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EDWARD M. BUCHAK

Exhibit D

Probabilistic Hydrothermal Modeling Study of Clinton Lake

Prepared by

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February 1989

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1.0 Executive Summary

Clinton Lake has been analyzed and modeled for 1988 realtime plant operational conditions and meteorological conditions. The model has been successfully verified for these conditions and used to determine the longitudinal and vertical distribution of temperatures throughout the lake for two cases of full load operations at different lake operating levels.

The model results have been combined with a statistical analysis of 34 years of meteorological data to determine the temperatures that would occur at certain specified annual frequencies for different daily durations. These results can be used to evaluate the effects of different thermal limitations relative to plant operations and to perform comparative fisheries thermal tolerance analyses.

2.0 Introduction

Hydrothermal modeling studies were conducted on Clinton Lake to predict temperatures throughout the lake at varying meteorological and plant operating conditions. These temperature predictions are used to establish thermal limits on the lake that will ensure the power station can operate as designed without adverse impact on biological conditions in the lake.

This study consisted of temperature predictions by the GLVHT model, verification of the model with 1988 observed temperatures, and a statistical analysis of 34 years of meteorological data to determine the probability of severe meteorological conditions.

Specifically, the hydrothermal modeling studies of Clinton Lake and Clinton Power Station operations are designed to: (a) verify the generalized, longitudinal-vertical and hydrodynamics and transport (GLVHT) model for the summer of 1988 realtime data and operations; (b) perform a statistical analysis

of meteorological data for 34 years of record extending from 1955 through 1988; and, (c) to combine the results of these two analyses for case studies of plant operations over the years. The GLVHT modeling for 1988 is discussed in report section 3.0, the statistical analysis is discussed in report section 4.0, and the combined case analyses are discussed in section 5.0

Previous hydrothermal analyses of Clinton Lake were carried out using the LARM (laterally averaged reservoir model) which is a predecessor to the GLVHT model. Different LARM simulations, designated by IPC as LARM 1, LARM 2 and LARM 3, were carried out over the years as input data improved on expected operating lake elevations, powerplant heat rejection rates, and powerplant condenser cooling water flow rates. Results of the previous LARM simulations are presented in Appendix A of this report. The significant differences between the present GLVHT modeling and the previous LARM modeling are discussed in Section 3.0 of this report.

3.0 Description and Verification of the Model

The GLVHT model design, development and examples of past applications are presented in Buchak and Edinger (1984). It is a continuously maintained model that is supported by routines to perform different types of analyses of model output.

The GLVHT model is based on the longitudinal and vertical, laterally averaged equations of momentum, continuity and constituent transport. The formulation includes the vertically varying longitudinal momentum balance, the vertical momentum in the form of the hydrostatic approximation, local continuity, the free-water surface condition based on vertically integrated continuity, and longitudinal and vertical transport of any number of constituents. Constituents that determine density such as temperature and salinity are related to momentum

through an equation of state. The vertically varying longitudinal momentum includes local acceleration of horizontal velocity, horizontal and vertical advective momentum transfer, the horizontal pressure gradient, and horizontal and vertical shear stress. Included in the latter are the surface wind stress and the bottom stress due to friction. The horizontal pressure gradient includes the barotropic surface slope and the baroclinic vertical integral of the horizontal density gradient which is the dominant term of density induced convective circulation.

The time-varying solution technique of the model is based on an implicit scheme that results from the simultaneous solution of the horizontal momentum equation and the free-water surface equation of vertically integrated continuity. This technique results in the surface long wave equation that is solved on each time step to give the water surface profiles, from which the vertical pressure distribution can be determined. The horizontal momentum is then computed, followed by internal continuity and then constituent transport. Upwind differencing is used for the advective processes in the momentum and constituent transport balances. Vertical turbulent transfer of momentum and constituents is determined from the vertical shear of horizontal velocity and a density gradient dependent Richardson number function.

Structural differences between the previous LARM model and the GLVHT model are given in Table 4-1 of Buchak and Edinger (1984). Improvements over the previous LARM simulations for Clinton Lake include:

a. The use of realtime operating data as input.

b. The use of a term by term heat budget for evaluating surface heat exchange from hourly meteorological data.

c. The ability to compute excess temperatures throughout the lake due to powerplant operations.

d. The inclusion of lake elevation changes due to natural and forced evaporation.

e. The inclusion of separate flows and heat rejection rates for the condenser cooling water pumping and the service water flows.

3.1 Model Setup and Data Sources

The GLVHT model was set up for the same lake geometry as used in the previous LARM simulations. The longitudinal lake segmentation and numbering is shown in Figure 3-1. The longitudinal segments are each 1518.5 m long. Also shown in Figure 3-1 is the location of the continuous recording Data Sondes used for model verification.

The geometry required in the model is the laterally averaged widths of the lake over the vertical in each longitudinal segment. These widths are shown in Table 3-1. The vertical thickness of the layers is 1.1 m with variable surface layer thickness. The relationship between lake elevation and model layers is given in Table 3-1.

The time series input data required to run the model over realtime periods are the meteorological data of cloud cover, air temperature, dewpoint temperature, windspeed and wind direction; the plant operating data of heat rejection rates, condenser cooling water pumping and service water pumping; and, the hydrological data of tributary surface inflows and temperatures and groundwater inflows and temperature.

The 1988 meteorological data were obtained hourly from the National Climatic Data Center for Springfield, Illinois. The 1988 plant operating data for the verification simulations were provided as daily average values of power factors, condenser pumping rates and service water pumping rates by IPC personnel. The heat rejection rate was established as 6.713×10^9 Btu/Hr at 100% power level and assumed to be proportional to the power level. Operational input data for the

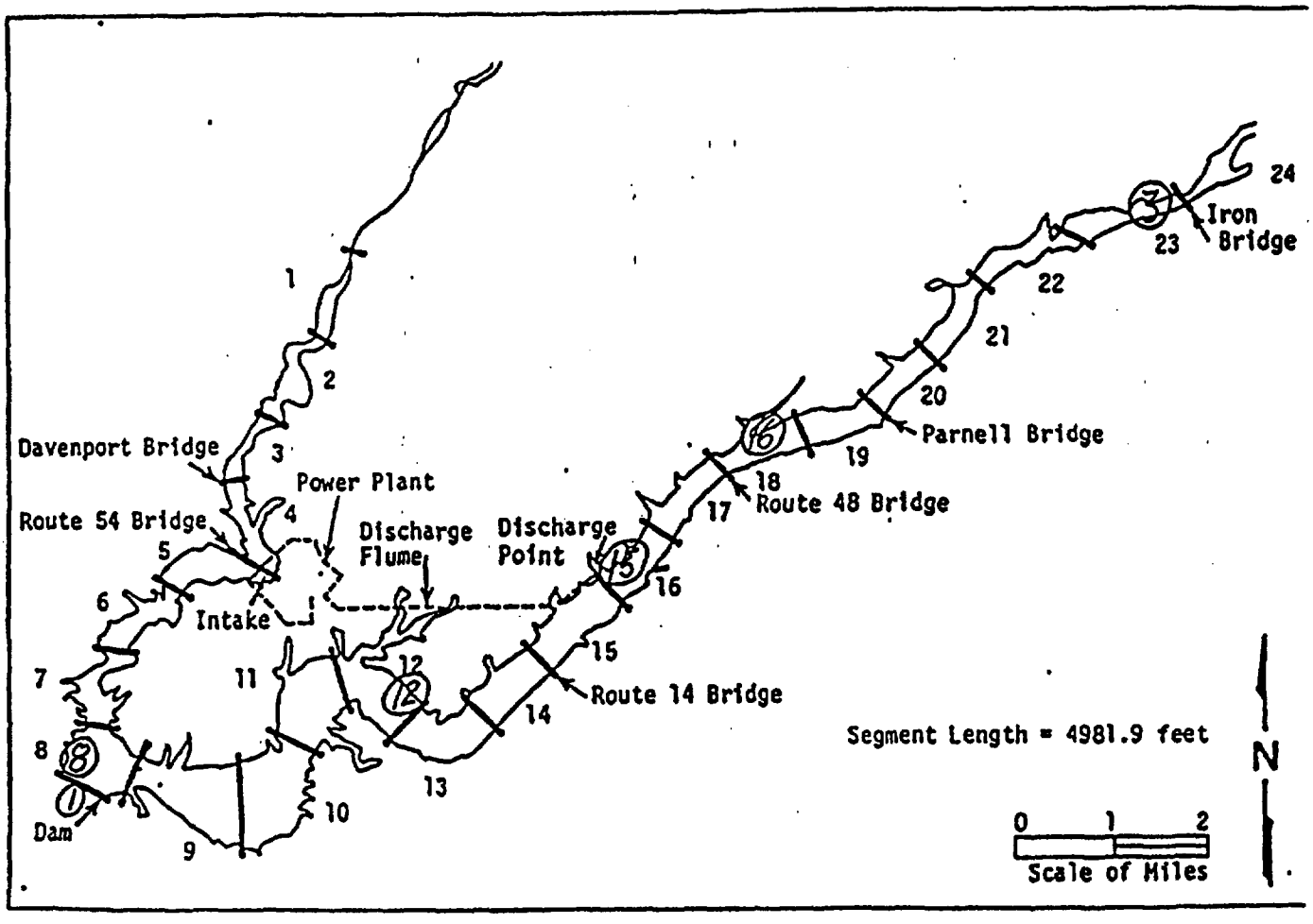

Figure 3-1. Map of Clinton Lake segments with Data Sonde site locations circled (six locations -- Site 3 in segment 23, Site 16 in segment 18, Site 15 in segment 16, Site 12 in segment 12, Site 8 in segment 8, Site 1 downstream of segment 8).

Table 3-1. GLVHT finite difference grid with Clinton Lake widths in meters shown for each segment and layer. Segment locations are shown in Figure 3-1. Elevations at the top of each layer are also shown. Normal pool elevation is 210.31 m (690 ft), with the water surface in layer 5.

	Segment Number																
Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	335.	377.	487.	580.	652.	709.	821.	872.	1074.	1075.	1018.	919.	789.	697.	661.	638.
3	0.	303.	353.	450.	567.	641.	699.	810.	957.	1051.	1043.	977.	883.	761.	672.	628.	591.
4	0.	256.	319.	428.	550.	627.	686.	797.	941.	1028.	1005.	928.	836.	726.	644.	592.	540.
5	0.	151.	234.	367.	511.	597.	660.	773.	913.	985.	932.	828.	733.	640.	564.	490.	401.
6	0.	151.	234.	367.	511.	597.	660.	773.	913.	985.	932.	828.	733.	640.	564.	490.	401.
7	0.	54.	138.	278.	437.	542.	622.	740.	873.	923.	838.	701.	585.	480.	396.	308.	200.
8	0.	24.	81.	188.	331.	457.	574.	708.	826.	854.	747.	584.	449.	338.	256.	184.	100.
9	0.	9.	36.	101.	212.	347.	492.	633.	735.	747.	625.	441.	295.	192.	128.	85.	41.
10	0.	3.	15.	54.	135.	253.	389.	516.	603.	609.	489.	305.	164.	82.	40.	23.	11.
11	0.	0.	8.	31.	85.	176.	298.	416.	486.	475.	358.	192.	78.	27.	0.	0.	0.
12	0.	0.	3.	14.	42.	104.	210.	321.	372.	336.	226.	102.	29.	6.	0.	0.	0.
13	0.	0.	0.	0.	15.	45.	110.	184.	212.	170.	96.	36.	7.	0.	0.	0.	0.
14	0.	0.	0.	0.	3.	11.	31.	59.	69.	47.	20.	5.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	3.	7.	9.	6.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

	Segment Number						
Layer	18	19	20	21	22	23	24
1	0.	0.	0.	0.	0.	0.	0.
2	621.	606.	558.	470.	397.	372.	0.
3	565.	548.	500.	413.	341.	316.	0.
4	504.	485.	438.	353.	282.	257.	0.
5	342.	319.	279.	206.	145.	124.	0.
6	342.	319.	279.	206.	145.	124.	0.
7	129.	109.	89.	53.	23.	12.	0.
8	45.	31.	25.	13.	4.	0.	0.
9	13.	6.	5.	3.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.

Layer	Thickness m	Elevation m	Area Millions of m2	Cumulative Volume Millions of m3
2	1.1	213.36	22.480	157.371
3	1.1	212.26	21.366	132.643
4	1.1	211.16	20.080	109.140
5	1.1	210.06	16.998	87.052
6	1.1	208.96	16.998	68.354
7	1.1	207.86	12.954	49.656
8	1.1	206.76	10.357	35.407
9	1.1	205.66	7.814	24.014
10	1.1	204.56	5.605	15.419
11	1.1	203.46	3.993	9.254
12	1.1	202.36	2.681	4.861
13	1.1	201.26	1.328	1.912
14	1.1	200.16	.372	.451
15	1.1	199.06	.038	.042

Map References	Segments	Layers
Davenport Bridge	3/4	
Route 54 Bridge	4/5	
Intake	5	7, 8, 9
Dam overflow	8	5
Dam underflow	8	10
Route 14 Bridge	14/15	
Discharge flume	16	
Route 48 Bridge	17/18	
Parnell Bridge	19/20	
Iron Bridge	23/24	

case simulations described in section 5.0 were provided by IPC personnel.

Hydrological surface inflow data were not available for 1988. However, 1988 was an abnormally dry summer that would have produced close to zero inflows. The validity of this assumption is demonstrated by the reproduction of falling lake elevations in the modeling over the summer. Groundwater inflow data for the lake were not available. The lake outflow to lower Salt Creek was assumed constant at 0.14 m^3/s (5 cfs).

3.2 Model Verification for 1988

The summer of 1988 represented the first period of continuous plant operation for which realtime operating data and meteorological data were available for modeling. It also represented a period for which there was complete verification data available for plant intake temperatures, flume discharge temperatures, mixing zone temperatures and at continuous recording Data Sonde stations throughout the lake.

Model verification consists of comparing model output to daily lake elevations and the average daily temperatures at each of the Data Sonde temperature recorders whose locations are shown in Figure 3-1.

Figure 3-2 shows the observed and computed lake levels for June through August 1988 due to natural and forced evaporation as well as downstream releases from the lake. It indicates that the model slightly overestimates lake drawdown by a few centimeters probably due to not including surface and groundwater inflows to the lake. However, the comparison is quite good.

Figure 3-3 shows a comparison of daily computed and observed intake temperatures based on the daily plant operating records. The comparison shows a slight tendency for the model to overestimate intake temperatures during June. This may be attributable to lack of surface and groundwater inflow data.

