Clinton Lake Period of Record Analysis – Spreadsheet Column by Column Explanation

Introduction

The period of record analysis was conducted to address questions regarding potential environmental impact on Clinton Lake due to additional power plant operations. The purpose of this analysis is to develop a model of Clinton Lake that can predict water surface elevations and downstream discharge rates to show the likely effects of new plant operations on lake elevation and the number of days per year that Clinton Lake will discharge at the minimum downstream discharge rate of 5 cfs. The findings of the analysis will be used by others to evaluate environmental impacts associated with the changes in stream flow frequency and lake elevation.

The model uses daily time steps with daily values of precipitation and evaporation combined with average monthly values for runoff and forced evaporation and consumptive loss due to plant operations to produce the desired results. Climactic and precipitation records were obtained for the 24-year period after construction of Clinton Lake, from June 1, 1978 until May 31, 2002. The analysis was conducted using several spreadsheet files. This memorandum describes the source of data and calculation performed in the analysis.

Assumptions and Data Sources

A normal lake elevation level of 690 feet (the crest elevation of the dam spillway) was used as the starting water surface level. The lake stage storage relationship for water surface elevations below 690 feet was obtained from Clinton Power Station (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). The lake stage storage relationship for water surface elevations above 690 feet was obtained from CPS USAR Figure 2.4-12 (Illinois Power 2001). A mass balance approach was used, inflow to the lake was added to the starting volume and outflow was subtracted from the lake on a daily basis throughout the period of record.

Inflow to the lake (in acre-feet) was computed on a daily basis by multiplying the precipitation depth (in feet) and a monthly runoff coefficient by the watershed area (in acres). To determine the monthly watershed runoff coefficients, a rainfall runoff relationship for each month of the year was calculated by determining the percent of total streamflow volume from data taken at the downstream Rowell stream gage divided by total rainfall volume in the watershed. These percentages were then multiplied by the precipitation data for each day and the Clinton Lake watershed area of 296 square miles to establish daily runoff volumes.

Outflow from the lake was assumed to be comprised of downstream discharge; natural lake evaporation; forced evaporation due to existing plant operations; and the cooling water utilized by the new facility. Downstream discharge through the dam was assumed to be a minimum discharge of 5 cubic feet per second (cfs; 298 acre-feet/month or 9.93 acre-feet/day) when lake levels are at or below the 690-foot spill elevation. 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). In this case, the rating curve for the spillway found in CPS USAR Figure 2.4-8 (Illinois Power 2001) was used to determine the discharge corresponding to water surface elevations above 690.0 feet. It was assumed that the minimum discharge gates would remain open and continue to discharge 5 cfs in addition to the discharge flow over the dam spillway.

Precipitation

Precipitation data were obtained for a rain gage station located in Clinton, IL (#111743) for the same period of record as the evaporation data (June 1, 1978 to May 31, 2002). Approximately 3 percent of the records contained data that was either missing or recorded as “trace” amounts of rainfall (265 of the 8917). Trace (T) records (141 records) were changed to 0.005-inches, which represents one-half of the smallest rainfall depth in the precipitation record. Missing (M) records (124 records) were replaced with values from Springfield, IL precipitation data, a rain gage near Clinton, IL.

Natural Lake Evaporation

Daily natural evaporation depths from Clinton Lake were estimated using measured pan evaporation depths from the nearest site to Clinton Lake (Urbana station, ID#118740). Daily pan evaporation records were obtained from the Urbana station for a time period between post dam construction and present. The pan evaporation data covers a 24 year time period between June 1, 1978 and May 31, 2002.

The daily pan evaporation depths were converted to lake evaporation depths for Clinton Lake using a pan-to-lake coefficient found in *Lake Evaporation in Illinois* developed by Roberts and Stall (1967). Any flawed and missing data were replaced with average monthly lake evaporation values.

Forced Evaporation

Existing plant forced evaporation data used in this analysis were 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 2001). Only one plant was constructed at 992 MWe but was uprated in 2002 to a 1138 MWe plant. The water usage of the existing plant with the power uprate was estimated based on the forced evaporation data found in the CPS USAR for the original two plants. 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. In order to account for the power uprate, the forced evaporation rates were then multiplied by 1138/992.

A thermal analysis was conducted to verify the forced evaporation data found in the CPS USAR. 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 confirm 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 climatological 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 climatological 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.

