Lake Drought Model Description

Introduction

In order to estimate the amount of cooling water available from Clinton Lake for the additional power plant operations, an analysis was conducted following the theoretical procedure outlined in the Clinton Power Station (CPS) Updated Safety Analysis Report (USAR) Section 2.4.11.1 (Illinois Power 2001). Two design droughts were established having a 5-year duration at 50-year and 100-year recurrence intervals. Low flow runoff data for both design droughts were obtained from the USAR, which cited the source *Low Flows of Illinois Stream for Impounding Reservoir Design* published as Bulletin 51 by the Illinois State Water Authority (Stall 1964).

Assumptions and Data Sources

A normal lake elevation level of 690 feet was used as the starting water surface level. Lake stage storage relationships were obtained from CPS Environmental Report – Operating License Stage (ER-OLS) Figure 2.4-6 based on the original lake volume of 74,200 ac-ft at normal lake level (Illinois Power 1982). Inflow to the lake (in acre-feet) was computed on a monthly basis by multiplying the rainfall runoff (in feet) by the watershed area (in acres). Outflow from the lake was assumed to be comprised of downstream discharge; net lake evaporation minus lake precipitation; forced evaporation due to existing plant operations; seepage; and the cooling water consumed by the new facility. Rainfall runoff flows for both drought events were obtained from CPS USAR Tables 2.4-20 and 2.4-24. Runoff values were multiplied by the watershed area of 296 square miles to establish a runoff volume. Downstream discharge through the dam was assumed to be a minimum discharge of 5 cubic feet per second (cfs; 298 acre-feet/month), when lake levels are at or below the 690-foot spill elevation. For the purpose of drought analysis calculations, the lake elevation was not allowed to exceed 690 feet. The discharge was allowed to be greater than 5 cfs if inflows would increase the lake level to a level above the spillway elevation of 690 (Illinois Power 2001).

Net lake evaporation minus precipitation data were obtained from CPS USAR Table 2.4-21 for both the 50-year and 100-year recurrence interval droughts.

Existing plant forced evaporation data used in this analysis was developed from data given in the CPS USAR Table 2.4-22, which was based upon two originally planned 992 MWe BWR plants at a 70-percent load factor (Illinois Power 1982). Forced evaporation is defined as the additional evaporation produced due to an increase in lake water temperature caused by the discharge of cooling water to the lake under the open-cycle lake cooling process for the two original plants. This factor accounts for the total evaporative loss that results from dissipation of the heat rejected to the lake. The evaporative loss will occur through the cooling loop. The term forced evaporation is used because the rejected heat and associated increase in lake temperature will "force" an increase in the rate of evaporation over ambient levels to dissipate the rejected heat.

Forced evaporation rate for the two proposed plants was revised to reflect the rate for the existing single uprated plant. Only one of the two original plants was constructed at 992 MWe but was uprated in 2002 to a 1138 MWe plant. The forced evaporation rates from the CPS USAR were divided by 0.7 to obtain the evaporation rate for a 100 percent load factor. The forced evaporation rates were then divided by two to account for the fact that only one plant is present. To account for the power uprate, the forced evaporation rates were then multiplied by 1.147 (1138/992). All three of these factors are equal to multiplying the original forced evaporation rates by a factor of 0.82.

The forced evaporation values for the original 992 MWe plant operating at 100 percent were verified through the EGC ESP analysis. The forced evaporation rates determined by that exercise closely matched the CPS USAR forced evaporation rates, but were slightly smaller, so it was decided to use the more conservative CPS USAR forced evaporation rates. The method used to check the forced evaporation rates is described below.

Forced and natural evaporation occur simultaneously as the circulating water flows through the cooling loop. In order to differentiate between the amounts of natural and forced evaporation, the equilibrium temperature for the lake was determined on a monthly basis using monthly climactic data over the period of record. The equilibrium temperature is the temperature of the lake water (about 1 foot below the surface) where the heat input to the lake water is exactly balanced by the heat output from the lake water. This equilibrium temperature is determined by performing a heat balance for solar heat gain, heat loss by convection, evaporative cooling and radiant heat transfer from the water to the surroundings. The amount of natural evaporation (per unit area of lake) is determined based on this equilibrium temperature.