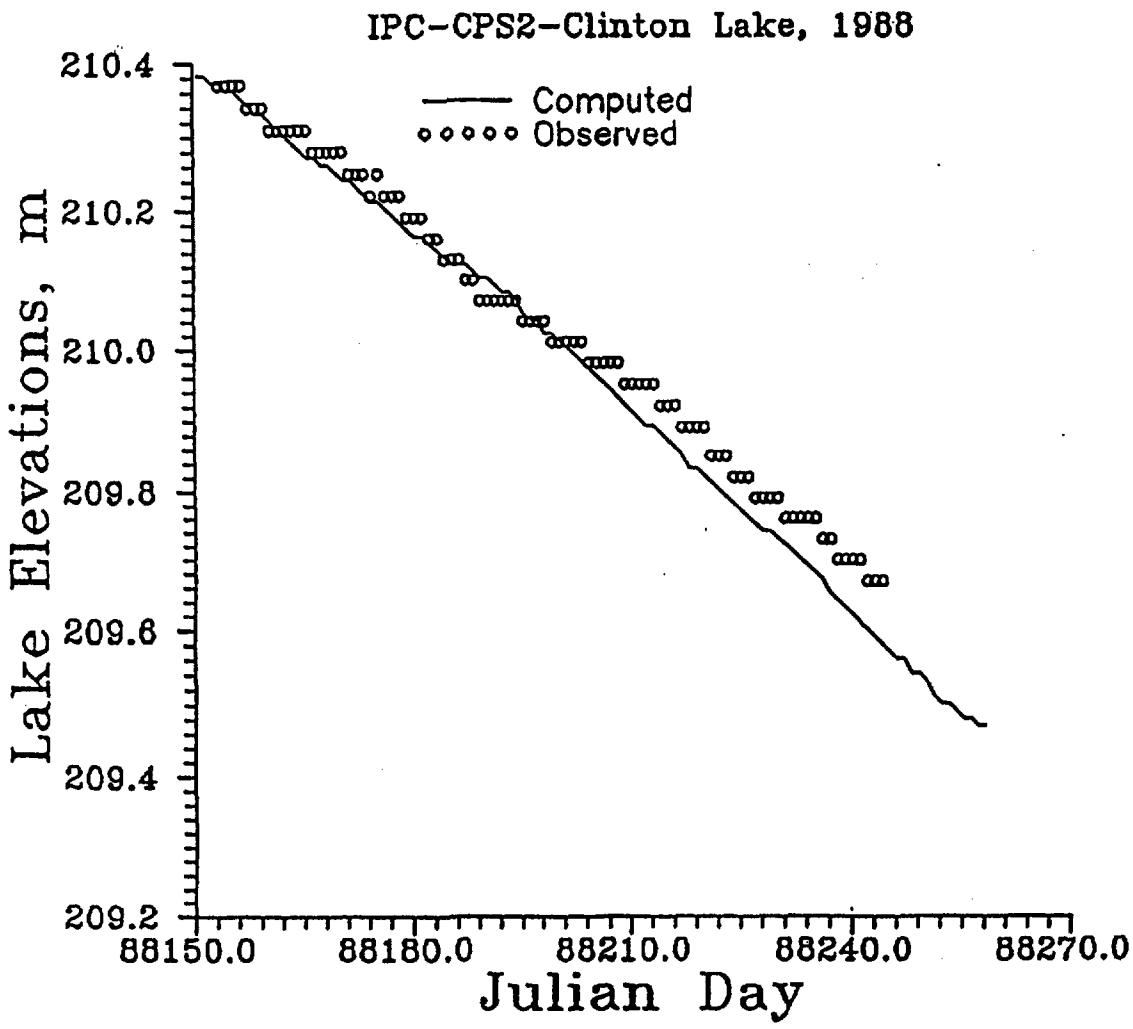

Figure 3-2. Computed and observed lake elevations for 1988 operating conditions.

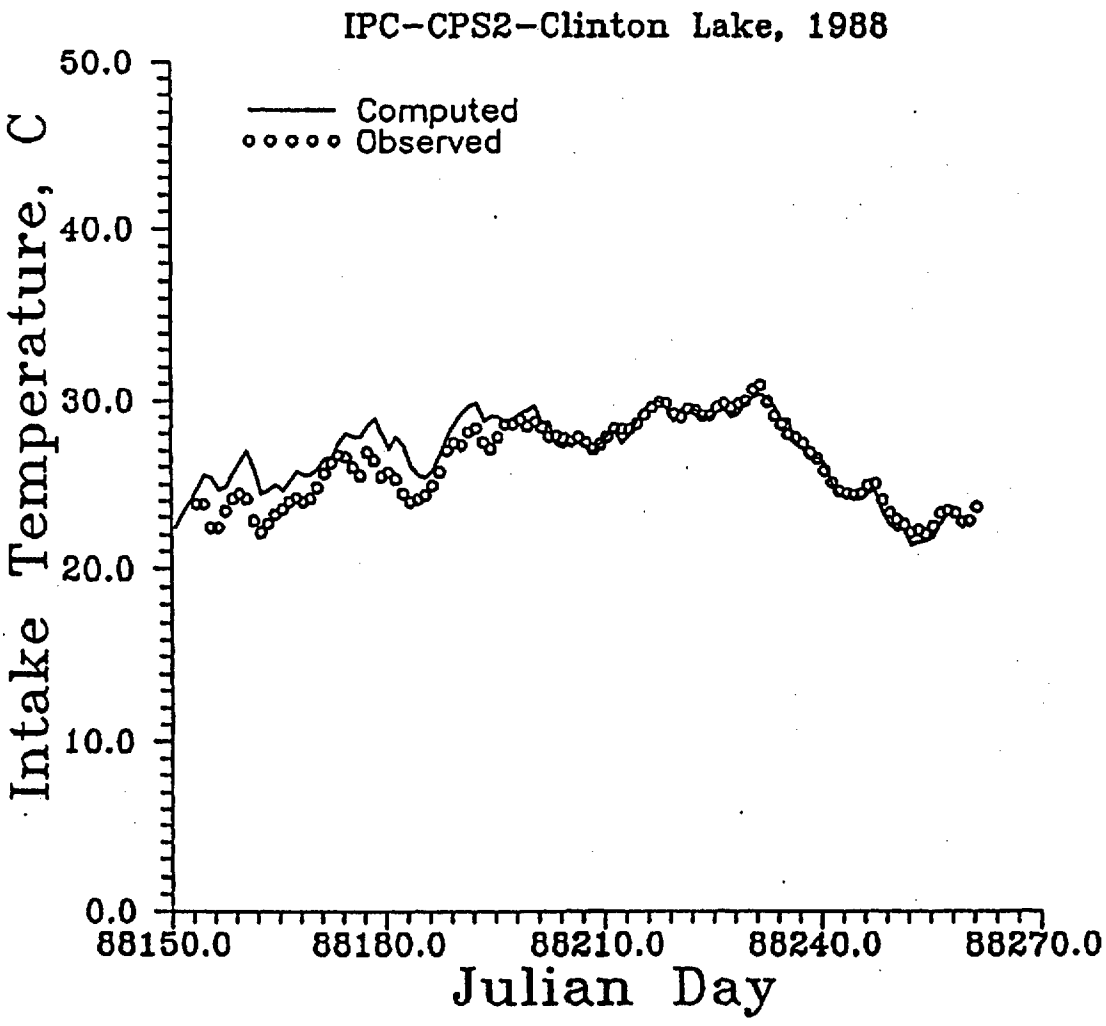

Figure 3-3. Computed and observed intake temperatures for 1988 operating conditions.

Figure 3-4(a) shows a comparison of the daily computed and observed flume temperatures at the second drop structure based on the daily plant operating records. The comparison shows a tendency to overestimate flume temperatures in the early part of the records because of the previously mentioned overestimate of intake temperatures. Figure 3-4(b) shows a comparison of the daily computed and observed difference between flume and intake temperatures, and indicates that the IPC heat loads and pumping rates were accurate.

Figure 3-5(a) shows a comparison of the computed and observed mixing zone temperatures from the Data Sondes placed around the surface of model segment 16. The computed values are taken from the surface cell of model segment 16. The comparison shows that the model at this segment slightly underestimates the spatially averaged temperatures computed from the Data Sondes. Figure 3-5(b) shows a comparison for the difference between mixing zone temperatures and intake temperatures.

Figure 3-6 shows a comparison of the computed and observed outlet temperatures from the lake downstream into Salt Creek. The model overestimates these temperatures as well as the daily temperature amplitudes because of the lack of groundwater inflow data into this deeper portion of the lake.

Figure 3-7 shows a comparison of the computed and observed temperatures at Data Sonde site 3 in the shallow upper end of the Salt Creek arm. These temperatures are highly variable from day to day because of the shallow nature of the arm. However, the comparisons are quite good.

Figure 3-8 shows a comparison of the computed and observed temperatures at Data Sonde site 8 located near the surface of model segment 8 at the dam. The comparisons are quite good.

Figure 3-9 shows a comparison of the computed and observed temperatures at Data Sonde site 12 located on the Salt Creek arm near the surface about half way

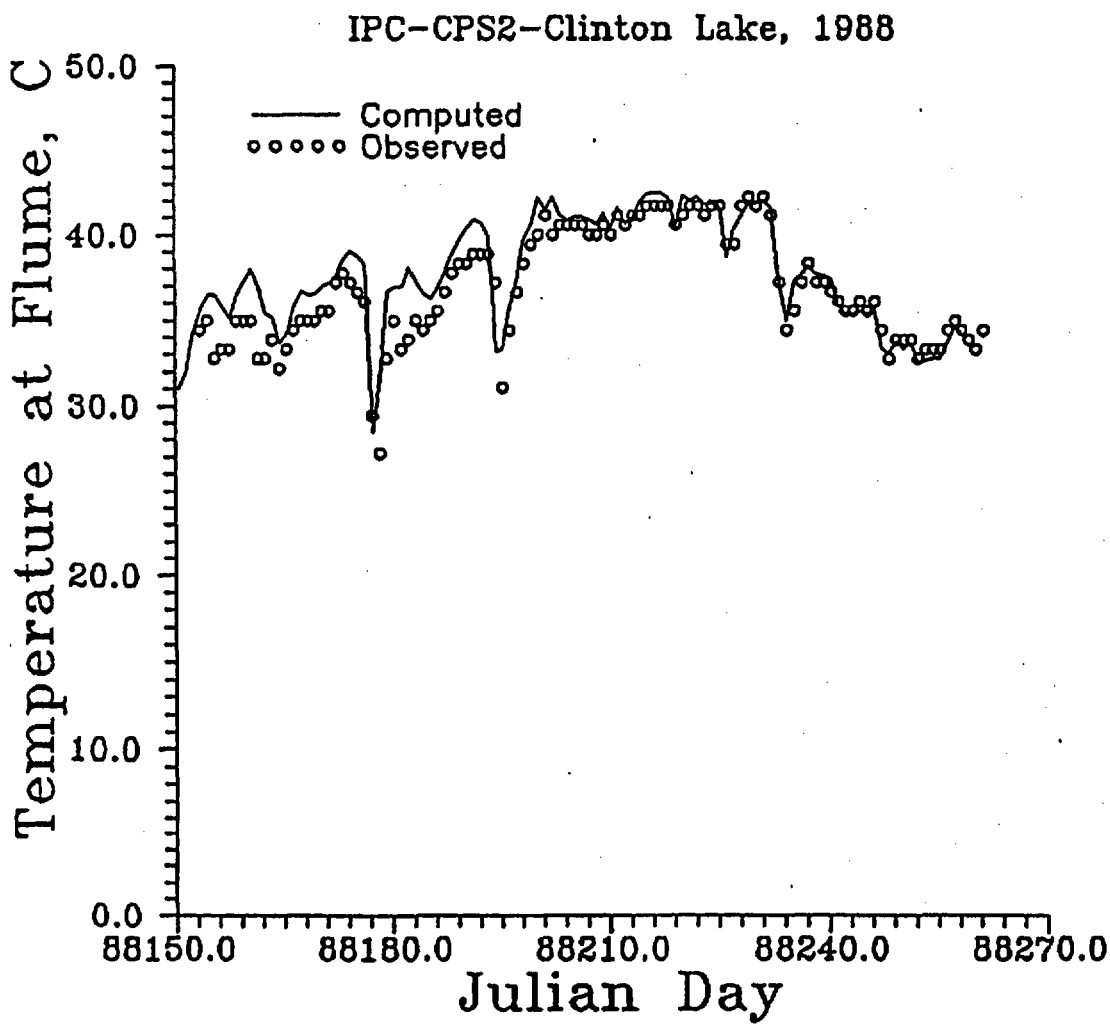

Figure 3-4(a). Computed and observed flume temperatures for 1988 operating conditions.

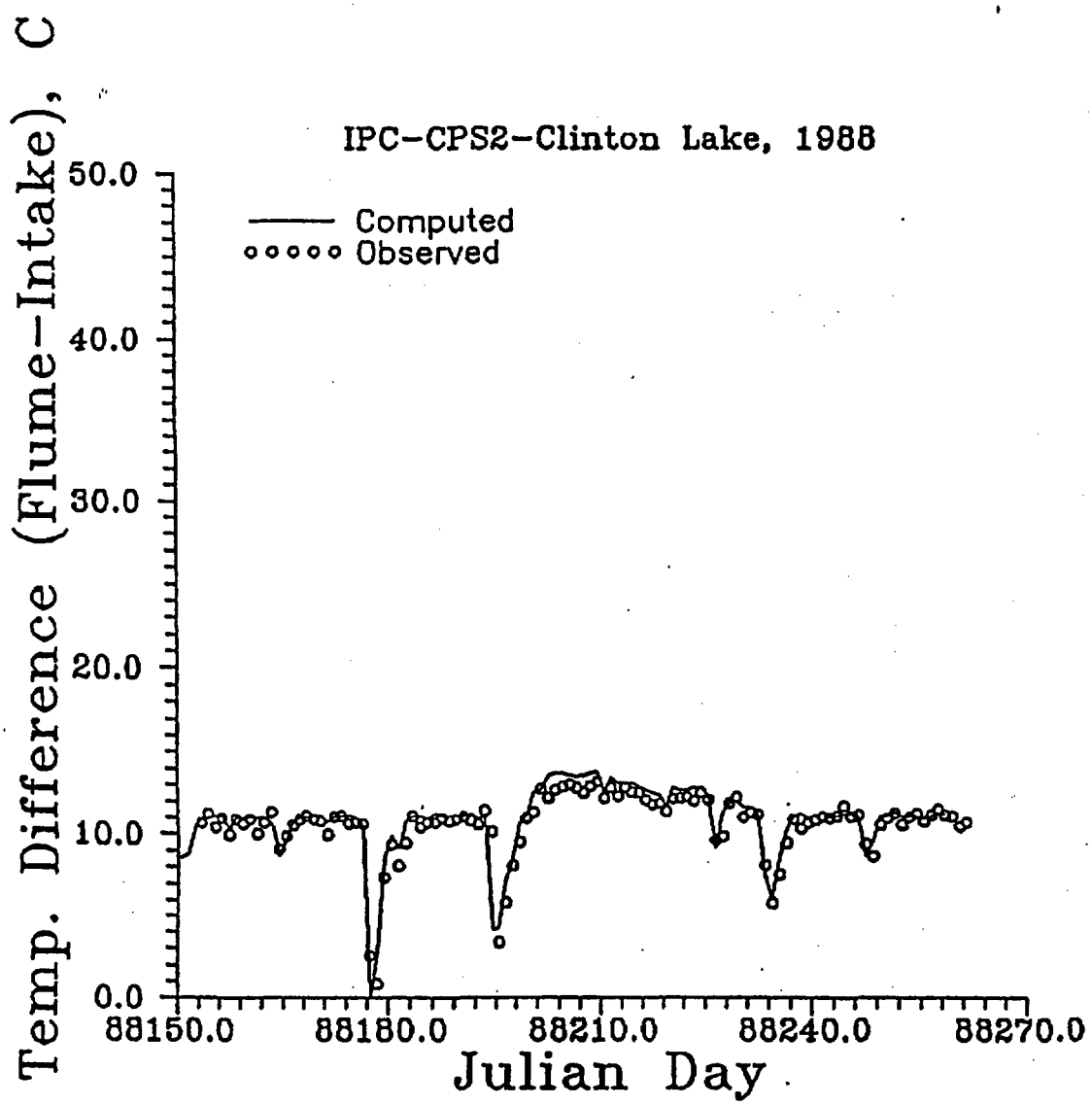

Figure 3-4(b). Computed and observed flume temperature rises for 1988 operating conditions.