Spreadsheet Descriptions

The detailed calculations were carried out in a series of four spreadsheet files. The first spreadsheet "Source-info-PeriodofRecordAnalysis-DAILY.xls" contains several worksheets of raw data that are referenced within the other three spreadsheet files, which each contain the main set of calculations for different scenarios. The worksheet "ER Table 2.3-2" contains mean runoff and mean rainfall data as well as percentage of rainfall as runoff. The worksheet "Forced Evaporation" contains Forced Evaporation data for the existing plant from the CPS USAR and also from independent calculations. The worksheet "Elev.-Vol. Curve Below Dam" contains the elevation, volume, and area data for points below the dam spillway elevation. Regression equations were fit to the data in order to predict elevation and area at given lake volumes. The worksheet "Elev.-Vol. Curve Above Dam" contains similar data and regression equations applicable for water surface elevations above the dam spillway elevation. The "Spillway Rating Curve" spreadsheet contains discharge and elevation data at points above the dam spillway elevation and a regression equation developed in order to calculate the discharge rate over the spillway at a known water surface elevation.

The three major spreadsheets reference the "Source-info-PeriodofRecordAnalysis-DAILY.xls" file. These three spreadsheets are listed and described below in Table 1.

TABLE 1
Descriptions of the major spreadsheet files

File Name	Description
"Existing_Plant-USAR_PeriodofRecordAnalysis-DAILY.xls"	This spreadsheet models the scenario with the existing uprated CPS 1138 MWe plant for the entire 24-year Period of Record.
"Existing_Plant-USAR-New_plant-Wet_PeriodofRecordAnalysis.xls"	This spreadsheet models the scenario with the existing uprated CPS 1138 MWe plant and a new plant using the wet cooling method for the entire 24-year Period of Record.
"Existing_Plant-USAR-New_plant-Wet/Dry_PeriodofRecordAnalysis.xls"	This spreadsheet models the scenario with the existing uprated CPS 1138 MWe plant and a new plant using the wet/dry cooling method for the entire 24-year Period of Record.

Column by Column Data and Calculation Descriptions

The following descriptions apply to the columns in the first worksheet of the three major calculations spreadsheets:

Columns A through D

Columns A through D contain the day, month, year, and full date for each row.

Column E

Column E contains a sequential number for every day during the 24-year period.

Column F

Column F contains the calculation estimating the Lake elevation for each day. The elevation is calculated using the lake volume (in Column G) to solve a regression equation developed from elevation-volume data presented in CPS ER-OLS Figure 2.4-6 and CPS USAR Figure 2.4-12. The elevation volume relationship is based on the normal lake volume of 74,200 ac-ft at normal lake level of 690.0 NGVD 1929 (Illinois Power 1982). The normal lake level is the level at the crest of the Clinton Dam Ogee Spillway and was used as the starting water surface level. The development of the regression equation is presented under the worksheets entitled “Elev.-Vol. Curve Below Dam” and “Elev.-Vol. Curve Above Dam” of the “Source-info-PeriodofRecordAnalysis-DAILY.xls” spreadsheet.

Column G

Column G contains a running total of Lake volume. The calculation adds the net gain or loss in volume of Clinton Lake for the previous day (Column U) to the volume of Clinton Lake for the previous day (Column G).

Column H

Column H contains a calculation that estimates the Lake area. The area is calculated using the lake volume (in Column G) to solve a regression equation developed from area-volume data presented in CPS ER-OLS Figure 2.4-6 and CPS USAR Figure 2.4-12. The area-volume relationship is based on the normal lake volume of 74,200 ac-ft and normal lake area of 4,895 acres at normal lake level of 690.0 NGVD 1929 (Illinois Power 1982). The normal lake area is the area of the lake when the water surface elevation is at the crest of the Clinton Dam Ogee Spillway and was used as the starting area value. The development of the regression equation is presented under the worksheets entitled “Elev.-Vol. Curve Below Dam” and “Elev.-Vol. Curve Above Dam” of the “Source-info-PeriodofRecordAnalysis-DAILY.xls” spreadsheet.

Column I

Column I contains daily evaporation depths in inches at the Clinton Lake water surface. The data were developed from pan evaporation data from Urbana as described above in the previous “Assumptions and Data Source” section.

