage rate from a reservoir is also related to water table conditions and to the depth of water storage within the reservoir. Average annual seepage from a 35,000 acre reservoir is approximately 56,700 GPM, based on data obtained from tests in the area of Arcadia.

The increase in the concentration of total dissolved solids in the cooling tower-condenser circulating water due to evaporation makes it necessary for the cooling tower to periodically blowdown to the water supply reservoir. As a result, periodic releases of water from a water supply reservoir are occasionally necessary in order to maintain concentrations of dissolved solids within the reservoir at desirable levels and to avoid exceeding water quality standards, set by the Florida Department of Environmental Regulation in the Peace River, when discharges are made to the river from the reservoir. Average annual amount released from a 35,000 acre reservoir is approximately 19,000 GPM.

It is also assumed that there are no other demands on the proposed cooling tower water supply reservoir system.

The results of the reservoir operation studies indicated that a firm supply of makeup water could be diverted from the Peace River to accommodate the requirements for an ultimate power station capacity of 12,000 MW(e) and also meet the State water quality requirements for blowdown. The total average long term diversion that would be required is indicated below:

12,000 MW(e) Power Station Capacity

Net Evaporation Makeup	104,100 GPM
Average Annual Seepage	56,700 GPM
Net Average Annual River Diversion	160,800 GPM

7.0 COOLING POND

7.1 Definitions

The following definitions have been set forth by the Environmental Protection Agency and in the Florida Statutes respectively. "The term 'cooling pond' shall mean any manmade water impoundment which does not impede the flow of a navigable stream and which is used to remove waste heat from heated condenser water prior to returning the recirculated cooling water to the main condenser." "A cooling pond is a body of water enclosed by natural or constructed restraints which has been approved by the Florida Department of Environmental Regulation for purposes of controlling heat dissipation from thermal discharges."

7.2 Heat Processes

In a cooling pond, heated cooling water is discharged from the condenser directly into the pond where the water circulates around mobilization dikes. The cooling pond system is illustrated in Figure 5. In the process of flowing to the point of condenser intake, heat is given up to the atmosphere through conduction, back radiation and evaporation. The various mechanisms by which heat is exchanged between the water and the atmosphere are shown in Figure 6. The following is a brief description of the more important mechanisms, their symbolic identifications on the aforementioned figure, and the various meteorological factors that affect them.

Short-wave solar radiation, Hs, and long-wave atmospheric radiation, Ha, are incident upon the body of water. The intensity of short-wave solar radiation varies with the latitude of the location, time of the day, season of the year and amount of cloud cover. Long-wave atmospheric radiation is a function of many variables, but is largely dependent upon the distribution of water vapor, temperature, ozone, carbon dioxide and other materials within the atmosphere. It increases as the moisture content of the air increases and adds the largest amount of heat to a body of water on warm cloudy days when short wave solar radiation decreases to zero.

Portions of the incoming solar and atmospheric radiant energy are reflected by the water surface before it can be absorbed by water. The reflected solar radiation, Hsr, is a function of the sun's altitude and the amount of cloud cover. The reflected atmospheric radiation, Har, has been measured and found to be relatively constant at Har = 0.03 Ha.

These four preceding radiation terms, Hs, Ha, Hsr and Har, algebraically constitute the net radiation absorbed by the water, Hr, and are independent of the temperature of the water upon which the radiation falls.

Since water radiates as an almost perfect black body, it rejects energy to the atmosphere in the form of long-wave back radiation, Hbr. Heat is also lost from the pond by evaporation, He, which is dependent upon wind speed (W) and the difference between the saturated water vapor pressure (es) at the surface of the pond and the water vapor pressure in the air (ea). The third temperature dependent heat exchange factor is heat conduction, Hc. If the air temperature (Ta) differs from the water temperature (Ts) the water can gain or lose heat through conduction. The rate at which heat is conducted (Hc) between the water and air is equal to the product of their temperature difference and a heat transfer coefficient. Since the heat transfer coefficient is dependent on wind speed, the heat conduction is affected by wind speed.

The algebraic sum of the previously mentioned heat transfer mechanisms is the net rate at which heat enters or leaves a body of water, H.

7.3 Effect on Climate on Cooling Pond Operation

For a given set of climatic factors and the mechanisms of heat transfer previously mentioned, there is a theoretical steady state or thermally balanced condition where the net heat transfer is zero. The temperature of the water surface of this condition is defined as the equilibrium temperature. The equilibrium temperature is dependent upon such climatic factors as air temperature, wind speed, dewpoint temperature, relative humidity and solar radiation. For a cooling pond it is also dependent upon the amount of heat rejected to the pond from a power plant.

The high values of incident solar radiation, relative humidity and ambient air temperatures prevalent in Florida combine to produce average annual equilibrium temperatures in the mid to upper 70's which rank as some of the highest equilibrium temperatures in the country on an annual basis. Conversely the average heat exchange coefficient, which is dependent on wind speed, dew point temperature and water surface temperature, is also quite high in Florida due primarily to the comparatively high wind speeds and high ambient water surface temperatures. The resultant effect is that more heat can be dissipated per unit surface area of a cooling pond located in Florida as compared to a pond located in other climatological regions of the United States.