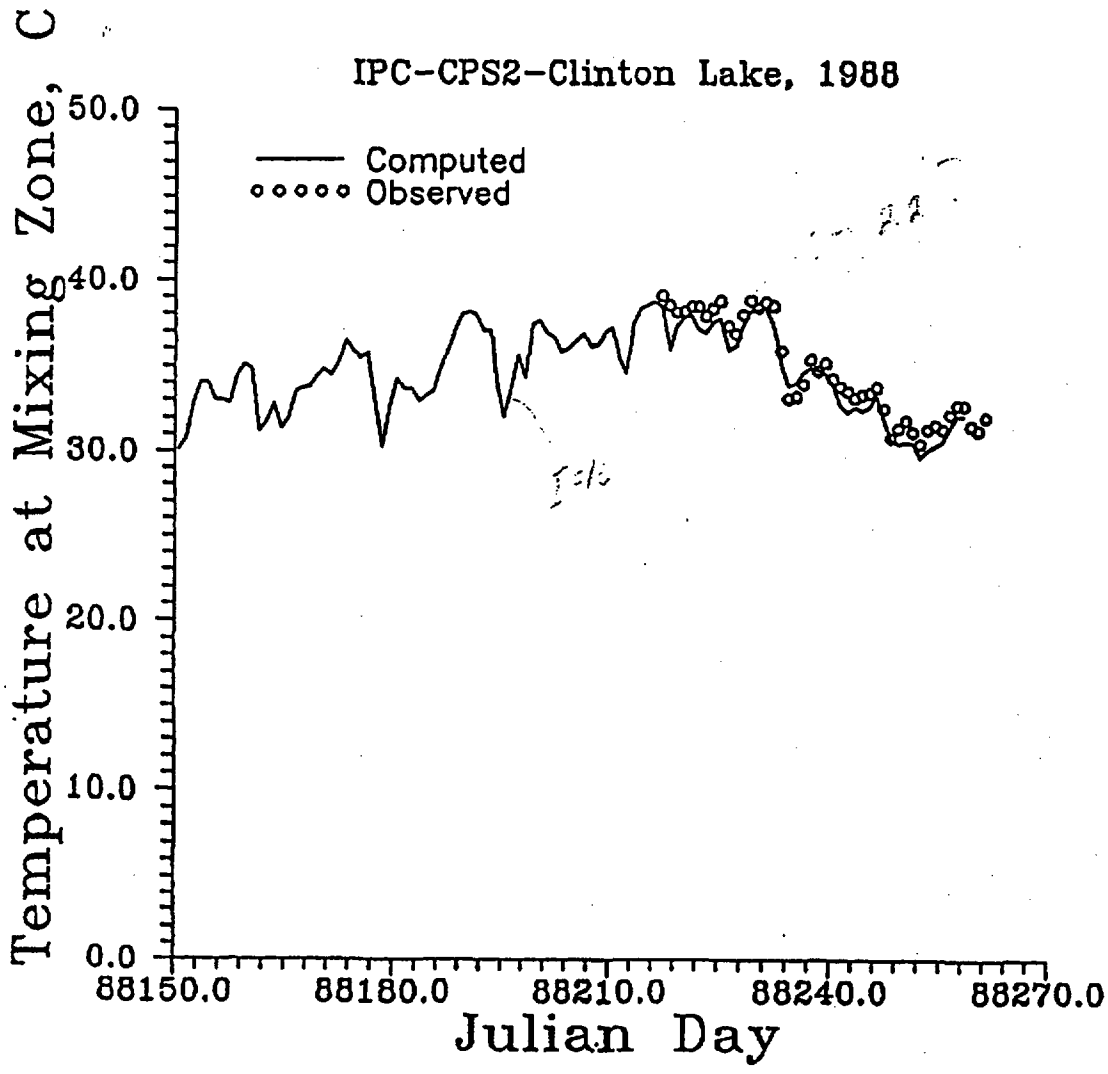

Figure 3-5(a). Computed and observed mixing zone temperatures for 1988 operating conditions.

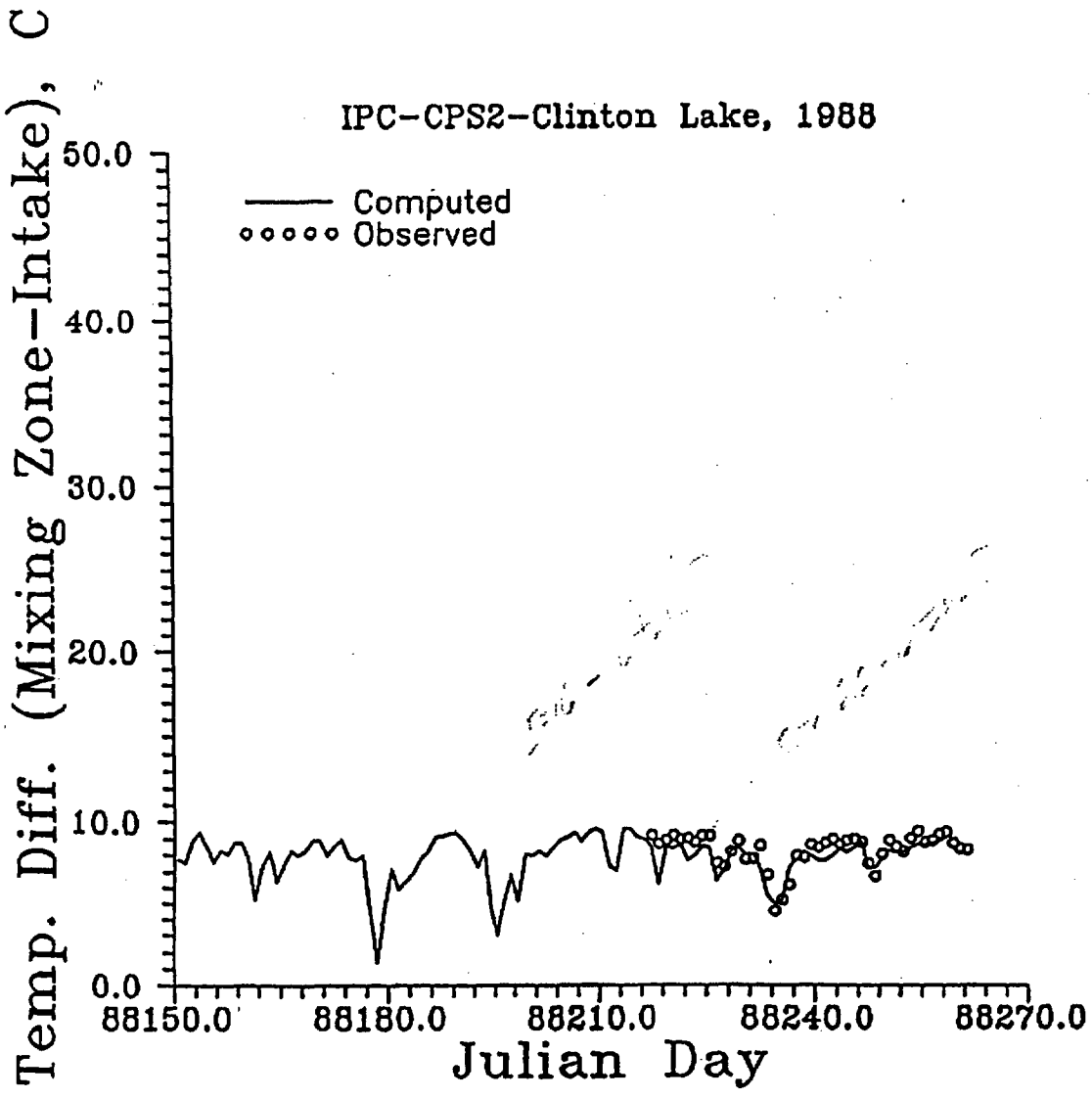

Figure 3-5(b). Computed and observed temperature rises in the mixing zone for 1988 operating conditions.

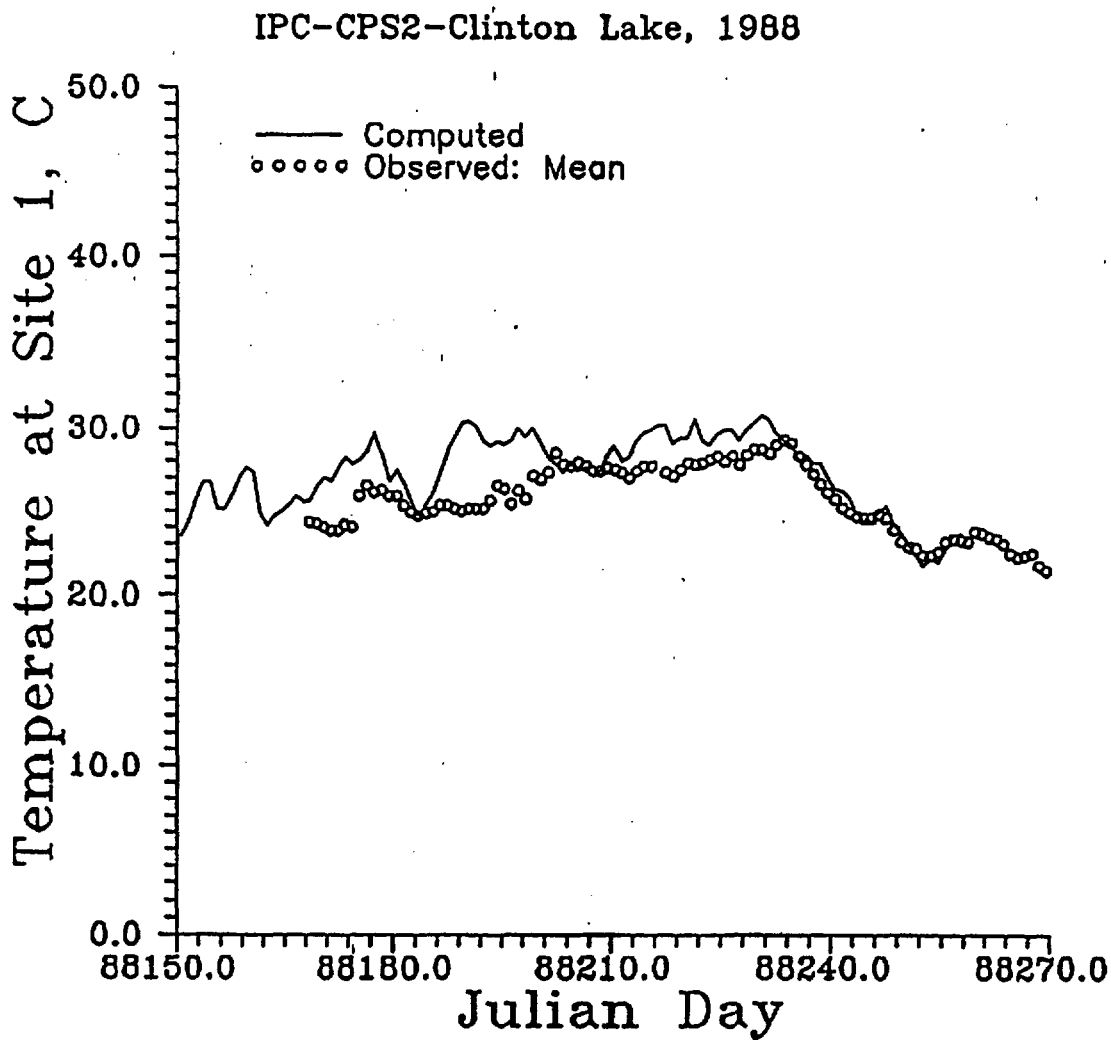

Figure 3-6. Computed and observed Data Sonde Site 1 temperatures for 1988 operating conditions.

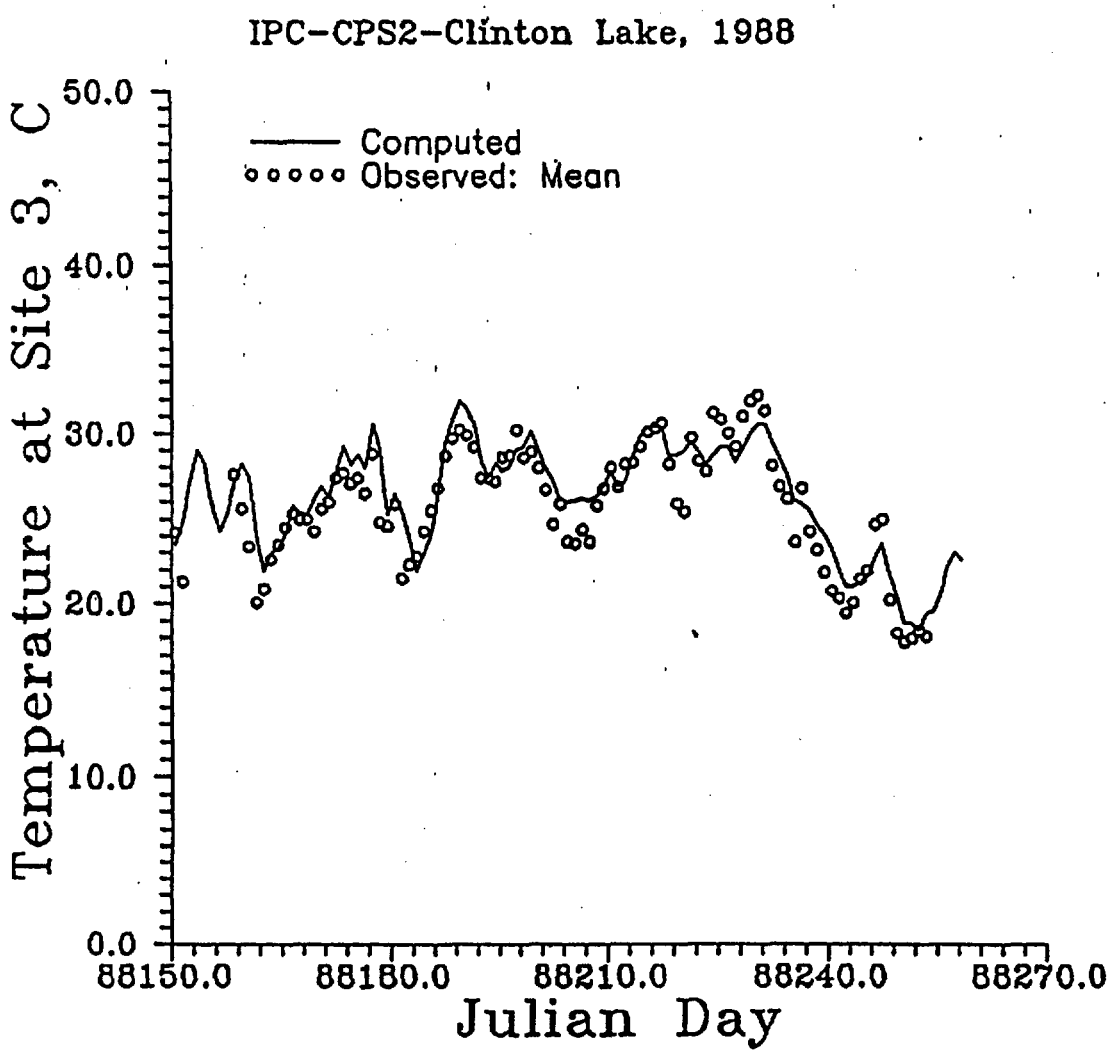

Figure 3-7. Computed and observed Data Sonde Site 3 temperatures for 1988 operating conditions.