Column J

Column J contains a calculation to determine lake evaporation volume loss in acre-feet. The daily lake water loss in inches (Column I) are multiplied by the area of the lake in acres (Column H) and divided by 12 to convert inches into feet.

Column K

Column K contains daily precipitation depths in inches for Clinton, IL. The data were obtained and handled as described above in the previous "Assumptions and Data Source" section.

Column L

Column L contains forced evaporation loss due to the originally planned two 992 MWe plants at a 70% LF as originally proposed. The data were taken directly from CPS USAR Table 2.4-22. (Illinois Power 2001). This factor accounts for the total evaporative loss occurring along the cooling loop that results from dissipation of the heat rejected to the lake from the two plants. 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.

Column M

Column M is used to convert the forced evaporation losses established for the original proposed two 992 MWe plants to the current single 992 MWe plant that was uprated to 1138 MWe. Because there is a linear relationship between power produced and heat rejected, Column L was divided by two to account for the one plant versus the two, then multiplied by 1.15 to account for the uprate from 992 MWe to 1138 MWe. The loading factor was also changed from 70% to 100% by dividing the data by a factor of 0.70. The net effect of this is equivalent to multiplying Column L by a factor of 0.82.

Column N

Column N contains the additional loss due to a new plant. The value represents the maximum amount of withdrawal for the new plant. This loss is considered a direct evaporative loss through the plant cooling process. No significant water volume is returned from the cooling process to the lake. Although the actual operation of the new plant may have some variations, this model represents the loss as a constant value over the 24-year duration.

Column O

Column O contains the amount of minimum downstream discharge (9.93 acre-feet/day which is equivalent to the required minimum lake discharge of 5 cfs) (Illinois Power 2001).

Column P

Column P contains the model calibration factor which is intended to account for error due to several assumptions behind the analysis. The intent of the model calibration factor is to create an overall water balance on a long-term basis. A comparison to the downstream Rowell stream gage was used as the basis for developing the model calibration factor. The calibration process is described below in the "Calibration" section. A positive number indicates a water loss from the system. A negative number indicates water added to the system.

Column Q

Column Q contains a calculation to compute total loss by adding net lake evaporation loss (Column J), uprated plant forced evaporation loss (Column M), additional loss for new plant

(Column N), minimum downstream discharge (Column O), and the calibration factor (Column P).

Column R

Column R contains runoff depths in inches. This column references a look-up table that uses the percent of rainfall as runoff and multiplies the appropriate monthly value times the daily precipitation (Column K).

Column S

Column S contains inflow due to runoff. This is calculated by dividing Column S by 12 to convert inches to feet and multiplying by the watershed area (189440 acres) to get acre feet of runoff.

Column T

Column T contains no data or calculations.

Column U

Column U calculates the net gain or loss in volume of water for the month by subtracting total loss (Column Q) from inflow (Column S).

Column V

Column V contains no data or calculations.

Columns W through AJ

These columns are used to tabulate the monthly average number of days that the lake is at minimum discharge.

Other Worksheets

The worksheets “Low_Flow_Summary”, “WSE_Results_Summary”, “Volume_Results_Summary”, and “Surface_Area_Summary” calculate and display monthly average results of the various items. Each spreadsheet file also contains a chart depicting the predicted water surface elevations throughout the period of record for each scenario. The “LinkstoSourceDataRegEquations” worksheet serves to simplify the references to the regression equations.