7.4 Cooling Pond Characteristics

An economic analysis was performed to estimate the characteristics of such a cooling pond that most economically provides cooling capacity for a plant near Arcadia, including periods of drought. The required pond characteristics include:

1. A surface area sufficient to effect the required net heat transfer to the atmosphere at all times, including those periods of time when the depth of water in the cooling pond is at its lowest point (minimum operating level).

2. A sufficient volume of storage to prevent the pond water surface dropping lower than the required minimum operation level.

The volume required to maintain operation during a drought is composed of:

1. The volume of water sufficient to fill the pond to the minimum operating level.

2. The volume of water sufficient to meet those withdrawals or losses (evaporation and seepage from the reservoir) that would occur for a period equal to the period of the longest drought of record., and

3. An additional 6-month carry-over storage allocation which is based on the assumption that the maximum probable drought is yet to occur and, consequently, some additional storage is required.

Cooling pond surface areas and embankment heights, which allowed for flood storage and wave runup, were computed and an economic comparison was made which considered the capital costs of construction, the dollar value of the land which would be occupied by the pond, and the economic penalty which would be incurred if the pond were "undersized." Inadequate cooling would occur if the pond were undersized, and consequently there would be a loss in generating efficiency as a result of higher turbine back pressures caused by this inadequate cooling. The most economic pond was found to have a 16,000 acre surface area with an embankment height averaging approximately 46 feet.

7.5 Water Requirements

Water requirements were computed for a plant located in West Florida based on full development of nuclear generating capacity (12,000 MW(e)) and a constant "load factor" of 80% of maximum capacity. Water supply for a cooling pond must meet the following demands: natural pond evaporation (net), forced evaporation from the pond, seepage from the pond, blowdown from the pond, and any additional outside demands.

Natural evaporation is influenced by wind speed and the difference between the saturated water vapor pressure at the surface of the cooling pond and the water vapor pressure in the air. Water vapor pressure difference is, in turn, influenced by air and water temperature, and humidity. For a cooling pond surface area of 16,000 acres, the average annual evaporation, based on computed monthly evaporation rates, is 42,100 GPM.

Net natural evaporation from a cooling pond surface is simply the difference between natural evaporation and the direct precipitation onto the pond surface. Based on computed monthly rainfall in the vicinity Arcadia, the average annual rainfall onto a 16,000 acre cooling pond is 45,800 GPM. Hence the net natural evaporation (natural evaporation minus rainfall) averages (-) 3,700 GPM. The negative value indicates a surplus of rainfall over evaporation in this region of Florida.

Forced evaporation from a cooling pond surface is the additional evaporation which is induced by the artificial heating of the reservoir by the condenser heat load. Heat is lost to the atmosphere due to evaporation, convection and back radiation resulting in a reduction of water temperature in the reservoir. The rate of forced evaporation is dependent upon the wind speed, air temperature and vapor pressure, plant discharge temperature and flow rate (heat load) effective pond surface area and mobilized volume, and pond flow-through time. For a cooling pond surface area of 16,000 acres, the average annual forced evaporation based on computed monthly evaporation rates is 89,800 GPM which constitutes approximately 71% of the total heat lost. Approximately 19% of the total heat is given up via convection with the remaining 10% lost by back radiation.

Seepage from a cooling pond is dependent upon the foundation conditions underlying the pond and the material composition of the cooling pond embankment. The seepage rate from a pond is also related to water table conditions and to the depth of water storage within the pond. Average annual seepage loss from a 16,000 acre cooling pond is approximately 34,100 GPM, based on data obtained from tests in the area of Arcadia.

Periodic releases of water from a cooling pond are necessary in order to maintain concentrations of dissolved solids within the cooling pond at desirable levels and to avoid exceeding water quality standards set by the Florida Department of Environmental Regulation. The average amount of blowdown released from a 16,000 acre cooling pond is approximately 59,000 GPM.

Finally it was assumed that there are no other demands on the proposed cooling pond system.

The results of the cooling pond operation studies indicated that a firm supply of makeup water could be diverted from the Peace River to accommodate the requirements for an ultimate power station capacity of 12,000 MW(e) and also meet the State water quality requirements for blowdown. The total average long term diversion that would be required are indicated below:

12,000 MW(e) Power Station Capacity

Net Evaporation Makeup	86,100 GPM
Average Annual Seepage	34,100 GPM
Net Average Annual River Diversion	120,200 GPM

8.0 SUMMARY

The manner in which the specific climatic conditions of Florida affect the operation of cooling towers may be summarized as follows. Florida's high ambient air temperatures make dry towers inefficient and the costs involved to improve efficiency make the system infeasible. The natural draft wet tower presents no advantage over the mechanical draft wet tower since both types evaporate approximately the same amount of water.

A major advantage of the mechanical draft tower over the natural draft tower is that operation of the mechanical draft tower is not subject to the limitations imposed by Florida's climate in the manner that the natural draft tower is. Wet-dry towers present few advantages over wet towers in Florida because fogging is not generally a problem and with the high ambient temperatures water consumption is virtually the same as for wet towers. Any slight advantage, however, is offset by the much greater cost of wet-dry towers. It can, therefore, be concluded that climatic conditions make the mechanical draft wet tower the most feasible of the alternative cooling towers.