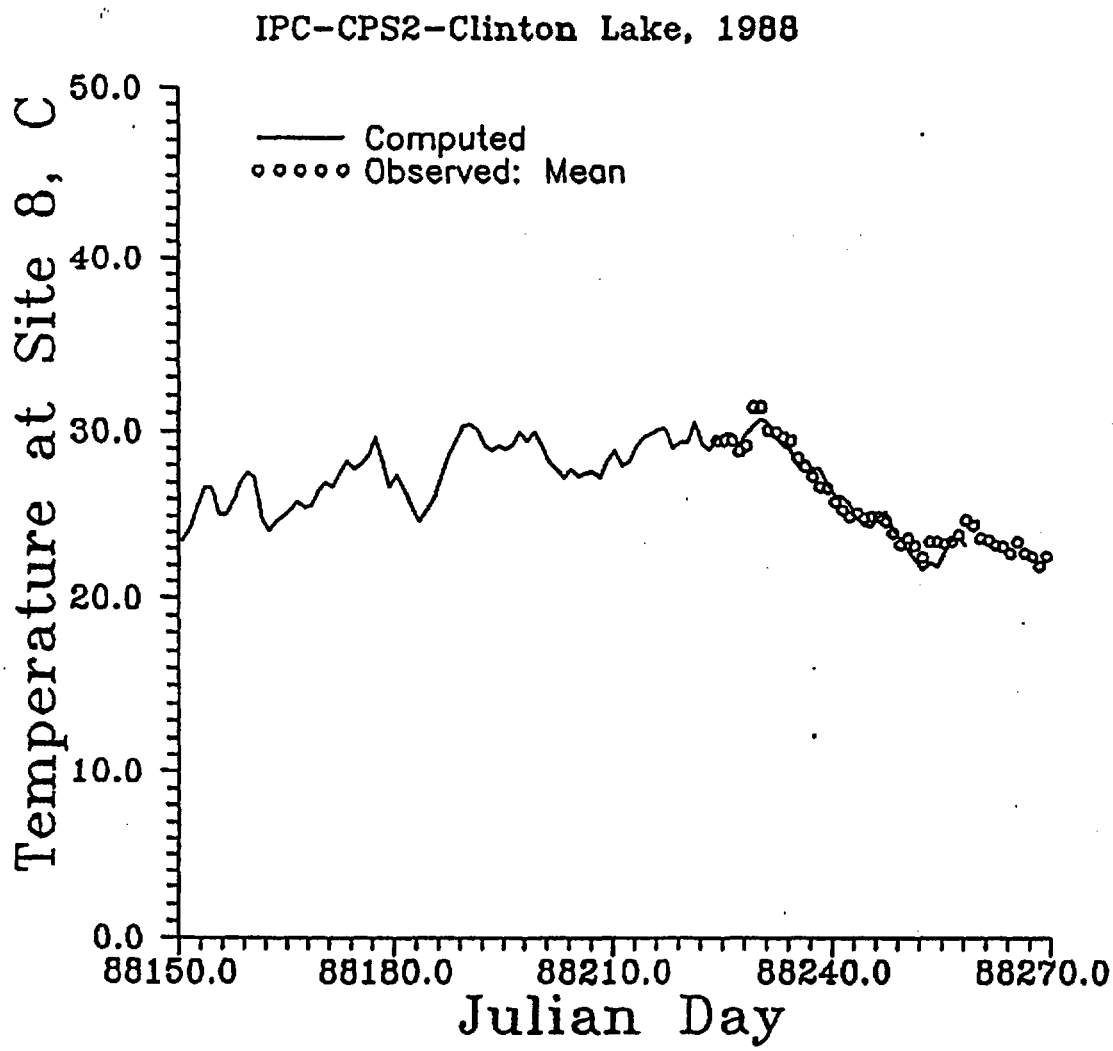

Figure 3-8. Computed and observed Data Sonde Site 8 temperatures for 1988 operating conditions.

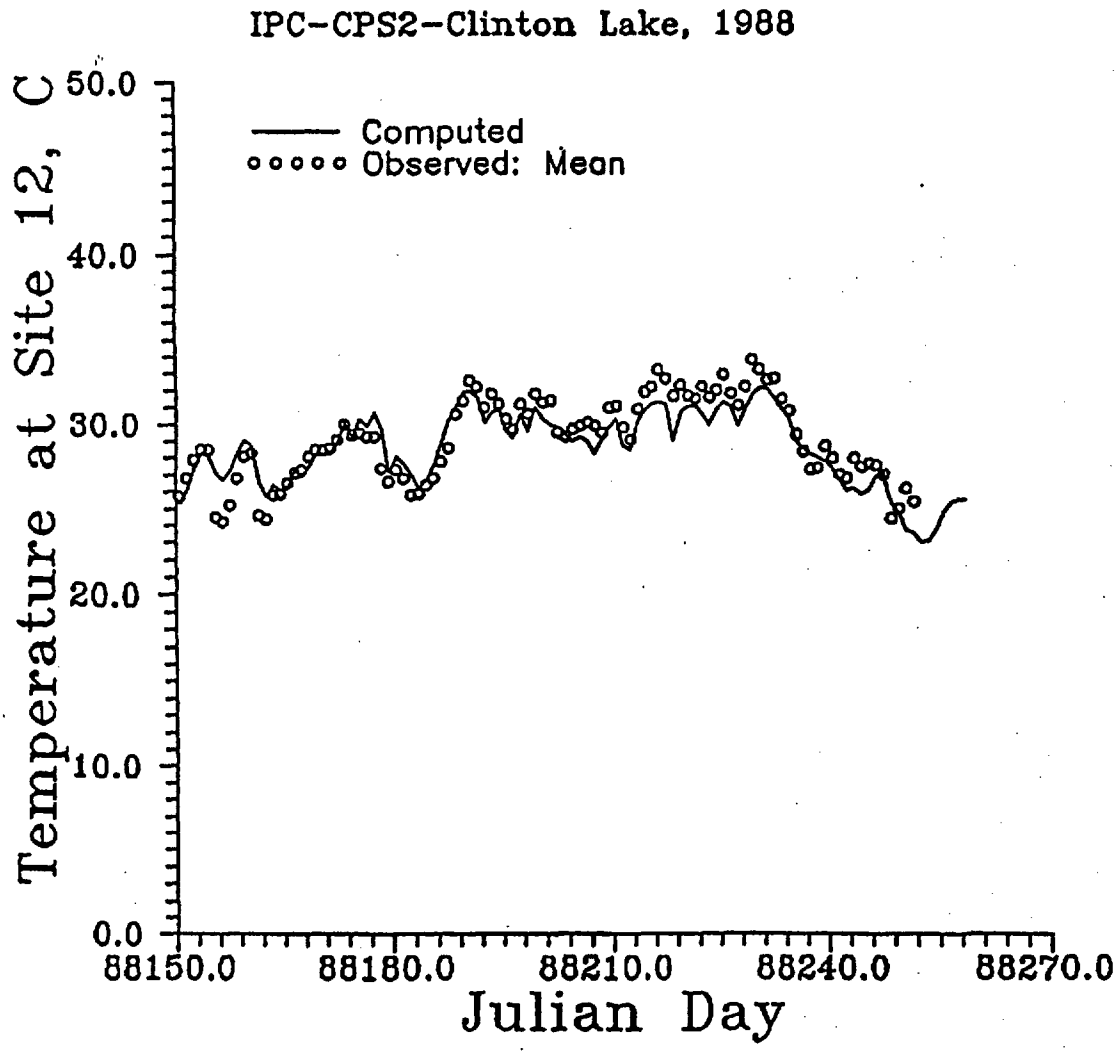

Figure 3-9. Computed and observed Data Sonde Site 12 temperatures for 1988 operating conditions.

between the point of discharge and the dam. It shows that the model slightly underestimates temperatures at site 12 probably due to a residual surface plume extending into the area from the discharge.

Figure 3-10 shows a comparison of the observed temperatures at Data Sonde site 15 located in the end of the discharge canal and the model temperatures for the flume discharge as shown previously in Figure 3-4(a). The observed temperatures at the end of the discharge canal are similar to the observed flume temperatures shown in Figure 3-4(a) indicating that there is insignificant cooling or mixing between the end of the second drop structure and the end of the canal.

Figure 3-11 shows a comparison of the observed and computed temperatures at Data Sonde site 16 in the surface of model segment 18 upstream from the point of discharge on the Salt Creek arm. The comparisons show a slight tendency for the model to overestimate temperatures in early June, as discussed previously, but in general, the comparison is excellent.

Based on the above comparisons, running the model with realtime plant operating data and Springfield meteorological data for 1988 produced good to excellent results.

Adjustments to the model during the verification period were:

a. Slight revisions to the daily plant pumping rates by IPC personnel.

b. Slight corrections on vertical mixing coefficients as indicated by the limited vertical profile temperature data in the vicinity of the mixing zone.

c. An empirical correction between the 108 acre surface layer of model segment 16 and the measured 26 acre mixing zone data.

No adjustments of the meteorological data for transfer between Springfield, Illinois and the lake were found necessary except for anemometer height relative to the lake elevation.

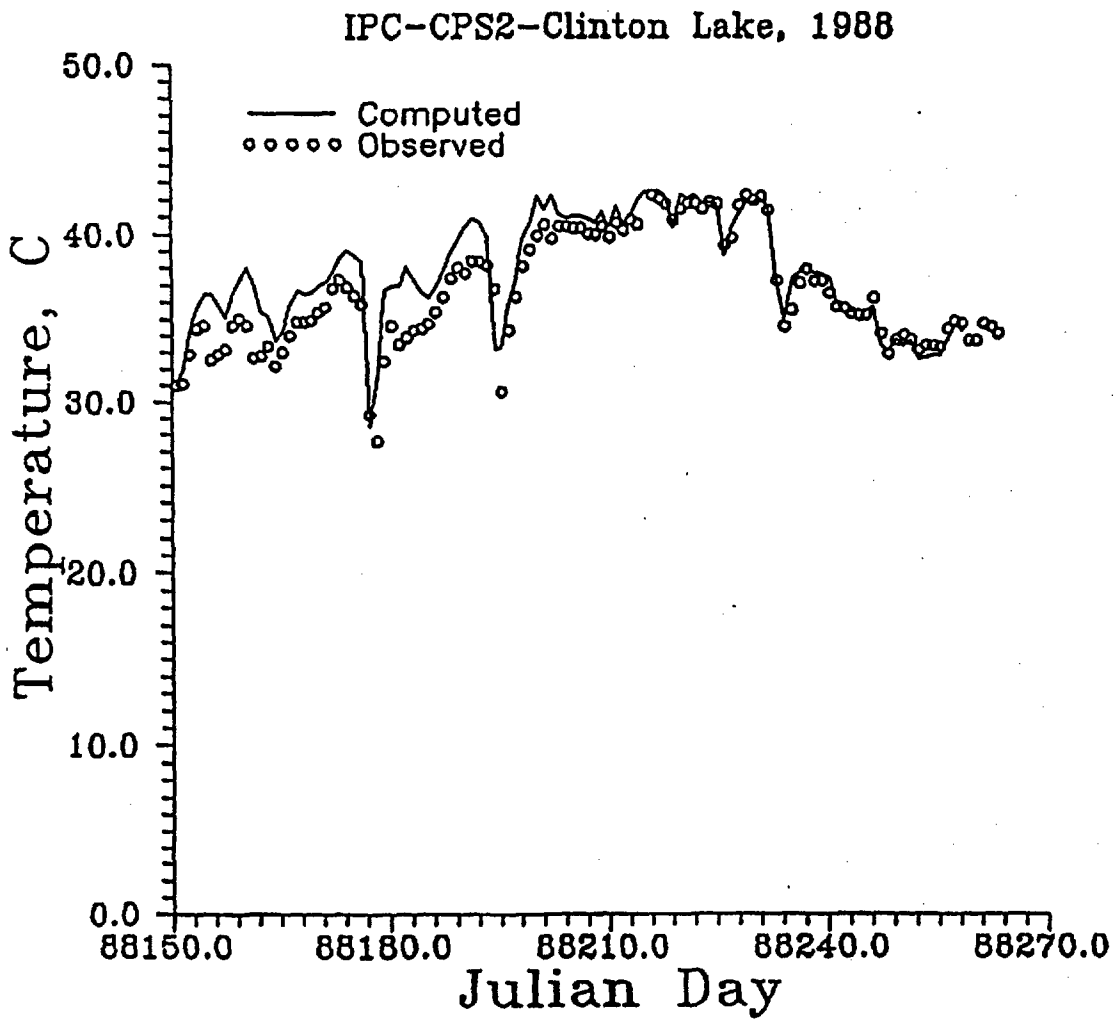

Figure 3-10. Computed discharge flume temperature and observed Data Sonde Site 15 temperature for 1988 operating conditions.