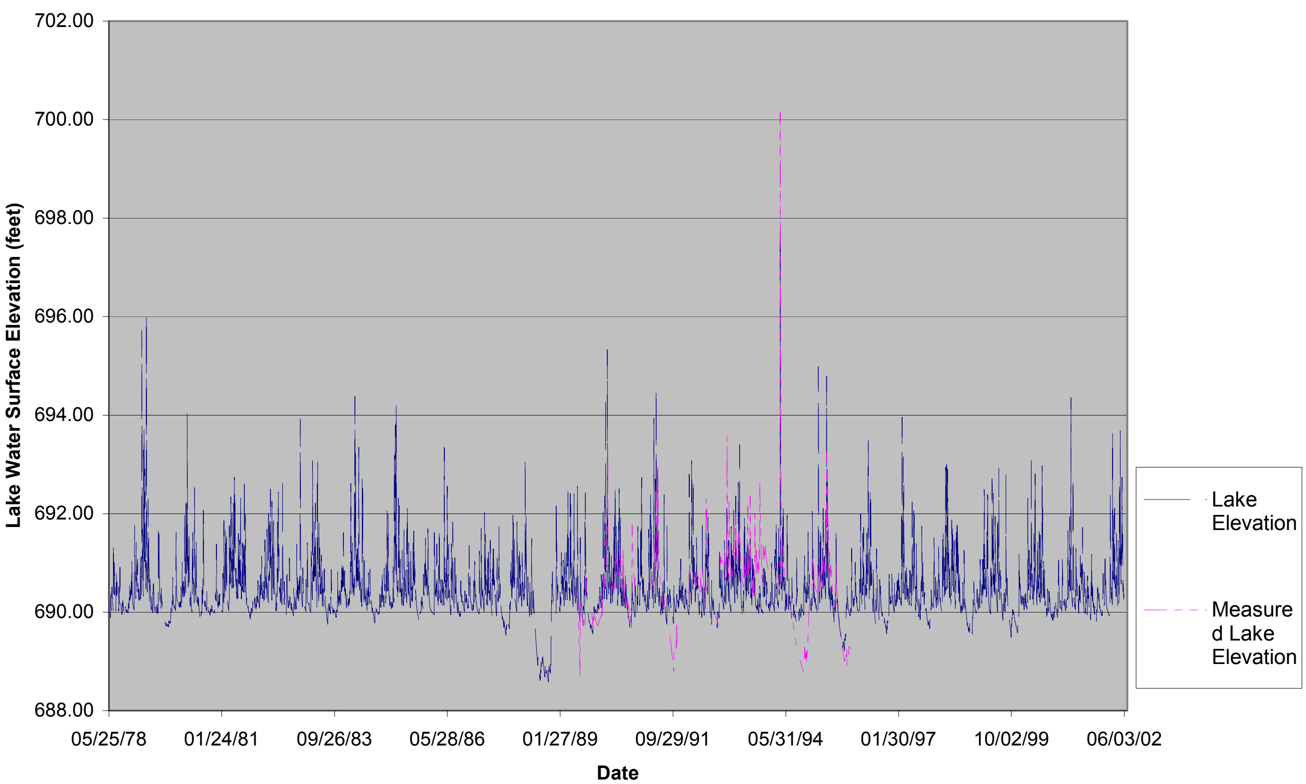
Calibration

A separate spreadsheet file was created to calibrate the model (not included herein). The total volume that passes through the downstream Rowell stream gage station is used to calibrate the model by determining the calibration factor that causes the calculated total volume through Clinton Lake to match the total measured volume through the Rowell gage for the 24-year period (with an adjustment for watershed area). A calibration factor of –5.29E-05 was determined to cause these volumes to match. The calibration factor is intended to correct for the lake evaporation that is embedded in the rainfall-runoff relationship, seepage and other groundwater interaction, the fact that rainfall is not actually evenly distributed over the watershed as assumed, and the variable power output of the existing CPS.

The rainfall runoff relationship used to develop runoff flows already accounts for lake evaporation because actual flows measured at the Rowell gage during 1978 through 1987 include the existing Clinton Lake evaporative losses, before plant operations began. Adding daily evaporation losses separately was necessary to more accurately simulate measured daily lake water surface elevation fluctuations. This was done to determine an estimate of the number of days Clinton Lake is at minimum discharge. Any inaccuracies caused by this approach are corrected for with the calibration factor.

Figure 1 shows a graph of calibrated modeled with predicted water surface elevation for the 24-year period as well as measured water surface elevation for periods available from 1989 through 1995. The comparison to measured water surface elevation serves to validate the calibration of the model.

FIGURE 1
Calibrated Modeled Predicted Water Surface Elevation and Measured Water Surface Elevation



Model Limitations

The model development methodology causes limitations on how well and accurately the model can simulate runoff values and the associated lake levels and flow rates. The model rainfall runoff relationship correlates daily precipitation and monthly average runoff totals with observed total flow at the downstream Rowell stream gage to determine daily flow rates. No differentiation is made between precipitation in the form or snow or in the form of rain. Consequently, runoff during snow and rain events are modeled the same. The modeling approach assumes that precipitation will run off immediately on the day it occurs, neglecting natural runoff flowpaths.