Section 7 discussed the cooling pond and it was shown to be a viable system for the disposal of waste heat from a nuclear power plant in Florida. While it has been concluded that mechanical draft wet towers are also a viable cooling system, the ramifications of the anticipated fluctuations in streamflows as discussed in Section 5 and 6.1, show that a storage reservoir must be incorporated into the cooling tower system to make it feasible in Florida. A reservoir will therefore be a component of either cooling tower or cooling pond system applied to inland Florida.

As is apparent from Section 6, the mechanical draft wet cooling tower system with a water supply reservoir will require approximately twice the land area (see Figure 7) and use more energy to operate than the cooling pond system while also incurring approximately twice the capital cost. Also of major significance is the fact that the cooling tower system requires the diversion of 40,600 GPM, or 33.8%, more water for operation than does the cooling pond system (see Figure 8). The conservation of this amount of water is a major advantage of the cooling pond system.

In summary, the interaction of climate and weather necessitates that for effective operation, cooling towers incorporate a water supply reservoir in the overall cooling system. The demands of the cooling tower water supply reservoir far exceed that of cooling pond capable of storing water and dissipating heat. It is concluded that cooling ponds are preferred for inland sites in Florida for use in waste heat dissipation.

ACKNOWLEDGEMENTS

The author wishes to thank Florida Power & Light Company for permission to publish this paper and in particular thank Mr. E. C. Weber and Mr. K. F. Rosanski for their comments and assistance.

TABLE 1

PEACE RIVER
MEAN MONTHLY FLOWS
(Jan., 1934 - Dec., 1970)

(MEAN MONTHLY DISCHARGE IN CFS)

MONTH OF	Zolfo Springs[1]		Arcadia[2]	YEAR
GPM	CFS	GPM		
January	456.6	204,920	637.6	286,150
February	544.6	244,420	820.8	368,380
March	651.4	292,170	1,004.3	450,730
April	477.6	214,350	696.2	312,450
May	307.0	137,780	386.3	173,370
June	773.8	347,280	1,324.0	594,210
July	1,090.0	489,190	2,084.9	935,700
August	1,237.3	555,300	2,300.5	1,032,460
September	1,549.4	695,370	2,939.8	1,319,390
October	991.1	444,810	1,916.2	859,990
November	420.8	188,860	613.2	275,200
December	351.1	157,570	488.4	219,190

NOTES: 1) Based on USGS records from Station 02295637 at Zolfo Springs, Florida.

2) Based on USGS records from Station 02296750 at Arcadia, Florida.

TABLE 2

LOW FLOW DURATION

AT USGS GAGE NO. 02296750

ARCADIA, FLORIDA (1931 - 1965)*

Number of Consecutive Days in Year Ending June 30	Lowest Mean Discharge		Year of Occurrence
	in CFS	in GPM	
1	39.0	17,500	(1949)
3	39.0	17,500	(1949)
7	42.9	19,250	(1949)
14	47.1	21,140	(1945)
30	54.3	24,370	(1945)
60	64.0	28,720	(1945)
90	70.0	31,420	(1945)
120	83.9	37,650	(1932)
150	86.7	38,910	(1932)
183	87.2	39,140	(1932)
274	206.0	92,450	(1956)