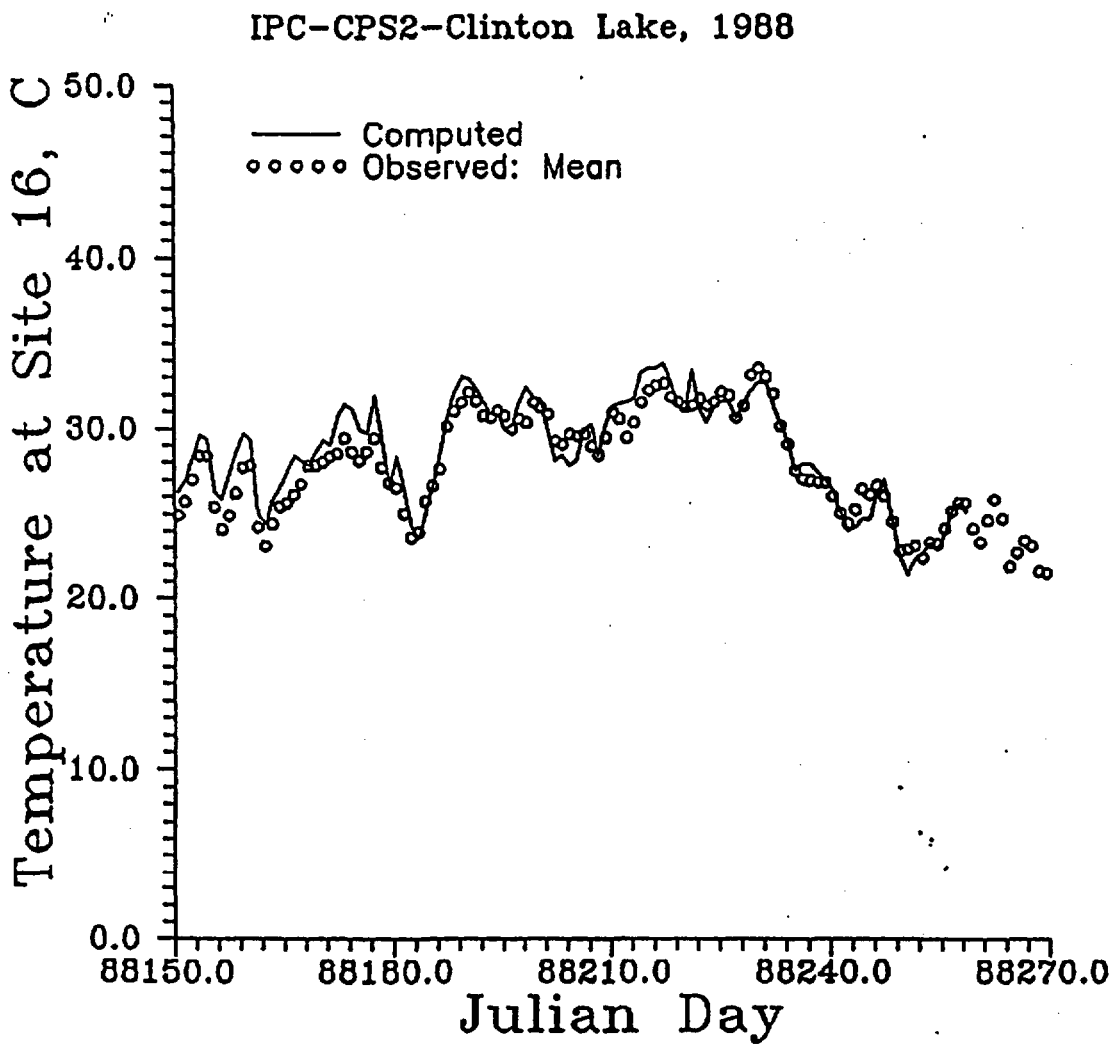

Figure 3-11. Computed and observed Data Sonde Site 16 temperatures for 1988 operating conditions.

3.3 Excess Temperatures for 1988

The GLVHT model enables excess temperatures to be calculated throughout the lake due to the plant operations. The excess temperatures are the temperature rise above ambient temperatures due to the heat source, plant pumping, surface heat dissipation, recirculation, and meteorological conditions (primarily windspeed).

A summary of the summer of 1988 (June through August) excess temperatures as the mean excess temperatures throughout the lake, their standard deviation over the summer due to time-varying plant operations and meteorological conditions, and the maximum value attained at any point in the lake over the summer is shown in Table 3-2.

Mean excess temperatures decay up and down the lake away from the point of discharge due to surface heat dissipation and decrease vertically due to re-entrainment and mixing of cooler water in the lake. The standard deviations demonstrate very little variation in excess temperatures despite the varying plant operations and varying meteorological conditions. Also, the standard deviations decrease up and down the lake and in the vertical along with the mean excess temperatures.

4.0 Meteorological Data Analysis and Statistics

Long term meteorological records were obtained from Springfield, Illinois for June through August from 1955 through 1988. The hourly 1988 records were used in the above GLVHT simulations. The records consisted of hourly, and in some years tri-hourly, data of cloud cover, air temperature, dewpoint temperature, windspeed and wind direction. These lengthy records were converted into hourly waterbody response temperatures which would be the water temperature that would result from meteorological conditions alone without accounting for

Table 3-2. Excess temperature means, standard deviations and maxima by lake segments and elevations for 1988 operating conditions. Layer elevations and landmark locations are shown in Table 3-1.

Mean discharge excess temperature is 9.9 deg C
Standard deviation of the discharge excess temperature is 1.84 deg C

Mean excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.3	.4	.6	.7	.8	1.0	1.2	1.4	1.7	2.2	2.9	3.8	5.1	8.0	4.6	2.5	.3
6	.3	.4	.6	.8	.9	1.0	1.2	1.4	1.7	2.2	3.0	4.0	5.2	6.9	4.3	2.3	.2
7	.3	.4	.6	.8	.9	1.0	1.2	1.5	1.7	2.1	2.8	3.7	4.9	5.8	4.0	2.1	.3
8	.3	.4	.6	.8	.9	1.0	1.2	1.4	1.7	2.0	2.5	3.3	4.4	4.9	3.6	2.0	.3
9	.4	.5	.6	.8	.9	1.0	1.2	1.4	1.6	1.8	2.3	3.0	4.0	4.3	3.4	1.9	.3
10	.4	.5	.6	.8	.9	1.0	1.1	1.3	1.5	1.7	2.0	2.5	3.6	3.9	3.3		
11	.4	.5	.6	.7	.9	1.0	1.1	1.2	1.4	1.6	1.7	2.0					
12	.4	.5	.6	.7	.8	.9	1.0	1.1	1.3	1.4	1.5	1.6					
13			.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4						
14			.6	.7	.8	.9	1.0	1.0	1.1	1.2							
15					.8	.9	.9	1.0									

Standard deviation of excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.10	.12	.15	.17	.20	.23	.27	.35	.46	.59	.70	.89	1.18	1.41	1.05	.89	.26
6	.13	.15	.19	.24	.27	.30	.36	.40	.46	.52	.57	.70	.89	1.22	.73	.53	.22
7	.16	.17	.20	.25	.27	.29	.33	.36	.39	.43	.48	.61	.79	1.05	.64	.46	.22
8	.18	.19	.21	.25	.27	.28	.32	.34	.36	.40	.46	.58	.75	.90	.57	.49	.23
9	.21	.21	.22	.26	.27	.28	.30	.32	.35	.39	.44	.56	.73	.84	.54	.49	.25
10	.23	.23	.24	.26	.27	.28	.29	.31	.32	.36	.41	.54	.72	.77	.54		
11	.25	.25	.25	.27	.27	.28	.28	.29	.30	.33	.37	.48					
12	.25	.26	.25	.27	.28	.28	.28	.27	.29	.31	.34	.42					
13			.25	.28	.28	.27	.27	.27	.28	.31	.32						
14			.26	.28	.28	.28	.27	.27	.28	.30							
15					.28	.28	.27	.27									

Maximum excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.6	.8	1.0	1.2	1.3	1.5	1.9	2.3	2.7	3.4	4.3	5.5	6.9	9.6	8.5	4.7	1.4
6	.8	.9	1.1	1.4	1.4	1.6	2.0	2.3	2.7	3.3	4.2	5.5	6.6	9.0	5.5	3.5	1.0
7	1.0	1.0	1.1	1.5	1.5	1.6	1.9	2.2	2.5	3.0	3.8	5.0	6.2	7.9	4.9	3.6	1.0
8	1.1	1.1	1.1	1.5	1.5	1.6	1.8	2.1	2.4	2.8	3.6	4.5	5.9	6.6	4.8	4.1	1.1
9	1.2	1.2	1.3	1.5	1.6	1.6	1.8	2.0	2.3	2.7	3.3	4.3	5.3	5.8	4.5	4.2	1.4
10	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.9	2.1	2.5	3.1	4.0	4.9	5.2	4.4		
11	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.7	2.0	2.4	3.0	3.5					
12	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.7	1.9	2.2	2.9	3.3					
13			1.4	1.5	1.6	1.6	1.7	1.7	1.8	2.1	2.7						
14			1.3	1.5	1.6	1.6	1.7	1.7	1.7	1.9							
15					1.6	1.6	1.7	1.7									

inflow hydrology, stratification, or plant operations.

The comparison between the 1988 response temperatures and the computed plant intake temperatures is shown in Figure 4-1. After complete mixing of the lake near the intake has begun the response temperatures are representative of intake temperatures. This relationship holds because, there is only an intake excess temperature (rise due to plant operations) of between 0.5°C and 0.8°C (Table 3-2). That is, the plant has a very small effect on intake temperatures due to recirculation.

The records for each year were subjected to a duration analysis to determine the temperature equalled or exceeded for a specified number of days. The results of the duration analysis for each year are shown in Table 4-1. The 1 day duration (maximum daily average temperature) for 1955 was 31.4 C (88.5 F) and did not recur until after 1978. Based on the previous analyses of the 1955 to 1978 records at Lake Decatur, this temperature was the worst in 24 years of record. However, as Table 4-1 shows, temperatures near or at this value occurred also in 1980 and 1987 making the 31.4 C the worst temperature in 7 to 8 years.

In order to determine the annual return periods of temperatures at each duration, the temperatures within each duration were subjected to a Gumbel extreme value statistical analysis. The Gumbel analysis was tested for this data and found to describe the annual frequency or return period with which the temperatures occur. The Gumbel analysis states that the probability, or annual frequency, of equalling or exceeding a given temperature at a given duration is:

$$P(T)=1-Exp[-Exp(-(T-b)/a)]$$

where T is the temperature; $b=Tm+0.45S$ where Tm is the mean temperature in the duration and S is the standard deviation; and, $a=S/1.283$. The mean temperature

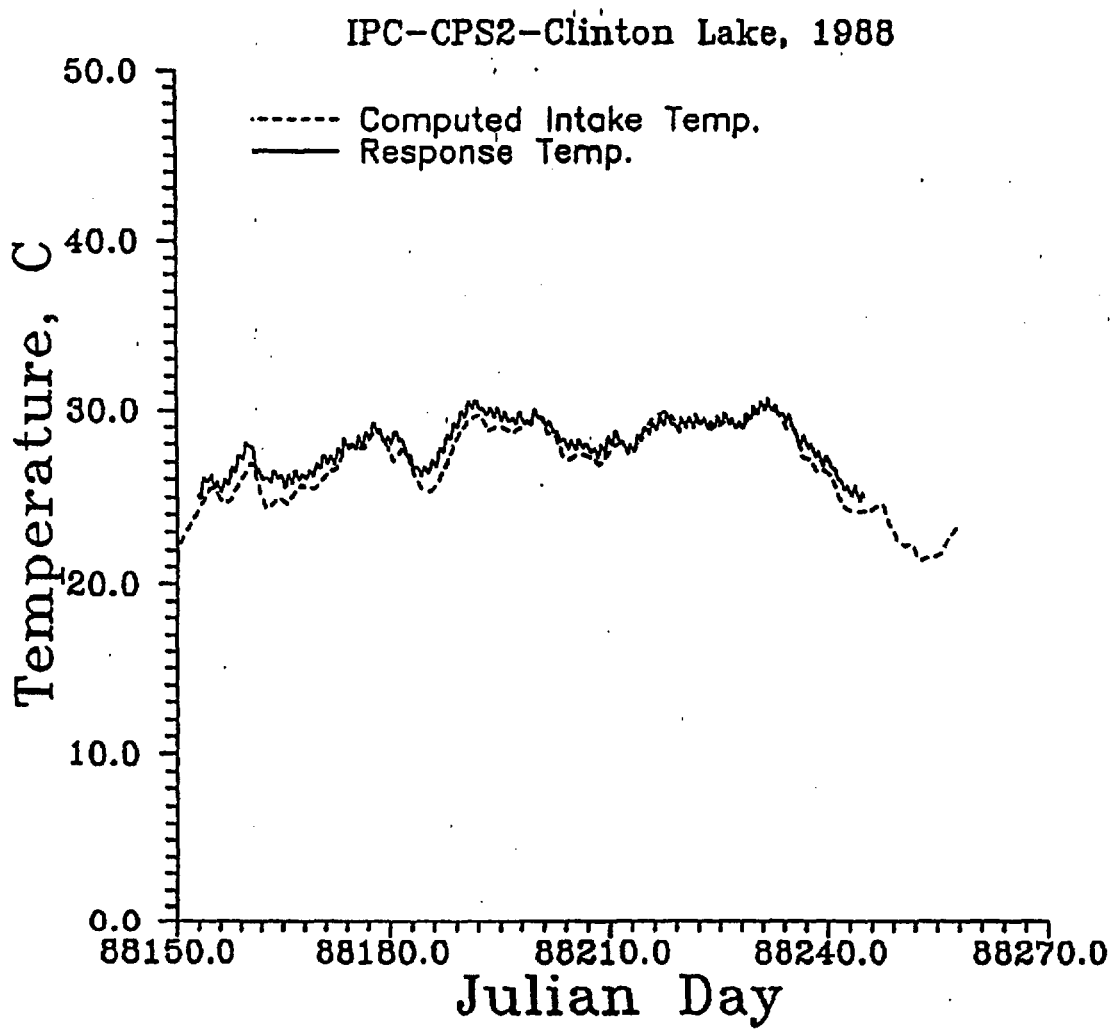

Figure 4-1. Time series of 1988 response temperatures superimposed on 1988 computed intake temperatures.

Table 4-1. Temperatures (C) equalled or exceeded for a given duration for each year 1955 to 1988 with means and standard deviations for each duration.