To determine the amount of forced evaporation, a spreadsheet model that follows the method of Langhaar (Langhaar 1953) was developed, and was validated by good agreement with results of an earlier study (Edinger 1989). The model was then applied to simulate the cooling lake for each month, using monthly average climactic conditions over the period of record. The simulation quantifies the aforementioned modes of heat transfer per unit area of lake. The evaporative cooling that is determined by the model is a “total” value (forced plus natural evaporation). The amount of forced evaporation, is simply the difference between the total and natural evaporation determined from the equilibrium temperature.

Existing and proposed plants discussed in this memorandum assume a 100-percent load factor in their operation. It was assumed that each drought event would begin during January of the first year of the drought. As in the USAR, seepage was assumed to be equal to 0.5 percent of the lake volume.

Likelihood of 50-year and 100-year Recurrence Interval Events During Plant Life

By definition, a 100-year recurrence interval event has a 1-percent exceedance probability to occur in any given year. Similarly, a 50-year recurrence interval event has a 2-percent exceedance probability to occur in any given year. Calculations were carried out to determine the likelihood of 50-year and 100-year recurrence interval events during the 40-year life of the proposed plant. It was determined that there is a 56-percent exceedance probability that at least one 50-year recurrence interval drought will occur during the 40-year life of the plant. There is a 33-percent exceedance probability that at least one, 100-year recurrence interval drought will occur during the same 40-year period.

Methodology

Calculations were carried out in the spreadsheet (NRC RAI E5.2-1&2 – Att C – Lake Drought Analysis Model). For each month, a net volume gain or loss was calculated by subtracting lake volume losses and adding lake volume gains (both in acre-feet) for that month. This net change was then added to the initial volume for that month to obtain the initial volume for the next month. The lake elevation–area capacity and -volume capacity relationships found in the ER-OLS were then used to estimate the lake elevation level and lake area for the following month (Illinois Power 1982). These calculations were carried out separately for the 60 months (the entire 5-year duration period) of the 50-year and 100-year recurrence interval droughts.

Cooling Alternatives

A base cooling alternative similar to the current CPS plant cooling process (Lake Cooling) and three other cooling options have been identified. The cooling options incorporate technology to reduce water loss. Each of the 4 cooling alternatives were applied to three (water-use bounding) plant concepts being considered: two AP-1000 units, one AP-1000 unit, and one ABWR unit.

BASE OPTION- Lake Cooling

This cooling process simply draws water from the lake, passes it through a heat exchange process and discharges the heated water back into the Lake. The heated water then cools as it travels in the lake from the plant discharge point to the intake point. Evaporative loss or forced evaporation is significant for this cooling option.