NOTE: *Heath, 1971

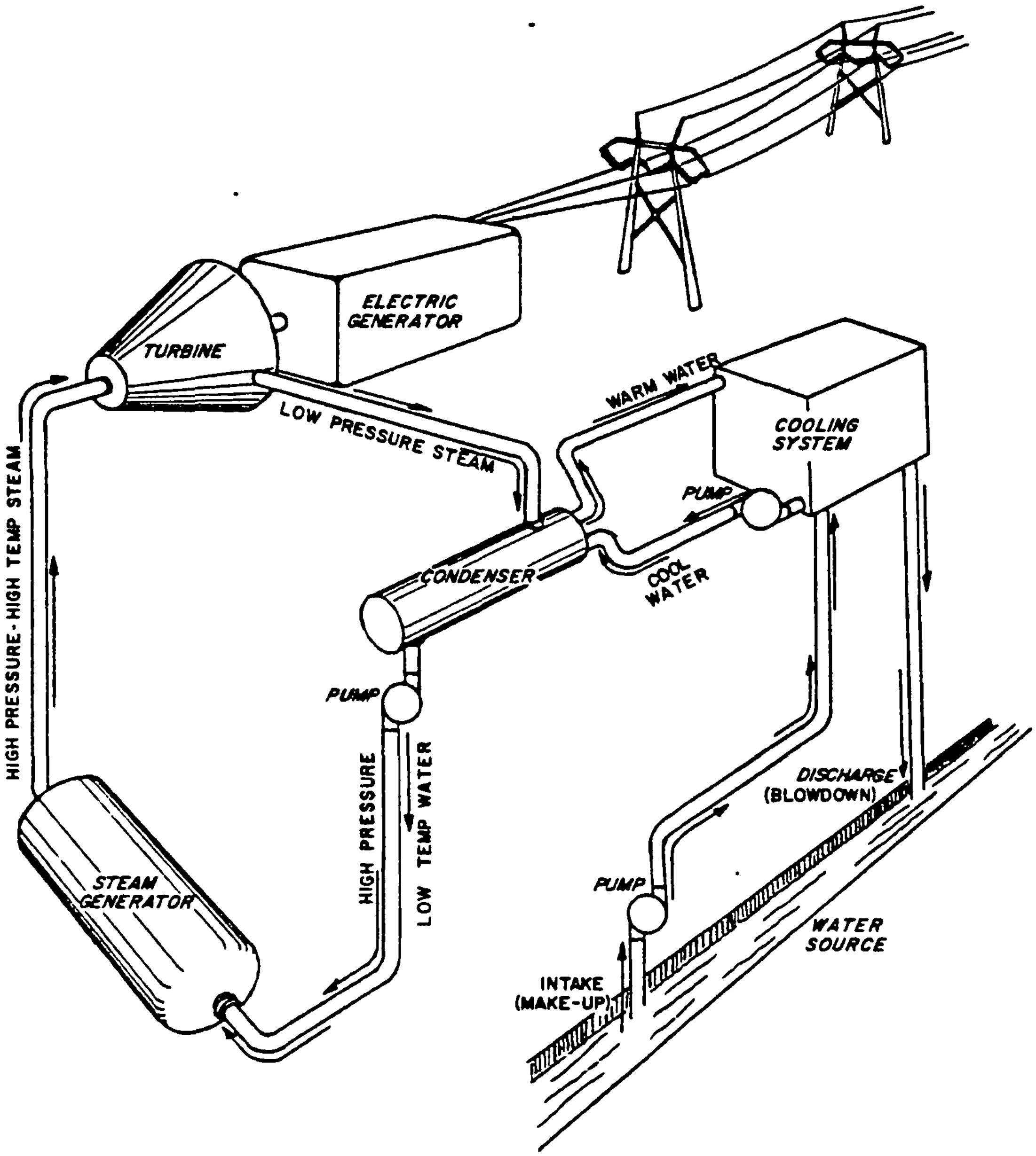


FIGURE I: STEAM ELECTRIC POWER PLANT

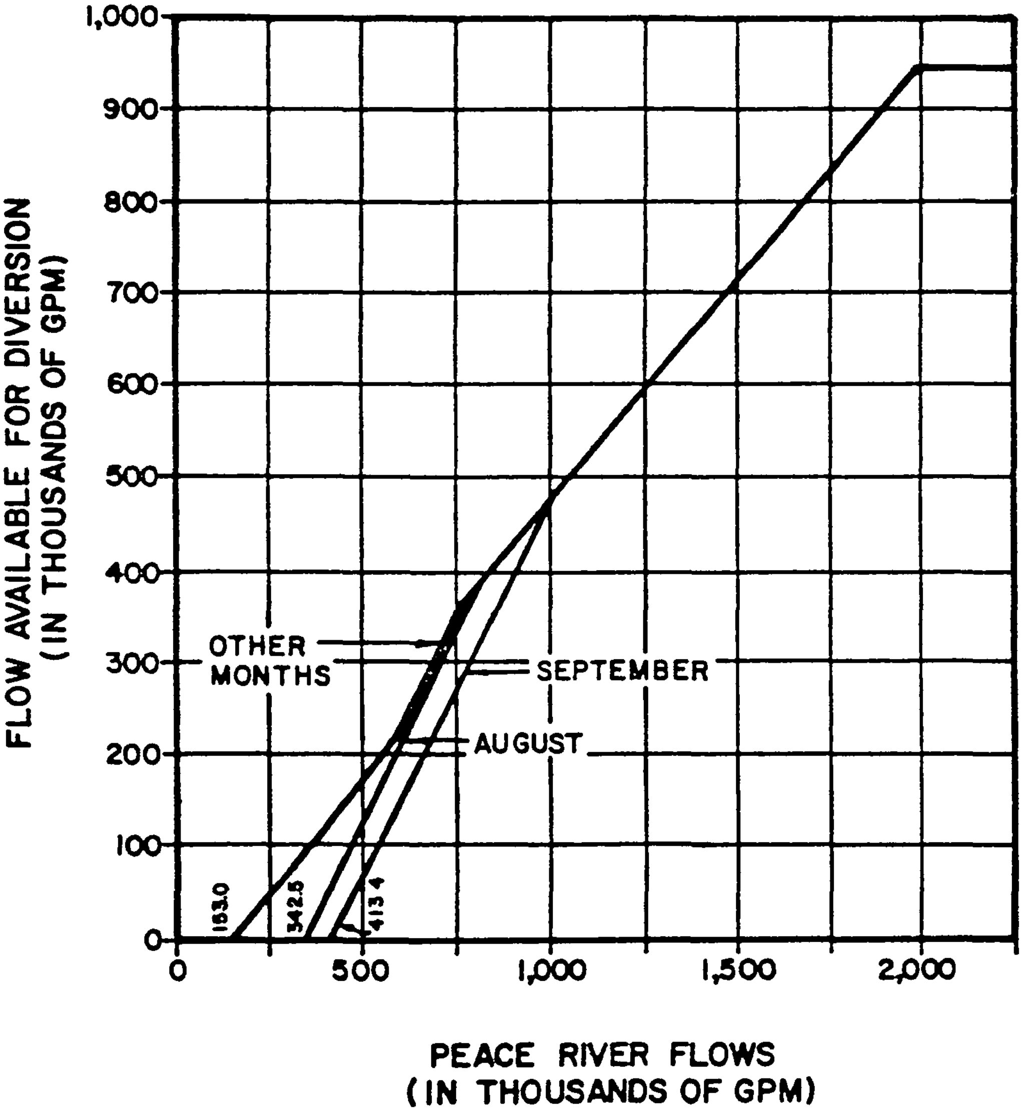


FIGURE 2: POSSIBLE DIVERSION FLOWS FROM PEACE RIVER

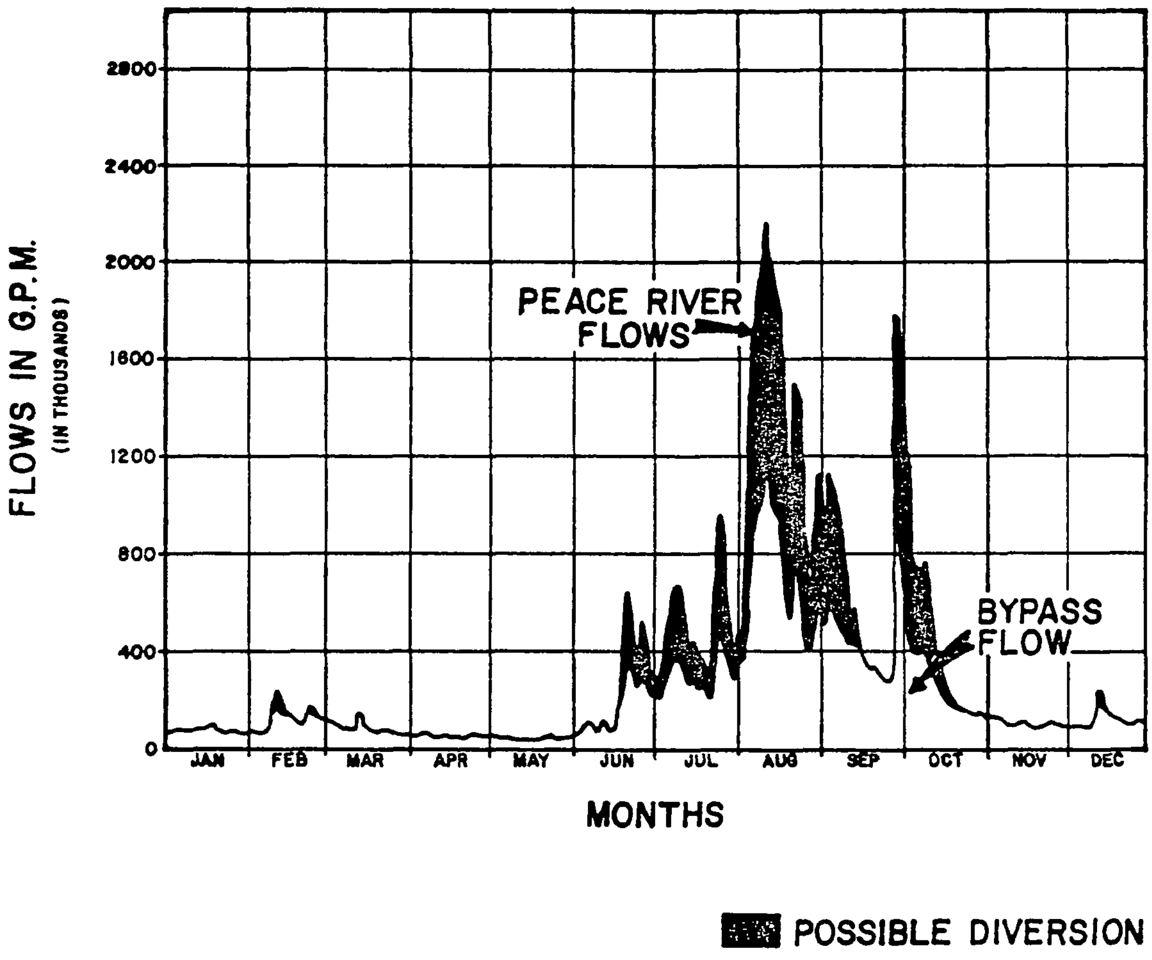