	Duration, Days							
Years	1	5	10	20	30	40	60	80
55	31.4	30.9	30.0	28.8	28.3	27.8	26.0	21.3
56	28.9	28.4	28.0	27.7	27.5	27.1	26.2	24.7
57	29.8	29.4	29.0	28.5	28.0	27.5	25.7	23.5
58	29.8	29.0	28.3	26.9	26.2	25.8	24.5	22.7
59	29.2	28.4	28.1	27.3	26.7	26.4	26.0	24.7
60	29.4	29.0	28.8	28.0	27.2	26.7	24.6	22.2
61	29.9	29.6	29.2	28.3	27.3	26.5	25.1	23.1
62	28.3	27.9	27.6	27.1	26.5	25.9	25.2	23.5
63	29.0	28.8	28.6	28.1	27.1	26.3	25.2	24.2
64	29.4	29.0	28.6	28.1	26.9	25.9	24.1	23.1
65	28.4	27.9	27.5	27.0	26.4	26.0	25.3	23.6
66	30.0	29.3	28.9	27.5	26.8	26.4	25.0	21.7
67	27.9	27.4	27.1	26.0	25.5	25.2	24.6	22.7
68	28.4	28.0	27.7	27.3	26.8	26.2	25.1	23.9
69	29.0	28.8	28.6	27.1	26.7	26.5	25.6	20.7
70	27.7	26.9	26.5	26.2	25.9	25.4	24.4	23.1
71	28.3	27.3	26.7	26.2	25.8	25.4	24.7	22.8
72	28.7	28.2	27.6	26.5	26.0	25.2	23.8	23.1
73	27.9	27.7	27.5	27.1	26.7	26.4	25.7	24.7
74	29.2	28.7	28.4	27.6	26.2	25.7	24.2	22.0
75	29.8	29.0	28.7	28.1	27.6	27.3	26.7	22.9
76	27.9	27.6	27.4	26.8	25.9	25.4	24.7	24.0
77	29.9	29.4	28.9	27.8	26.5	26.1	25.1	23.6
78	28.3	27.9	27.8	27.3	26.7	26.3	25.7	23.7
79	29.8	28.5	27.4	26.8	26.3	25.7	24.4	23.2
80	31.4	30.9	30.5	29.4	28.8	28.5	27.3	23.8
81	30.2	29.5	28.7	27.2	26.6	26.1	25.3	24.1
82	28.9	28.6	28.4	27.8	26.8	26.4	24.6	23.0
83	30.4	30.0	29.5	29.1	28.7	28.4	27.6	23.0
84	29.3	28.9	28.7	28.0	27.5	27.2	26.2	25.1
85	28.0	27.8	27.5	27.2	26.9	26.5	25.2	22.7
86	30.9	30.7	30.3	28.8	28.0	27.6	26.2	24.7
87	31.5	30.8	30.2	29.1	28.6	28.1	27.0	25.6
88	30.4	30.1	29.9	29.5	29.1	28.5	27.7	26.3
Mean	29.3	28.8	28.4	27.7	27.0	26.5	25.4	23.4
Std. Dev.	1.05	1.04	1.01	.90	.91	.93	.98	1.15

(Tm) and standard deviation (S) for each duration are given in Table 4-1. The return period, in years, is R=1/P(T) from the above equation.

The overall frequency-duration analysis of the records from 1955 to 1988 can be generalized as shown in Table 4-2 to give the response temperature equalled or exceeded for a given return period and duration. In Table 4-2 a given temperature would move diagonally downward for increasing durations and return periods; for example, 31.0 C (87.8 F) is equalled or exceeded for 1 day once in 5 years, for 5 days once in 8 years, for 10 days once in 18 years and so on.

Thus, based on the 1988 modeling and analysis, the response temperatures are representative of intake temperatures as they would have occurred in previous years, and their statistics over 1955 to 1988 are representative of their duration in any year and their return period in years.

5.0 Case Analyses

Two operating cases have been identified for analysis, those being (1) 100 percent power, 100 percent circulating water flow, and the lake starting at normal elevation, and (2) 100 percent power, 100 percent circulating water flow, and the lake starting at 685.5 ft. These cases were evaluated to determine temperature effects in the lake for normal station operations over the extremes of lake level conditions reasonably anticipated. The parameters in each case are as follows:

(1410 cfs · .87 cfs) = 42.39 m³ s⁻¹

Case	Plant Load, %	Pumping Rate, cfs	May 31 El., Ft.	
1	100	1410	690.0	(Normal pool)
2	100	1373	685.5	(Drought level pool)

6.713×10⁶ Btu h⁻¹ · °C m³ s⁻¹ / 1.439×10⁻² Btu h⁻¹ · Btu / 10⁶ Btu = 469.7 °C m³ s⁻¹

11.08 °C

Table 4-2. Table of response (intake) temperatures (C) as a function of annual frequency and duration computed from Springfield, Illinois climatological data for 1955 to 1988.

Return Period Years	Duration, Days					
	1	5	7	10	20	30
2	30.1	29.6	29.4	29.1	28.4	27.7
5	31.0	30.5	30.3	30.1	29.1	28.5
10	31.6	31.1	30.9	30.6	29.7	29.0
20	32.2	31.7	31.5	31.2	30.2	29.5
30	32.6	32.0	31.8	31.5	30.5	29.8

The 100% plant load heat rejection rate is 6.713 x 10^9 Btu/Hr. The service water pumping rate in each case is 87 cfs.

The excess temperatures through the lake and their statistics are given for each case in Table 5-1 and Table 5-2 respectively. The excess temperatures near the discharge are slightly higher for Case 2 than for Case 1 because of the lower starting lake elevation in Case 2. The standard deviations of excess temperature in each case are less than those shown for the 1988 operating conditions because the Case 1 and Case 2 heat rejection rates are constant through the summer and the plant pumping rates vary only slightly with lake level drawdown due to evaporation (Table 3-2). The excess temperatures in Table 5-1 and Table 5-2 can be combined with the intake response temperature statistics in Table 4-2 to give the lake temperatures that would occur for a normal year, one year in ten and one year in thirty at a duration of one day, seven days and thirty days.

The temperature distributions are shown for Case 1 in Table 5-3 for a one day duration at each annual frequency, in Table 5-4 for a seven day duration and in Table 5-5 for a thirty day duration. The temperature distributions are shown for Case 2 in Table 5-6 for a one day duration, in Table 5-7 for a seven day duration and in Table 5-8 for a thirty day duration. In each case, the response temperature, the flume discharge temperature, and the mixing zone temperature in the surface layer of segment 16 is indicated. For Case 1, the one in thirty year one day flume discharge temperature is 43.7 C (110.7 F) and the one in thirty year one day mixing zone temperature is 41.4 C (106.5 F) (Table 5-3). Since the surface water and ground water inflows are unknown for past years, the deeper water temperatures in Table 5-3 through Table 5-8 are over-estimated.

The frequency-duration analysis was used to determine the number of days that a temperature limit of 99 F (37.22 C) would be exceeded for each case at the mixing zone and at the discharge flume for a normal year, one year in ten

Table 5-1. Excess temperature means, standard deviations and maxima by lake segments and elevations for Case 1 conditions (normal lake elevation and 1410 cfs pumping). Layer elevations and landmark locations are shown in Table 3-1.

Discharge excess temperature is 11.1 deg C
Mixing zone excess temperature is 8.8 deg C

Mean excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.4	.5	.8	1.0	1.1	1.3	1.5	1.8	2.1	2.7	3.4	4.5	5.9	8.6	5.1	2.7	.3
6	.4	.5	.8	1.0	1.1	1.2	1.5	1.7	2.1	2.7	3.5	4.8	5.9	7.8	4.8	2.5	.2
7	.4	.6	.8	1.0	1.1	1.3	1.5	1.8	2.1	2.6	3.4	4.4	5.6	6.6	4.5	2.4	.3
8	.4	.6	.8	1.0	1.2	1.3	1.5	1.8	2.0	2.4	3.0	3.9	5.2	5.8	4.1	2.2	.3
9	.4	.6	.8	1.0	1.1	1.3	1.5	1.7	1.9	2.2	2.7	3.5	4.7	5.0	3.8	2.1	.3
10	.5	.6	.8	1.0	1.1	1.2	1.4	1.6	1.8	2.1	2.4	3.1	4.3	4.5	3.8		
11	.5	.6	.8	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.4					
12	.5	.6	.8	.9	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0					
13			.8	.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7						
14			.8	.9	1.0	1.1	1.2	1.3	1.4	1.5							
15					1.0	1.1	1.2	1.3									

Standard deviation of excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.11	.12	.14	.14	.17	.19	.22	.30	.40	.49	.58	.69	.78	.53	.92	.76	.22
6	.15	.17	.19	.24	.26	.29	.34	.38	.42	.42	.43	.49	.53	.82	.47	.40	.21
7	.18	.18	.19	.24	.25	.26	.30	.32	.33	.33	.36	.48	.58	.78	.39	.37	.22
8	.22	.21	.21	.25	.25	.25	.28	.29	.31	.34	.40	.51	.59	.61	.33	.41	.25
9	.25	.24	.23	.25	.25	.26	.27	.28	.30	.34	.41	.52	.61	.57	.33	.45	.28
10	.28	.27	.25	.27	.26	.26	.26	.27	.29	.33	.39	.54	.66	.53	.31		
11	.30	.29	.27	.28	.27	.26	.26	.26	.28	.32	.38	.51					
12	.31	.30	.26	.29	.28	.27	.25	.25	.27	.31	.35	.45					
13			.28	.29	.28	.27	.25	.24	.27	.31	.33						
14			.28	.30	.29	.27	.25	.25	.27	.31							
15					.29	.27	.26	.26									

Maximum excess temperature (deg C)

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	.7	.8	1.1	1.4	1.5	1.8	2.2	2.6	3.1	3.8	4.8	6.0	7.4	9.8	6.4	4.5	1.8
6	.9	1.0	1.2	1.6	1.6	1.9	2.3	2.7	3.1	3.7	4.7	5.9	7.1	9.2	6.0	3.6	1.3
7	1.1	1.1	1.2	1.7	1.7	1.9	2.3	2.5	2.9	3.5	4.4	5.5	6.8	8.1	5.5	3.8	1.2
8	1.3	1.3	1.4	1.7	1.7	1.9	2.1	2.4	2.8	3.3	4.2	4.9	6.3	7.0	5.1	4.3	1.2
9	1.4	1.4	1.5	1.7	1.8	1.8	2.0	2.3	2.6	3.5	4.2	4.7	5.9	6.3	4.7	4.4	1.5
10	1.5	1.5	1.6	1.8	1.8	1.9	2.0	2.3	2.7	3.4	4.3	4.7	5.4	5.8	4.7		
11	1.5	1.6	1.6	1.8	1.8	1.8	1.9	2.2	2.6	3.3	4.2	4.6					
12	1.5	1.6	1.6	1.8	1.8	1.8	1.9	2.1	2.6	3.1	4.1	4.6					
13			1.6	1.8	1.8	1.8	1.9	2.0	2.5	2.9	3.7						
14			1.6	1.8	1.8	1.8	1.8	1.8	2.4	2.7							
15					1.8	1.8	1.8	1.8									

Table 5-2. Excess temperature means, standard deviations and maxima by lake segments and elevations for Case 2 conditions (low lake elevation and 1373 cfs pumping). Layer elevations and landmark locations are shown in Table 3-1.

Discharge excess temperature is 11.4 deg C
Mixing zone excess temperature is 10.0 deg C

Mean excess temperature (deg C)

Layer	Segment Number 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	.4	.6	.9	1.1	1.3	1.5	1.8	2.1	2.6	3.2	4.3	5.4	7.0	10.0	5.3	2.4	.1
7	.2	.4	.7	.9	1.0	1.2	1.4	1.8	2.2	2.9	3.9	5.2	6.9	9.2	4.2	1.4	.0
8	.3	.4	.8	1.0	1.1	1.3	1.5	1.9	2.3	3.0	4.0	5.4	7.0	7.9	3.9	1.4	.0
9	.3	.5	.8	1.0	1.1	1.3	1.6	1.8	2.2	2.8	3.7	5.0	6.8	6.6	3.6	1.3	.1
10	.3	.5	.8	1.0	1.1	1.3	1.5	1.8	2.1	2.5	3.3	4.5	6.3	5.8	3.7		
11	.4	.5	.8	1.0	1.1	1.3	1.4	1.7	2.0	2.3	2.8	3.7					
12	.4	.5	.7	1.0	1.1	1.2	1.4	1.6	1.9	2.1	2.5	3.0					
13			.7	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.1						
14			.8	.9	1.1	1.2	1.3	1.4	1.6	1.7							
15					1.1	1.2	1.3	1.3									

Standard deviation of excess temperature (deg C)

Layer	Segment Number 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	.14	.14	.14	.13	.13	.20	.24	.32	.44	.50	.49	.62	.76	.49	.96	.60	.05
7	.17	.19	.24	.30	.32	.35	.42	.48	.55	.58	.66	.73	.69	.44	.66	.65	.06
8	.20	.23	.26	.31	.32	.33	.36	.41	.45	.44	.45	.48	.51	.51	.55	.64	.08
9	.25	.27	.30	.32	.31	.32	.35	.37	.41	.42	.46	.57	.52	.57	.54	.65	.12
10	.29	.31	.33	.33	.31	.33	.34	.36	.40	.44	.52	.62	.56	.62	.53		
11	.32	.34	.35	.34	.32	.33	.34	.34	.38	.43	.51	.66					
12	.34	.36	.37	.35	.33	.33	.33	.33	.36	.41	.50	.69					
13			.37	.36	.34	.33	.33	.32	.35	.39	.44						
14			.37	.37	.34	.32	.31	.30	.34	.36							
15					.34	.32	.31	.31									

Maximum excess temperature (deg C)

Layer	Segment Number 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	.7	.9	1.2	1.5	1.6	1.9	2.3	2.8	3.5	4.3	5.4	6.7	8.4	10.8	6.4	3.7	.2
7	1.0	1.2	1.3	1.7	1.8	2.1	2.4	2.9	3.5	4.3	5.5	7.0	8.5	10.4	6.0	3.1	.4
8	1.3	1.4	1.5	1.8	1.9	2.1	2.5	2.9	3.4	4.1	5.2	6.6	8.3	9.3	5.8	4.2	.7
9	1.5	1.6	1.7	1.9	1.9	2.1	2.4	2.8	3.2	3.8	4.8	6.3	8.2	8.4	5.8	4.7	1.2
10	1.6	1.7	1.8	1.9	1.9	2.1	2.3	2.6	3.0	3.6	4.6	6.1	8.0	7.8	5.6		
11	1.7	1.8	1.8	1.9	2.0	2.0	2.2	2.5	2.8	3.6	4.6	5.5					
12	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.3	2.6	3.5	4.6	5.3					
13			1.9	1.9	2.0	2.0	2.1	2.2	2.6	3.3	4.4						
14			1.9	1.9	2.0	2.0	2.1	2.1	2.5	3.0							
15					2.0	2.0	2.0	2.0									