The combination of these factors creates a higher confidence in monthly average values than from the value on any given particular day. The assumption that runoff occurs immediately when precipitation occurs may also tend to overestimate the number of low flow days under circumstances when the immediate flow increase causes volume to drain out of the lake more quickly than may actually occur if the runoff would naturally flow into the lake over the period of several days. Consequently, the results should be viewed as trends and as theoretical values instead of as the actual number of days a given condition will occur.

Results and Discussion

A 24-year Period of Record model was developed to determine any change in the duration of stream minimum discharges with addition of the ESP facility. The Period of Record model was run for the 24 year period from June 1, 1978 to April 31, 2002 for three scenarios:

- with the current 1138 MWe CPS plant operating at 100 percent power
- with the current CPS and new ESP with wet/dry cooling
- with the current CPS and new ESP with wet cooling

Plant operating conditions for the three scenarios were imposed over the total 24-year period of record. The results of the model simulation are presented in Table 2. The yearly average number of days at low flow for the CPS plant only, is estimated to be 76 days per year. With a new ESP facility and wet/dry cooling the average number of days at low flow increases by 35 days per year. With a new ESP and wet cooling the average number of days at low flow increases by 114 days per year. The monthly distribution of days at low flow range from 0 days in April to 27 days in October for wet/dry cooling and 2 days in April to 31 days in October for wet cooling.

TABLE 2
Monthly Average Number of Days at Low Flow Discharge (5 cfs) from Clinton Lake During 24-year Period of Record

Month	CPS Plant	CPS with ESP and Wet/Dry Cooling	CPS with ESP and Wet Cooling
January	2	6	21
February	2	4	12
March	0	1	3
April	0	0	2
May	1	2	5
June	3	4	9
July	7	10	15
August	8	11	18
September	18	22	27
October	23	27	31
November	9	17	27
December	2	6	19
Annual Average	76	111	190

Note: Values are established based on a 24-year period of local hydrologic record from June of 1978 to April of 2002. The Period of Record model does not simulate actual operating conditions but rather continuous operation of the designated plants over the total period of record. This allows determination of relative differences or expected change in the duration of low flow discharge.

The same Period of Record was used to determine changes in lake levels with addition of the ESP facility. The Period of Record model was run for the 24 year period from June 1, 1978 to April 31, 2002 for the same three scenarios:

- with the current 1138 MWe CPS plant operating at 100 percent power
- with the current CPS and new ESP with wet/dry cooling
- with the current CPS and new ESP with wet cooling

The results of the model simulation are presented in Table 3. The average water surface elevation of Clinton Lake with the CPS plant only, is estimated to be 690.4-feet. With a new ESP facility and wet/dry cooling the average annual lake level is reduced by 0.2-feet to 690.2-feet. With a new ESP and wet cooling the average lake level is reduced by 0.7-feet to 689.7-feet. The monthly distribution of reduced lake levels range from 0.0-feet in March, April, May and June to 0.4-feet in October and November for the Wet/dry cooling and from 0.1-feet in April and May to 1.9-feet in November for wet cooling.

TABLE 3
Monthly Average Water Surface Elevation of Clinton Lake During 24-year Period of Record

Month	CPS Plant (Elev. in feet)	CPS with ESP and Wet/Dry Cooling (Elev. in feet)	CPS with ESP and Wet/Dry Cooling (Change in Elev. in feet)	CPS with ESP and Wet Cooling (Elev. in feet)	CPS with ESP and Wet Cooling (Change in Elev. in feet)
January	690.3	690.2	-0.1	689.4	-0.9
February	690.5	690.5	-0.1	690.0	-0.5
March	690.9	690.8	0.0	690.7	-0.2
April	690.8	690.7	0.0	690.7	-0.1
May	690.7	690.7	0.0	690.6	-0.1
June	690.5	690.5	0.0	690.3	-0.2
July	690.3	690.2	-0.1	690.0	-0.3
August	690.2	690.1	-0.1	689.8	-0.5
September	689.9	689.7	-0.2	689.1	-0.8
October	689.8	689.4	-0.4	688.2	-1.6
November	690.1	689.8	-0.4	688.3	-1.9
December	690.4	690.3	-0.2	689.1	-1.3
Annual Average	690.4	690.2	-0.1	689.7	-0.7

Note: Values are established based on a 24-year period of local hydrologic record from June of 1978 to April of 2002. The Period of Record model does not simulate actual operating conditions but rather continuous operation of the designated plants over the total period of record. This allows determination of relative differences or expected change in lake levels.

References

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