FIGURE 3: DIVERSION CHARACTERISTICS

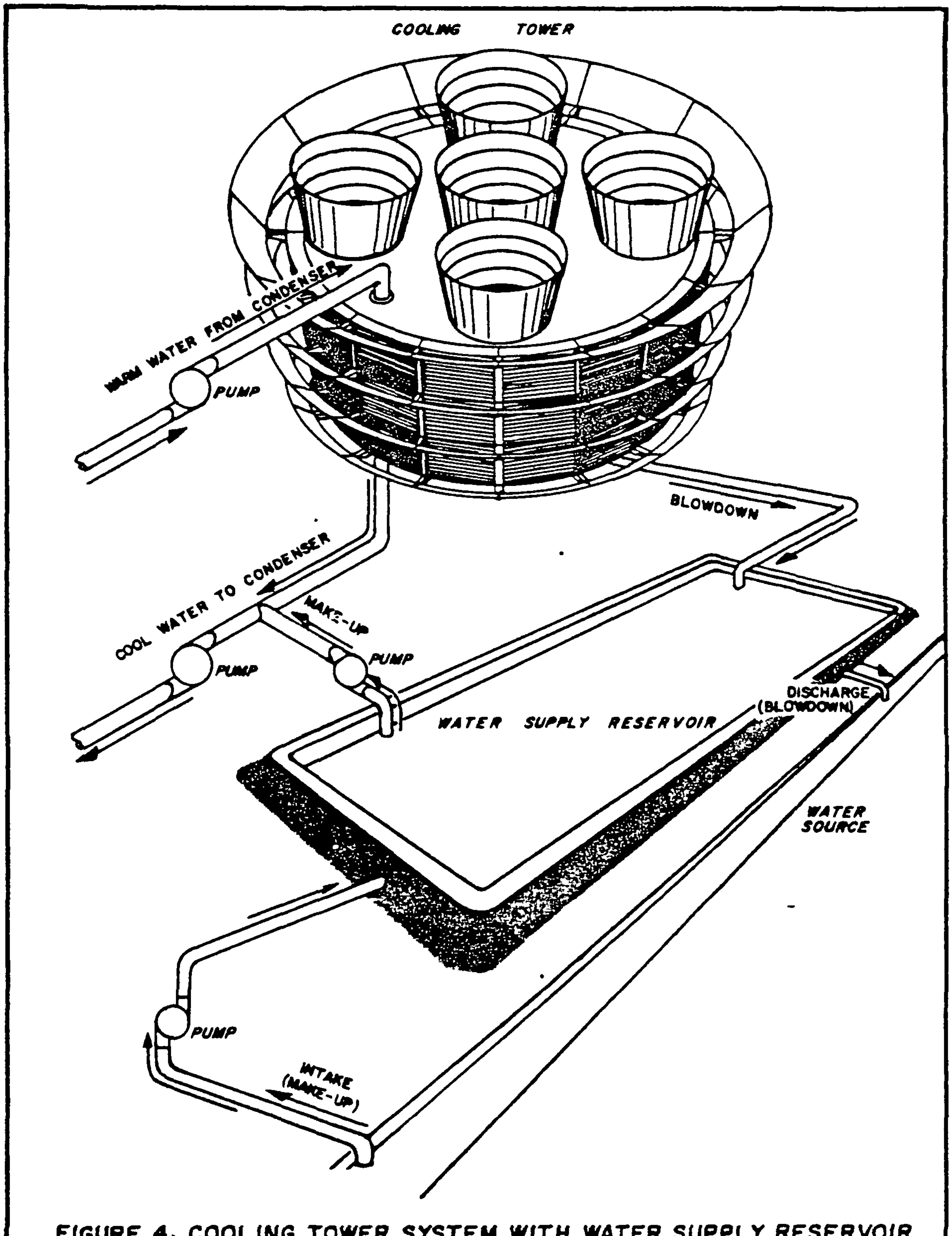


FIGURE 4. COOLING TOWER SYSTEM WITH WATER SUPPLY RESERVOIR

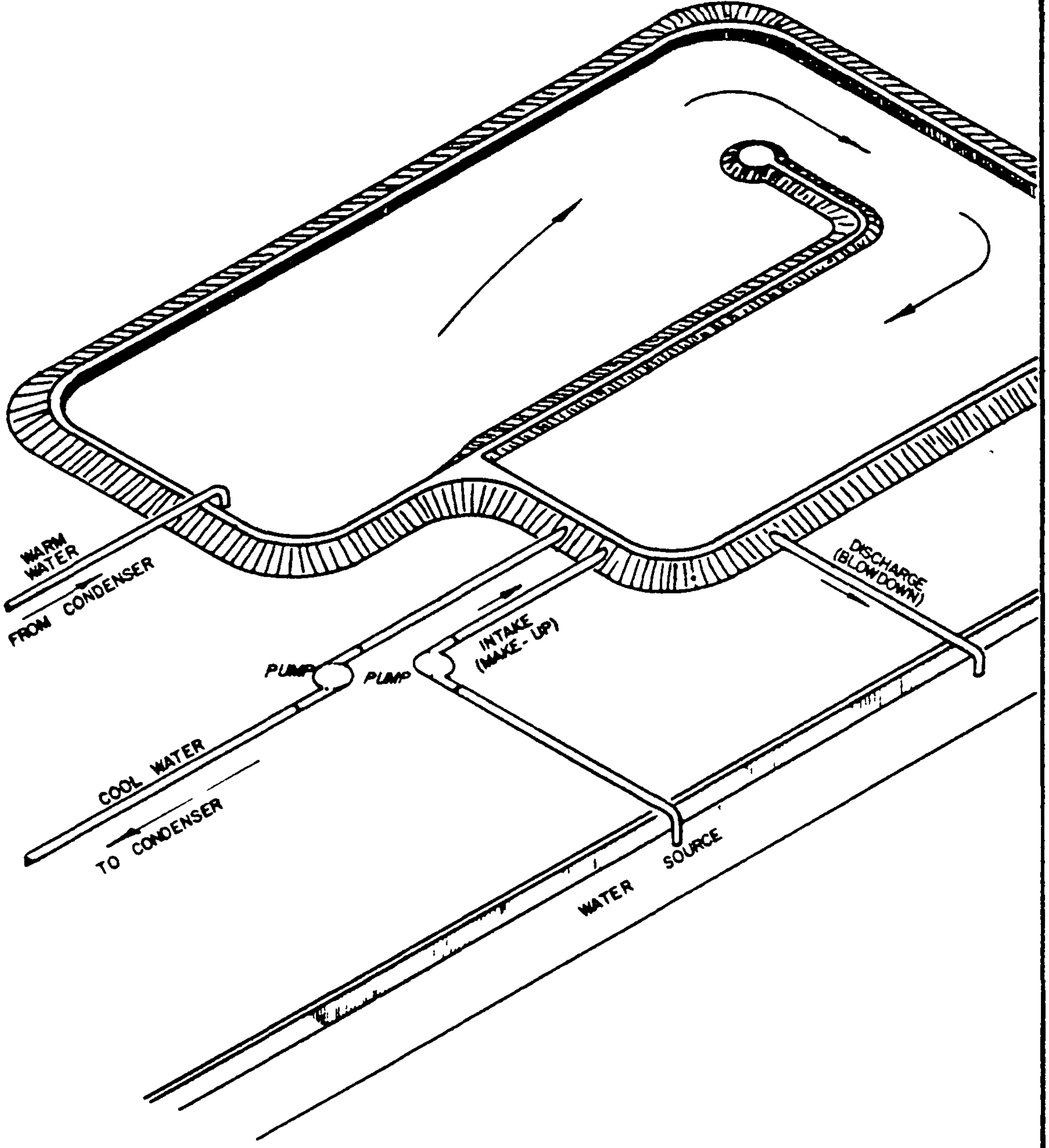
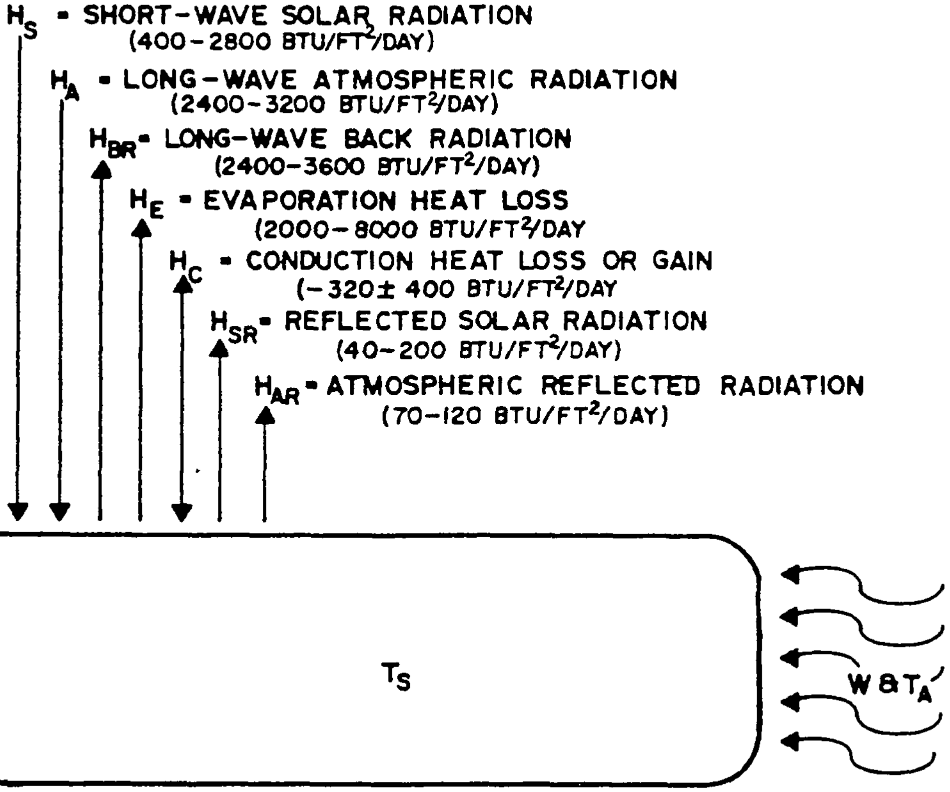


FIGURE 5: COOLING POND SYSTEM



ΔH = DAILY NET RATE AT WHICH HEAT IS GAINED OR LOST ACROSS A WATER SURFACE

$$\Delta H = \underbrace{(H_S + H_A - H_{SR} - H_{AR})}_{H_R} - \underbrace{(H_{BR} \pm H_C + H_E)}\ \text{BTU / FT. DAY}$$

H_R

ABSORBED RADIATION INDEPENDENT OF TEMP

$H_{BR} \sim (T_S + 460)^4$

$H_C \sim W(T_S - T_A)$

$H_E \sim W(e_S - e_A)$

TERMS DEPENDENT ON TEMP

W = WIND SPEED (MI/DAY)

T_A = AIR TEMP (°F)