Table 5-3. Case 1 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for one day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 30.1 C
Discharge temperature is 41.2 C
Mixing zone temperature is 38.9 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	30.5	30.6	30.9	31.1	31.2	31.4	31.6	31.9	32.2	32.8	33.5	34.6	36.0	38.9	35.2	32.8	30.4
6	30.5	30.6	30.9	31.1	31.2	31.3	31.6	31.8	32.2	32.8	33.6	34.7	36.0	37.9	34.9	32.6	30.3
7	30.5	30.7	30.9	31.1	31.2	31.4	31.6	31.9	32.2	32.7	33.5	34.5	35.7	36.7	34.6	32.5	30.4
8	30.5	30.7	30.9	31.1	31.3	31.4	31.6	31.9	32.1	32.5	33.1	34.0	35.3	35.7	34.2	32.3	30.4
9	30.5	30.7	30.9	31.1	31.2	31.4	31.6	31.8	32.0	32.3	32.8	33.6	34.8	35.1	33.9	32.2	30.4
10	30.6	30.7	30.9	31.1	31.2	31.3	31.5	31.7	31.9	32.2	32.5	33.2	34.4	34.6	33.9		
11	30.6	30.7	30.9	31.1	31.2	31.3	31.5	31.6	31.8	32.0	32.2	32.5					
12	30.6	30.7	30.9	31.0	31.2	31.3	31.4	31.5	31.7	31.8	31.9	32.1					
13			30.9	31.0	31.1	31.2	31.3	31.4	31.6	31.7	31.8						
14			30.9	31.0	31.1	31.2	31.3	31.4	31.5	31.6							
15					31.1	31.2	31.3	31.4									

(b) One year in ten

Response temperature is 31.6 C
Discharge temperature is 42.7 C
Mixing zone temperature is 40.4 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	32.0	32.1	32.4	32.6	32.7	32.9	33.1	33.4	33.7	34.3	35.0	36.1	37.5	40.4	36.7	34.3	31.9
6	32.0	32.1	32.4	32.6	32.7	32.8	33.1	33.3	33.7	34.3	35.1	36.2	37.5	39.4	36.4	34.1	31.8
7	32.0	32.2	32.4	32.6	32.7	32.9	33.1	33.4	33.7	34.2	35.0	36.0	37.2	38.2	36.1	34.0	31.9
8	32.0	32.2	32.4	32.6	32.8	32.9	33.1	33.4	33.6	34.0	34.6	35.5	36.8	37.2	35.7	33.8	31.9
9	32.0	32.2	32.4	32.6	32.7	32.9	33.1	33.3	33.5	33.8	34.3	35.1	36.3	36.6	35.4	33.7	31.9
10	32.1	32.2	32.4	32.6	32.7	32.8	33.0	33.2	33.4	33.7	34.0	34.7	35.9	36.1	35.4		
11	32.1	32.2	32.4	32.6	32.7	32.8	33.0	33.1	33.3	33.5	33.7	34.0					
12	32.1	32.2	32.4	32.5	32.7	32.8	32.9	33.0	33.2	33.3	33.4	33.6					
13			32.4	32.5	32.6	32.7	32.8	32.9	33.1	33.2	33.3						
14			32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1							
15					32.6	32.7	32.8	32.9									

(c) One year in thirty

Response temperature is 32.6 C
Discharge temperature is 43.7 C
Mixing zone temperature is 41.4 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	33.0	33.1	33.4	33.6	33.7	33.9	34.1	34.4	34.7	35.3	36.0	37.1	38.5	41.4	37.7	35.3	32.9
6	33.0	33.1	33.4	33.6	33.7	33.8	34.1	34.3	34.7	35.3	36.1	37.2	38.5	40.4	37.4	35.1	32.8
7	33.0	33.2	33.4	33.6	33.7	33.9	34.1	34.4	34.7	35.2	36.0	37.0	38.2	39.2	37.1	35.0	32.9
8	33.0	33.2	33.4	33.6	33.8	33.9	34.1	34.4	34.6	35.0	35.8	36.5	37.8	38.2	36.7	34.8	32.9
9	33.0	33.2	33.4	33.6	33.7	33.9	34.1	34.3	34.5	34.8	35.3	36.1	37.3	37.6	36.4	34.7	32.9
10	33.1	33.2	33.4	33.6	33.7	33.8	34.0	34.2	34.4	34.7	35.0	35.7	36.9	37.1	36.4		
11	33.1	33.2	33.4	33.6	33.7	33.8	34.0	34.1	34.3	34.5	34.7	35.0					
12	33.1	33.2	33.4	33.5	33.7	33.8	33.9	34.0	34.2	34.3	34.4	34.6					
13			33.4	33.5	33.6	33.7	33.8	33.9	34.1	34.2	34.3						
14			33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1							
15					33.6	33.7	33.8	33.9									

Table 5-4. Case 1 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for seven day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 29.4 C
Discharge temperature is 40.5 C
Mixing zone temperature is 38.2 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	29.8	29.9	30.2	30.4	30.5	30.7	30.9	31.2	31.5	32.1	32.8	33.9	35.9	38.2	34.5	32.1	29.7
6	29.8	29.9	30.2	30.4	30.5	30.6	30.9	31.1	31.5	32.1	32.9	34.0	35.3	37.2	34.2	31.9	29.6
7	29.8	30.0	30.2	30.4	30.5	30.7	30.9	31.2	31.5	32.0	32.8	33.8	35.0	36.0	33.9	31.8	29.7
8	29.8	30.0	30.2	30.4	30.6	30.7	30.9	31.2	31.4	31.8	32.4	33.3	34.6	35.0	33.5	31.6	29.7
9	29.8	30.0	30.2	30.4	30.5	30.7	30.9	31.1	31.3	31.6	32.1	32.9	34.1	34.4	33.2	31.5	29.7
10	29.9	30.0	30.2	30.4	30.5	30.6	30.8	31.0	31.2	31.5	31.8	32.5	33.7	33.9	33.2		
11	29.9	30.0	30.2	30.4	30.5	30.6	30.8	30.9	31.1	31.3	31.5	31.8					
12	29.9	30.0	30.2	30.3	30.5	30.6	30.7	30.8	31.0	31.1	31.2	31.4					
13			30.2	30.3	30.4	30.5	30.6	30.7	30.9	31.0	31.1						
14			30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9							
15					30.4	30.5	30.6	30.7									

(b) One year in ten

Response temperature is 30.9 C
Discharge temperature is 42.0 C
Mixing zone temperature is 39.7 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	31.3	31.4	31.7	31.9	32.0	32.2	32.4	32.7	33.0	33.6	34.3	35.4	36.8	39.7	36.0	33.6	31.2
6	31.3	31.4	31.7	31.9	32.0	32.1	32.4	32.6	33.0	33.6	34.4	35.5	36.8	38.7	35.7	33.4	31.1
7	31.3	31.5	31.7	31.9	32.0	32.2	32.4	32.7	33.0	33.5	34.3	35.3	36.5	37.5	35.4	33.3	31.2
8	31.3	31.5	31.7	31.9	32.1	32.2	32.4	32.7	32.9	33.3	33.9	34.8	36.1	36.5	35.0	33.1	31.2
9	31.3	31.5	31.7	31.9	32.0	32.2	32.4	32.6	32.8	33.1	33.6	34.4	35.6	35.9	34.7	33.0	31.2
10	31.4	31.5	31.7	31.9	32.0	32.1	32.3	32.5	32.7	33.0	33.3	34.0	35.2	35.4	34.7		
11	31.4	31.5	31.7	31.9	32.0	32.1	32.3	32.4	32.6	32.8	33.0	33.3					
12	31.4	31.5	31.7	31.8	32.0	32.1	32.2	32.3	32.5	32.6	32.7	32.9					
13			31.7	31.8	31.9	32.0	32.1	32.2	32.4	32.5	32.6						
14			31.7	31.8	31.9	32.0	32.1	32.2	32.3	32.4							
15					31.9	32.0	32.1	32.2									

(c) One year in thirty

Response temperature is 31.8 C
Discharge temperature is 42.9 C
Mixing zone temperature is 40.6 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	32.2	32.3	32.6	32.8	32.9	33.1	33.3	33.6	33.9	34.5	35.2	36.3	37.7	40.6	36.9	34.5	32.1
6	32.2	32.3	32.6	32.8	32.9	33.0	33.3	33.5	33.9	34.5	35.3	36.4	37.7	39.6	36.6	34.3	32.0
7	32.2	32.4	32.6	32.8	32.9	33.1	33.3	33.6	33.9	34.4	35.2	36.2	37.4	38.4	36.3	34.2	32.1
8	32.2	32.4	32.6	32.8	33.0	33.1	33.3	33.6	33.8	34.2	34.8	35.7	37.0	37.4	35.9	34.0	32.1
9	32.2	32.4	32.6	32.8	32.9	33.1	33.3	33.5	33.7	34.0	34.5	35.3	36.5	36.8	35.6	33.9	32.1
10	32.3	32.4	32.6	32.8	32.9	33.0	33.2	33.4	33.6	33.9	34.2	34.9	36.1	36.3	35.6		
11	32.3	32.4	32.6	32.8	32.9	33.0	33.2	33.3	33.5	33.7	33.9	34.2					
12	32.3	32.4	32.6	32.7	32.9	33.0	33.1	33.2	33.4	33.5	33.6	33.8					
13			32.6	32.7	32.8	32.9	33.0	33.1	33.3	33.4	33.5						
14			32.6	32.7	32.8	32.9	33.0	33.1	33.2	33.3							
15					32.8	32.9	33.0	33.1									

Table 5-5. Case 1 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for thirty day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 27.7 C
Discharge temperature is 36.8 C
Mixing zone temperature is 36.5 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	28.1	28.2	28.5	28.7	28.8	29.0	29.2	29.5	29.8	30.4	31.1	32.2	33.6	36.5	32.8	30.4	28.0
6	28.1	28.2	28.5	28.7	28.8	28.9	29.2	29.4	29.8	30.4	31.2	32.3	33.6	35.5	32.5	30.2	27.9
7	28.1	28.3	28.5	28.7	28.8	29.0	29.2	29.5	29.8	30.3	31.1	32.1	33.3	34.3	32.2	30.1	28.0
8	28.1	28.3	28.5	28.7	28.9	29.0	29.2	29.5	29.7	30.1	30.7	31.6	32.9	33.3	31.8	29.9	28.0
9	28.1	28.3	28.5	28.7	28.8	29.0	29.2	29.4	29.6	29.9	30.4	31.2	32.4	32.7	31.5	29.8	28.0
10	28.2	28.3	28.5	28.7	28.8	28.9	29.1	29.3	29.5	29.8	30.1	30.8	32.0	32.2	31.5		
11	28.2	28.3	28.5	28.7	28.8	28.9	29.1	29.2	29.4	29.6	29.8	30.1					
12	28.2	28.3	28.5	28.6	28.8	28.9	29.0	29.1	29.3	29.4	29.5	29.7					
13			28.5	28.6	28.7	28.8	28.9	29.0	29.2	29.3	29.4						
14			28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2							
15					28.7	28.8	28.9	29.0									

(b) One year in ten

Response temperature is 29.0 C
Discharge temperature is 40.1 C
Mixing zone temperature is 37.8 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	29.4	29.5	29.8	30.0	30.1	30.3	30.5	30.8	31.1	31.7	32.4	33.5	34.9	37.8	34.1	31.7	29.3
6	29.4	29.5	29.8	30.0	30.1	30.2	30.5	30.7	31.1	31.7	32.5	33.6	34.9	36.8	33.8	31.5	29.2
7	29.4	29.6	29.8	30.0	30.1	30.3	30.5	30.8	31.1	31.6	32.4	33.4	34.6	35.6	33.5	31.4	29.3
8	29.4	29.6	29.8	30.0	30.2	30.3	30.5	30.8	31.0	31.4	32.0	32.9	34.2	34.6	33.1	31.2	29.3
9	29.4	29.6	29.8	30.0	30.1	30.3	30.5	30.7	30.9	31.2	31.7	32.5	33.7	34.0	32.8	31.1	29.3
10	29.5	29.6	29.8	30.0	30.1	30.2	30.4	30.6	30.8	31.1	31.4	32.1	33.3	33.5	32.6		
11	29.5	29.6	29.8	30.0	30.1	30.2	30.4	30.5	30.7	30.9	31.1	31.4					
12	29.5	29.6	29.8	29.9	30.1	30.2	30.3	30.4	30.6	30.7	30.8	31.0					
13			29.8	29.9	30.0	30.1	30.2	30.3	30.5	30.6	30.7						
14			29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5							
15					30.0	30.1	30.2	30.3									

(c) One year in thirty

Response temperature is 29.8 C
Discharge temperature is 40.9 C
Mixing zone temperature is 38.6 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
5	30.2	30.3	30.6	30.8	30.9	31.1	31.3	31.6	31.9	32.5	33.2	34.3	35.7	38.6	34.9	32.5	30.1
6	30.2	30.3	30.6	30.8	30.9	31.0	31.3	31.5	31.9	32.5	33.3	34.4	35.7	37.6	34.6	32.3	30.0
7	30.2	30.4	30.6	30.8	30.9	31.1	31.3	31.6	31.9	32.4	33.2	34.2	35.4	36.4	34.3	32.2	30.1
8	30.2	30.4	30.6	30.8	31.0	31.1	31.3	31.6	31.8	32.2	32.8	33.7	35.0	35.4	33.9	32.0	30.1
9	30.2	30.4	30.6	30.8	30.9	31.1	31.3	31.5	31.7	32.0	32.5	33.3	34.5	34.8	33.6	31.9	30.1
10	30.3	30.4	30.6	30.8	30.9	31.0	31.2	31.4	31.6	31.9	32.2	32.9	34.1	34.3	33.6		
11	30.3	30.4	30.6	30.8	30.9	31.0	31.2	31.3	31.5	31.7	31.9	32.2					
12	30.3	30.4	30.6	30.7	30.9	31.0	31.1	31.2	31.4	31.5	31.6	31.8					
13			30.6	30.7	30.8	30.9	31.0	31.1	31.3	31.4	31.5						
14			30.6	30.7	30.8	30.9	31.0	31.1	31.2	31.3							
15					30.8	30.9	31.0	31.1									

Table 5-6. Case 2 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for one day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 30.1 C
Discharge temperature is 41.5 C
Mixing zone temperature is 40.1 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	30.5	30.7	31.0	31.2	31.4	31.6	31.9	32.2	32.7	33.3	34.4	35.5	37.1	40.1	35.4	32.5	30.2
7	30.3	30.5	30.8	31.0	31.1	31.3	31.5	31.9	32.3	33.0	34.0	35.3	37.0	39.3	34.3	31.5	30.1
8	30.4	30.5	30.9	31.1	31.2	31.4	31.6	32.0	32.4	33.1	34.1	35.5	37.1	38.0	34.0	31.5	30.1
9	30.4	30.6	30.9	31.1	31.2	31.4	31.7	31.9	32.3	32.9	33.8	35.1	36.7	36.7	33.7	31.4	30.2
10	30.4	30.6	30.9	31.1	31.2	31.4	31.6	31.9	32.2	32.6	33.4	34.6	36.4	35.9	33.8		
11	30.5	30.6	30.9	31.1	31.2	31.4	31.5	31.8	32.1	32.4	33.0	33.8					
12	30.5	30.6	30.8	31.1	31.2	31.3	31.5	31.7	32.0	32.2	32.6	33.1					
13			30.8	31.1	31.2	31.3	31.4	31.6	31.8	32.0	32.2						
14			30.9	31.0	31.2	31.3	31.4	31.5	31.7	31.8							
15					31.2	31.3	31.4	31.4									