OPTION 1–Dry/Wet Surface Cooling

This option consists of a combination dry/wet surface cooling tower. The 1-percent design temperatures from a Fluor evaluated weather data handbook for Decatur, IL are 96 degrees Fahrenheit (F) dry bulb and 79 degree F wet bulb. (Decatur values exceed Bloomington, IL and Springfield, IL). Using the ABWR Condenser temperature rise of 25 degrees F (i.e., the most restrictive value for the designs encompassing the Plant Parameter Envelope (PPE)) and the inlet temperature of 100 degrees F given in the PPE, the circulating water discharge temperature is 125 degrees F. Assuming a 10 F terminal temperature, a dry surface coil could reduce the circulating water temperature to 96 + 10 = 106 degrees F for a delta temperature (T) of 19 degrees F (125 F – 106 F). This should result in a reduction of the water usage for the wet portion of the cooling tower by the ratio of the remaining delta T over the 25 degree F original delta T (i.e., (25 - 19)/25), resulting in 24 percent less water required for straight wet cooling. Thus, a combination dry/wet surface tower can reduce the makeup water consumption for cooling by 76 percent. A water consumption rate of 70 percent will be used with the wet/dry option to provide a small degree of margin from the theoretical value of 76 percent. The 10 degree F terminal temperature for the air cooling section is at the limit. A temperature differential between the fluid and the air is required for heat transfer to occur. Values of 5 degrees F are typical for liquid to liquid and 20 degrees F for liquid to gas. The 10 degrees F value used is considered to be the minimum value for water to air. A higher terminal temperature difference with increased water consumption would be more economical. Water usage for an ABWR plant with a wet/dry tower used for main condenser cooling to reduce water evaporation loss by 70 percent is 6,000 gpm. Water usage for a two unit AP-1000 plant with a wet/dry tower used for the main condenser to reduce cooling water evaporation loss by 70 percent is 11,000 gpm. These water usage values are acceptable during the 50-year drought condition, and at least for the single unit ABWR and AP-1000 would also be acceptable during the 100-year drought condition.

OPTION 2–Lake Water with Cooling Towers

This option uses lake cooling water with cooling towers to reduce the discharge temperature to the 99 degree F National Pollution Discharge Elimination System (NPDES) permit limit for

90 days in a year. For this option, a 95 degree F inlet water temperature is assumed with a 25 degree F rise from the PPE. This would result in a Circulating Water discharge of 120 degree F. The cooling tower delta T required is 120-99 = 21 degrees F. The reduction in water usage for the cooling tower in this option is only 1-(21/25) = 16 percent.

OPTION 3–Dry Surface Cooling

This option uses a dry surface to cool the circulating water. This would reduce the water consumption for condenser cooling to zero. The dry cooling option would result in higher condenser vacuum (approximately 9.6 in. hg. [4.7 psia]) and a reduction in thermal efficiency. The increased exhaust pressure could also increase turbine cost. Table 1 shows water use for the different plant options and cooling methods.

TABLE 1
Water Use for Plant Options and Cooling Methods

Option	Base	1 *	2 *	3 *
Type of Plant Unit	**Wet Cooling**	**Dry/Wet Cooling**	**Lake Water with Cooling Towers**	**Dry Cooling**
Two AP-1000	34,700 gpm	11,000 gpm (a)	30,700 gpm	0.00 gpm (b)
One AP-1000	17,300 gpm	5,500 gpm (b)	15,400 gpm	0.00 gpm (b)
One ABWR	20,100 gpm	6,000 gpm (b)	16,900 gpm	0.00 gpm (b)

* Additional forced evaporation due to these options is insignificant and not included in water use estimates

(a) Compatible with 50-year drought

(b) Compatible with 50 and 100-year drought

Lake Drawdown for Base Cooling Option During Drought Periods

A lake drawdown analysis was performed including an additional withdrawal amount necessary for wet-cooling for three potential new power generation concepts.

For the **two AP-1000 units**, the water consumption rate supplied by the reactor vendor for evaporative loss with wet cooling was estimated at 34,700 gpm (4,600 acre-ft/month). In the attached spreadsheet (NRC RAI E5.2-1&-2 Att C – Lake Drought Analysis), worksheet "100-YR DUAL AP-1000," calculations show that the additional amount of water demanded by the AP-1000 units would draw the lake level below the minimum 677-foot elevation during a 5-year duration, 100-year recurrence interval drought. The lake level would similarly be drawn below the 677-foot minimum elevation during a 5-year duration, 50-year recurrence interval drought. Accordingly, assuming the lake size and maximum water elevation remain unchanged, the plants would likely have to be powered down or shut down during drought events if the two AP-1000 units were to be used with the wet-cooling method.