T_S = WATER SURFACE TEMP (°F)

e_S = SATURATED VAPOR PRESSURE

e_A = AIR VAPOR PRESSURE

FIGURE 6: MECHANISMS OF HEAT TRANSFER ACROSS A WATER SURFACE

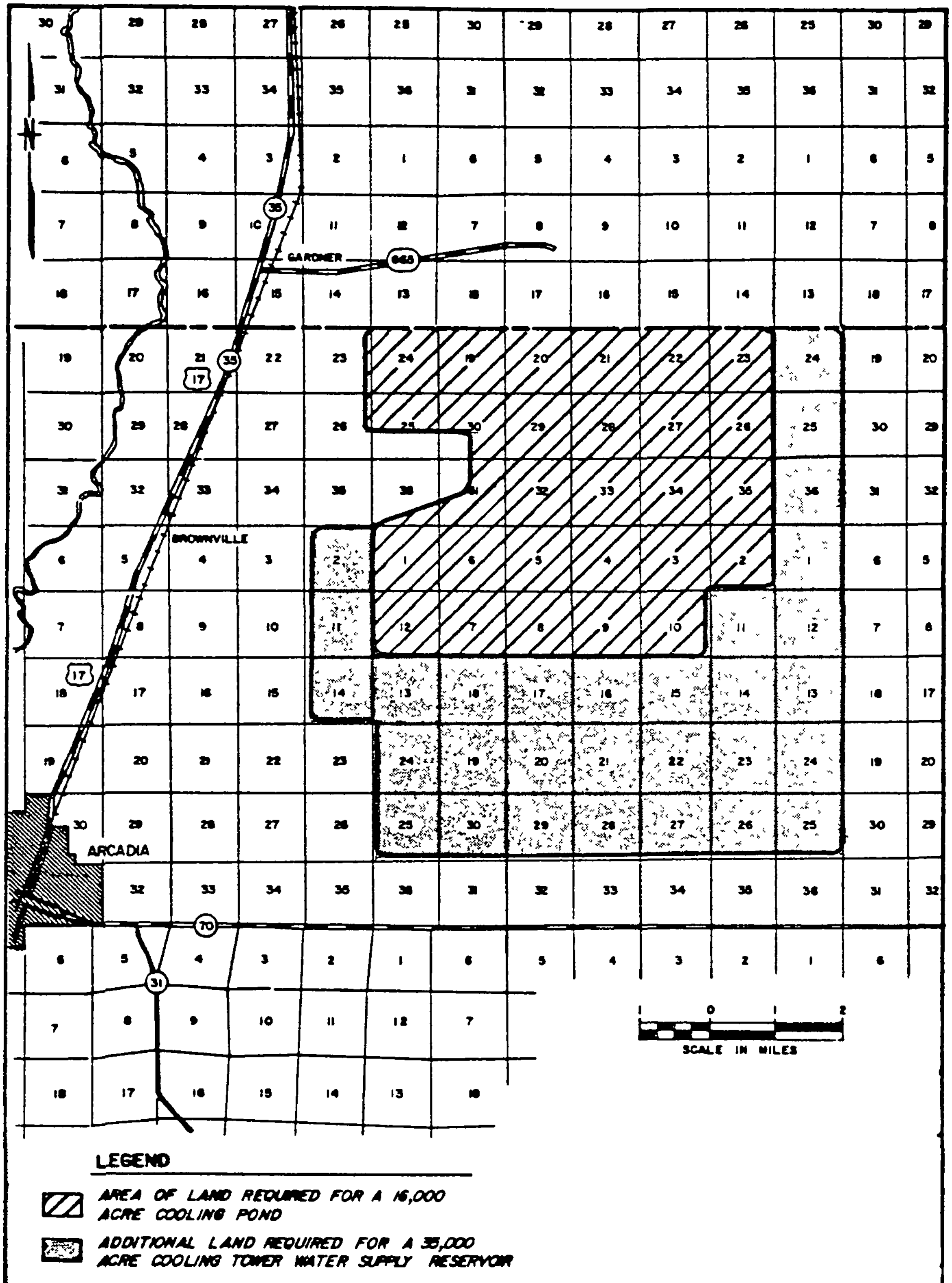


FIGURE 7: LAND AREA COMPARISON

	COOLING POND	COOLING TOWER WATER SUPPLY RESERVOIR
PUMPING STATION		
MAXIMUM CAPACITY (GPM)	942,500	942,500
SURFACE AREA (ACRES)	16,000	35,000
ELEVATIONS (FEET MSL)		
AVERAGE BOTTOM	85.0	85.0
MINIMUM OPERATING LEVEL	94.0	94.0
MAXIMUM OPERATING LEVEL	117.4	118.5
FLOOD STORAGE LEVEL	120.4	121.5
AVERAGE TOP OF EMBANKMENT	131.0	133.0
VOLUMES (ACRE FEET)		
MINIMUM OPERATING LEVEL	144,000	315,000
MAXIMUM OPERATING LEVEL	518,400	1,172,500
FLOOD STORAGE LEVEL	566,400	1,277,500
MAKEUP WATER REQUIREMENTS (GPM)		
AVERAGE ANNUAL SEEPAGE	34,100	56,700
NET AVERAGE EVAPORATION	86,100	104,100
NET AVERAGE ANNUAL RIVER DIVERSION	120,200	160,800

FIGURE 8: COMPARATIVE WATER AND LAND REQUIREMENTS