(b) One year in ten

Response temperature is 31.8 C
Discharge temperature is 43.0 C
Mixing zone temperature is 41.6 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	32.0	32.2	32.5	32.7	32.9	33.1	33.4	33.7	34.2	34.8	35.9	37.0	38.6	41.6	36.9	34.0	31.7
7	31.8	32.0	32.3	32.5	32.6	32.8	33.0	33.4	33.8	34.5	35.5	36.8	38.5	40.8	35.8	33.0	31.6
8	31.9	32.0	32.4	32.6	32.7	32.9	33.1	33.5	33.9	34.6	35.6	37.0	38.8	39.5	35.5	33.0	31.6
9	31.9	32.1	32.4	32.6	32.7	32.9	33.2	33.4	33.8	34.4	35.3	36.6	38.2	38.2	35.2	32.9	31.7
10	31.9	32.1	32.4	32.6	32.7	32.9	33.1	33.4	33.7	34.1	34.9	36.1	37.9	37.4	35.3		
11	32.0	32.1	32.4	32.6	32.7	32.9	33.0	33.3	33.6	33.9	34.5	35.3					
12	32.0	32.1	32.3	32.6	32.7	32.8	33.0	33.2	33.5	33.7	34.1	34.6					
13			32.3	32.6	32.7	32.8	32.9	33.1	33.3	33.5	33.7						
14			32.4	32.5	32.7	32.8	32.9	33.0	33.2	33.3							
15					32.7	32.8	32.9	32.9									

(c) One year in thirty

Response temperature is 32.6 C
Discharge temperature is 44.0 C
Mixing zone temperature is 42.6 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	33.0	33.2	33.5	33.7	33.9	34.1	34.4	34.7	35.2	35.8	36.9	38.0	39.6	42.6	37.9	35.0	32.7
7	32.8	33.0	33.3	33.5	33.6	33.8	34.0	34.4	34.8	35.5	36.5	37.8	39.5	41.8	36.8	34.0	32.6
8	32.9	33.0	33.4	33.6	33.7	33.9	34.1	34.5	34.9	35.6	36.6	38.0	39.6	40.5	36.5	34.0	32.6
9	32.9	33.1	33.4	33.6	33.7	33.9	34.2	34.4	34.8	35.4	36.3	37.6	39.2	39.2	36.2	33.9	32.7
10	32.9	33.1	33.4	33.6	33.7	33.9	34.1	34.4	34.7	35.1	35.9	37.1	38.9	38.4	36.3		
11	33.0	33.1	33.4	33.6	33.7	33.9	34.0	34.3	34.6	34.9	35.5	36.3					
12	33.0	33.1	33.3	33.6	33.7	33.8	34.0	34.2	34.5	34.7	35.1	35.6					
13			33.3	33.6	33.7	33.8	33.9	34.1	34.3	34.5	34.7						
14			33.4	33.5	33.7	33.8	33.9	34.0	34.2	34.3							
15					33.7	33.8	33.9	33.9									

Table 5-7. Case 2 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for seven day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 29.4 C
Discharge temperature is 40.8 C
Mixing zone temperature is 39.4 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	29.8	30.0	30.3	30.5	30.7	30.9	31.2	31.5	32.0	32.6	33.7	34.8	36.4	39.4	34.7	31.8	29.5
7	29.6	29.8	30.1	30.3	30.4	30.6	30.8	31.2	31.8	32.3	33.3	34.6	36.3	38.8	33.6	30.8	29.4
8	29.7	29.8	30.2	30.4	30.5	30.7	30.9	31.3	31.7	32.4	33.4	34.8	36.4	37.3	33.3	30.8	29.4
9	29.7	29.9	30.2	30.4	30.5	30.7	31.0	31.2	31.6	32.2	33.1	34.4	36.0	36.0	33.0	30.7	29.5
10	29.7	29.9	30.2	30.4	30.5	30.7	30.9	31.2	31.5	31.9	32.7	33.9	35.7	35.2	33.1		
11	29.8	29.9	30.2	30.4	30.5	30.7	30.8	31.1	31.4	31.7	32.3	33.1					
12	29.8	29.9	30.1	30.4	30.5	30.6	30.8	31.0	31.3	31.5	31.9	32.4					
13			30.1	30.4	30.5	30.6	30.7	30.9	31.1	31.3	31.5						
14			30.2	30.3	30.5	30.6	30.7	30.8	31.0	31.1							
15					30.5	30.6	30.7	30.7									

(b) One year in ten

Response temperature is 30.9 C
Discharge temperature is 42.3 C
Mixing zone temperature is 40.9 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	31.3	31.5	31.8	32.0	32.2	32.4	32.7	33.0	33.5	34.1	35.2	36.3	37.9	40.9	36.2	33.3	31.0
7	31.1	31.3	31.8	31.8	31.9	32.1	32.3	32.7	33.1	33.8	34.8	36.1	37.8	40.1	35.1	32.3	30.9
8	31.2	31.3	31.7	31.9	32.0	32.2	32.4	32.8	33.2	33.9	34.9	36.3	37.9	38.8	34.8	32.3	30.9
9	31.2	31.4	31.7	31.9	32.0	32.2	32.5	32.7	33.1	33.7	34.6	35.9	37.5	37.5	34.5	32.2	31.0
10	31.2	31.4	31.7	31.9	32.0	32.2	32.4	32.7	33.0	33.4	34.2	35.4	37.2	36.7	34.6		
11	31.3	31.4	31.7	31.9	32.0	32.2	32.3	32.6	32.9	33.2	33.8	34.6					
12	31.3	31.4	31.6	31.9	32.0	32.1	32.3	32.5	32.8	33.0	33.4	33.9					
13			31.6	31.9	32.0	32.1	32.2	32.4	32.6	32.8	33.0						
14			31.7	31.8	32.0	32.1	32.2	32.3	32.5	32.6							
15					32.0	32.1	32.2	32.2									

(c) One year in thirty

Response temperature is 31.8 C
Discharge temperature is 43.2 C
Mixing zone temperature is 41.8 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	32.2	32.4	32.7	32.9	33.1	33.3	33.6	33.9	34.4	35.0	36.1	37.2	38.8	41.8	37.1	34.2	31.9
7	32.0	32.2	32.5	32.7	32.8	33.0	33.2	33.6	34.0	34.7	35.7	37.0	38.7	41.0	36.0	33.2	31.8
8	32.1	32.2	32.6	32.8	32.9	33.1	33.3	33.7	34.1	34.8	35.8	37.2	38.8	39.7	35.7	33.2	31.8
9	32.1	32.3	32.6	32.8	32.9	33.1	33.4	33.6	34.0	34.6	35.5	36.8	38.4	38.4	35.4	33.1	31.9
10	32.1	32.3	32.6	32.8	32.9	33.1	33.3	33.6	33.9	34.3	35.1	36.3	38.1	37.6	35.5		
11	32.2	32.3	32.6	32.8	32.9	33.1	33.2	33.5	33.8	34.1	34.7	35.5					
12	32.2	32.3	32.5	32.8	32.9	33.0	33.2	33.4	33.7	33.9	34.3	34.8					
13			32.5	32.8	32.9	33.0	33.1	33.3	33.5	33.7	33.9						
14			32.6	32.7	32.9	33.0	33.1	33.2	33.4	33.5							
15					32.9	33.0	33.1	33.1									

Table 5-8. Case 2 temperatures (C) by lake segment and elevations and discharge and mixing zone temperatures for thirty day duration for (a) normal year; (b) one year in ten; (c) one year in thirty. Layer elevations and landmark locations are shown in Table 3-1.

(a) Normal year

Response temperature is 27.7 C
Discharge temperature is 39.1 C
Mixing zone temperature is 37.7 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	28.1	28.3	28.6	28.8	29.0	29.2	29.5	29.8	30.3	30.9	32.0	33.1	34.7	37.7	33.0	30.1	27.8
7	27.9	28.1	28.4	28.6	28.7	28.9	29.1	29.5	29.9	30.8	31.6	32.9	34.6	36.9	31.9	29.1	27.7
8	28.0	28.1	28.5	28.7	28.8	29.0	29.2	29.6	30.0	30.7	31.7	33.1	34.7	35.6	31.6	29.1	27.7
9	28.0	28.2	28.5	28.7	28.8	29.0	29.3	29.5	29.9	30.5	31.4	32.7	34.3	34.3	31.3	29.0	27.8
10	28.0	28.2	28.5	28.7	28.8	29.0	29.2	29.5	29.8	30.2	31.0	32.2	34.0	33.5	31.4		
11	28.1	28.2	28.5	28.7	28.8	29.0	29.1	29.4	29.7	30.0	30.6	31.4					
12	28.1	28.2	28.4	28.7	28.8	28.9	29.1	29.3	29.6	29.8	30.2	30.7					
13			28.4	28.7	28.8	28.9	29.0	29.2	29.4	29.6	29.8						
14			28.5	28.6	28.8	28.9	29.0	29.1	29.3	29.4							
15					28.8	28.9	29.0	29.0									

(b) One year in ten

Response temperature is 29.0 C
Discharge temperature is 40.4 C
Mixing zone temperature is 39.0 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	29.4	29.6	29.9	30.1	30.3	30.5	30.8	31.1	31.6	32.2	33.3	34.4	36.0	39.0	34.3	31.4	29.1
7	29.2	29.4	29.7	29.9	30.0	30.2	30.4	30.8	31.2	31.9	32.9	34.2	35.9	38.2	33.2	30.4	29.0
8	29.3	29.4	29.8	30.0	30.1	30.3	30.5	30.9	31.3	32.0	33.0	34.4	36.0	36.9	32.9	30.4	29.0
9	29.3	29.5	29.8	30.0	30.1	30.3	30.6	30.8	31.2	31.8	32.7	34.0	35.6	35.6	32.6	30.3	29.1
10	29.3	29.5	29.8	30.0	30.1	30.3	30.5	30.8	31.1	31.5	32.3	33.5	35.3	34.8	32.7		
11	29.4	29.5	29.8	30.0	30.1	30.3	30.4	30.7	31.0	31.3	31.9	32.7					
12	29.4	29.5	29.7	30.0	30.1	30.2	30.4	30.6	30.9	31.1	31.5	32.0					
13			29.7	30.0	30.1	30.2	30.3	30.5	30.7	30.9	31.1						
14			29.8	29.9	30.1	30.2	30.3	30.4	30.6	30.7							
15					30.1	30.2	30.3	30.3									

(c) One year in thirty

Response temperature is 29.8 C
Discharge temperature is 41.2 C
Mixing zone temperature is 39.6 C

	Segment Number																
Layer	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	21
6	30.2	30.4	30.7	30.9	31.1	31.3	31.6	31.9	32.4	33.0	34.1	35.2	36.8	39.8	35.1	32.2	29.9
7	30.0	30.2	30.5	30.7	30.8	31.0	31.2	31.6	32.0	32.7	33.7	35.0	36.7	39.0	34.0	31.2	29.8
8	30.1	30.2	30.6	30.8	30.9	31.1	31.3	31.7	32.1	32.8	33.8	35.2	36.8	37.7	33.7	31.2	29.8
9	30.1	30.3	30.6	30.8	30.9	31.1	31.4	31.6	32.0	32.6	33.5	34.8	36.4	36.4	33.4	31.1	29.9
10	30.1	30.3	30.6	30.8	30.9	31.1	31.3	31.6	31.9	32.3	33.1	34.3	36.1	35.6	33.5		
11	30.2	30.3	30.6	30.8	30.9	31.1	31.2	31.5	31.8	32.1	32.7	33.5					
12	30.2	30.3	30.5	30.8	30.9	31.0	31.2	31.4	31.7	31.9	32.3	32.8					
13			30.5	30.8	30.9	31.0	31.1	31.3	31.5	31.7	31.9						
14			30.6	30.7	30.9	31.0	31.1	31.2	31.4	31.5							
15					30.9	31.0	31.1	31.1									

and one year in thirty. The results of this analysis are given in Table 5-9. The table shows that for Case 1 the 99 F limit is exceeded in the discharge flume for more than 90 days one year in thirty and is exceeded in the mixing zone for 60 days one year in thirty.

6.0 Sensitivity Analyses

Sensitivity analyses were performed for different plant loads, plant pumping rates and lake elevations to determine the change in mixing zone temperatures to each of these parameters. The results of the sensitivity analyses are as follows:

a. For heat rejection rate, the temperatures in the mixing zone decrease by 0.80 °C (1.44°F) for each 10% decrease in plant load.

b. For pumping rates, the temperatures in the mixing zone increase by 0.23 °C (0.41°F) for each 100 cfs decrease in pumping rate.

c. For lake elevations, the temperatures in the mixing zone increase by 0.24 °C (0.43°F) for each foot decrease in May 31 lake starting elevation.

These sensitivity values can be used to estimate changes in mixing zone conditions for small changes in the above parameters.

7.0 Conclusions

The GLVHT model has been successfully verified for 1988 realtime operating conditions. It has been used to compute excess temperature distributions for continuous 100% full load operations for two different initial lake elevations.

The results of the GLVHT analysis have been combined with the results of a statistical analysis of 34 years of meteorological records to produce lake temperatures that would occur at certain specified annual frequencies over different daily durations. These results can be used to judge the significance of different temperature limitations and to perform comparative fisheries thermal

Table 5-9. Days exceeding 99 F at the discharge flume and at the mixing zone for Case 1 and Case 2 for normal year, one year in five, one year in ten, one year in twenty and one year in thirty.

Days exceeding temperature limits

Return period, years	Mixing zone Days exceeding 37.22 C		Discharge flume Days exceeding 37.22 C	
	Case 1	Case 2	Case 1	Case 2
normal	19	39	60	63
5	31	55	70	74
10	43	64	78	>90
20	54	72	>90	>90
30	60	76	>90	>90

tolerance studies.

Additional effort is required to further verify the modeling results, to develop realtime operating rules to meet thermal limits, and to relate temperature distributions in the lake to future fisheries studies. For verification, the 1988 results show that the model is satisfactorily related to plant realtime operating conditions and the Springfield, Illinois meteorological data, but further work is required to characterize the stratification in the deeper segments of the lake due to surface and groundwater inflows. Development of realtime operating rules relative to thermal limits requires determining the monitoring and operational procedures to be followed over realtime to meet the thermal limits. The fisheries evaluations requires a comparison of absolute temperatures with excess temperatures at different locations in the lake to separate plant operating effects from natural temperature variations due to meteorological conditions.

References

Buchak, E. M. and J. E. Edinger. 1984. Generalized, Longitudinal-Vertical Hydrodynamics and Transport: Development, Programming and Applications. Prepared for U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. Contract No. DACW39-84-M-1636. Prepared by J. E. Edinger Associates, Inc., Wayne, PA. Document No. 84-18-R. June.