For the **single AP-1000 unit** the water consumption rate for evaporative loss from wet cooling was estimated to be 17,300 gpm (2,300 ac-ft/month). In the attached spreadsheet (NRC RAI E5.2-1&-2 Att C – Lake Drought Analysis), worksheet "100-YR SINGLE AP-1000," calculations show that the additional amount of water demanded by the AP-1000 unit would draw the lake level below the minimum 677-foot elevation during a 5-year duration, 100-year recurrence interval drought. The lake level would similarly be drawn below the 677-foot minimum elevation during a 5-year duration, 50-year recurrence interval drought.

For the **one ABWR unit** the water consumption rate for evaporative loss from wet cooling was estimated to be 20,100 gpm (2,700 ac-ft/month). In the attached spreadsheet (NRC RAI E5.2-1&-2 Att C – Lake Drought Analysis), worksheet “100-YR SINGLE ABWR,” calculations show that the additional amount of water demanded by the AP-1000 unit would draw the lake level below the minimum 677-foot elevation during a 5-year duration, 100-year recurrence interval drought. The lake level would similarly be drawn below the 677-foot minimum elevation during a 5-year duration, 50-year recurrence interval drought.

The lake drawdown analysis was not completed for other cooling methods (Dry/Wet surface cooling, Lake cooling with Cooling Towers, and Dry surface cooling). Rather, a volumetric assessment of the lake capacity was used to compare the four cooling options for these three plant types. These assessments are discussed below.

Lake Volume Consumption for Cooling Options During Drought Periods

A determination of the amount of water available for cooling water use during drought periods was conducted and is described below. The amount of water consumed on an average annual basis by the existing CPS plant at 100 percent of its rated capacity is 1,100 acre-feet/month (12.0 MGD or 8,300 gpm). The total amount of water available for consumption for the 100-year drought event is equal to 2,400 acre-feet/month (25.6 MGD or 17,800 gpm). Thus, the amount of water available for use in addition to the amount already used by the existing plant is 1,300 acre-feet/month (13.7 MGD or 9,500 gpm). Lake level drawdown due to a withdrawal of this amount at a constant rate is shown on the “100-YR MAX. ADD’L. LOSS” worksheet of the attached spreadsheet (NRC RAI E5.2-1&-2 Att C – Lake Drought Analysis).

As shown on the attached spreadsheet (NRC RAI E5.2-1&-2 Att C – Lake Drought Analysis), a similar analysis was performed for the 50-year drought event. The amount of water consumed on an annual basis by the existing plant was calculated out to a rate of 1,100 acre-feet/month (12.0 MGD or 8,300 gpm). The total amount of water available for consumption is equal to 3,100 acre-feet/month (33.7 MGD or 23,400 gpm). Thus, the amount of water available for use in addition to the amount already used by the existing plant is 2,000 acre-feet/month (21.7 MGD or 15,100 gpm).

Table 2 below shows the water available for use during the 50-year and 100-year drought event periods.

TABLE 2
Water Available for use During Drought Events

Water Use	50-year Drought Event	100-year Drought Event
Total water available for withdrawal	23,400 gpm	17,800 gpm
Estimated water consumed by existing uprated plant	8,300 gpm	8,300 gpm
Estimated water available for additional use	15,100 gpm	9,500 gpm

Summary

A comparison of Table 1 and Table 2 indicates that the wet cooling options with each of the three plant units requires more water than is available in the cooling lake during both the 50-year and 100-year droughts. The wet/dry cooling option with two AP-1000 plant units requires more water than is available during the 100-year drought, but less water than is available in the cooling lake during the 50-year drought. The wet/dry cooling option with the other two plant units requires less water than is available in the cooling lake during both the 50-year and 100-year droughts. The lake cooling with cooling towers option with each of the three plant units requires more water than is available in the cooling lake during both the 50-year and 100-year droughts . The dry cooling option with each of the three plant units requires near zero consumption and therefore is compatible with both the 50 and 100-year droughts. Values marked with a (b) on Table 1 indicate plant and cooling options that are compatible with cooling water availability during a 50 and 100-year drought.

References

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