THERMAL ANALYSIS OF LAKE GREESON, ARKANSAS AND SARDIS LAKE, MISSISSIPPI

by

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INTRODUCTION

The Vicksburg District Corps of Engineers has constructed seven dams on rivers within the District boundaries. The Vicksburg District is charged with the operation and maintenance of the lakes impounded by these dams (Table 1).

In order to optimize water quality in these lake/river systems, it has become necessary to evaluate project operations and proposed operational changes to determine their overall effect on water quality. Mathematical or computer models are ideally suited for this purpose. Once verified against actual occurrences, models can be used to simulate operational changes and their net effect on key parameters.

PURPOSE

The purpose of this study was twofold: (1) to determine the capability of a selected temperature change in two dissimilar, large manmade lakes, and (2) to apply the model to determine optimum discharge elevations to satisfy downstream water quality objectives for one of the lakes being studied.

APPROACH

Lake Greeson was selected for study as being representative of a deep, long detention, cold-water-release lake. Sardis Lake, by contrast, is relatively shallow, with medium detention, and warm-water releases (Figure 1). Lake Greeson is characteristic of the three District lakes in Arkansas, with DeGray and Ouachita being the other two (Figure 2). Sardis Lake is characteristic of the four District lakes in Mississippi, with Arkabutla, Enid, and Grenada being the other three (Figure 3).

The study was performed with the use of a numerical simulation model. The approach involved the selection of five study years for each lake and simulation of each of these years. The study years selected, 1972-76 for Lake Greeson and 1966-70 for Sardis Lake, had variations of inflows, discharges, and air temperatures which created conditions of thermal stratification in both lakes.

Field data temperature profiles were available for the selected periods of study as shown in Table II. These profiles were taken in the deepest part of the lake just upstream from the dam in both cases. To model these profiles, the heat transfer into and out of the lakes was simulated to maintain a heat budget throughout the simulation periods. Lake operations were programmed into the model as they had actually occurred during the study periods. Output from the simulations included graphical comparison of the actual and predicted lake temperature profiles and a prediction of release temperatures on specified days of each year. A sample printout of the model is shown in Figure 4.

Following calibration and verification of the models, the Lake Greeson model was applied to a problem improving downstream water quality by releasing warmer discharges. For this application, two alternatives were examined to evaluate their potential to release water of a temperature approaching that of the inflowing stream temperature. The lake surface elevation, selected discharge outlet elevation, inflow water temperature, and discharge water temperature were all plotted for analysis. By evaluating this output it was possible to select discharge outlet elevations and a schedule of operation to allow discharge water temperature to approach inflow water temperature. An analysis on the effects of the change of lake operations on the temperature balance of the lake was also performed by varying the outlet elevations and comparing predicted temperature profiles.

A WORD ON THERMAL STRATIFICATION

The phenomenon of thermal stratification, or segregation of lake waters into layers that exhibit differences in temperature and density, is characteristic of large, deep lakes. Such lakes are said to be bouyancy-dominated as opposed to being flow-dominated, and are said to have long detention times.

The stratification is a result of (1) the unique temperature-density relationship of water, (2) the low thermal conductivity of water, and (3) the limited penetration of solar energy into a body of water.

The temperature-density relationship of water is such that water reaches maximum density at 4° C. As temperatures increase or decrease from 4° C, the changes result in an increased rate of change in density. Much larger density changes are observed at high temperatures for each 1° C temperature change compared to those at low temperatures. For example, a column of water that is 5° C at the bottom and 6° C at the top is of fairly uniform density, and is therefore easily mixed. A column of water that is 25° C at the bottom and 26° C at the top exhibits large density differences, and requires much more energy to bring about mixing.

All deep, long-detention-time lakes do not exhibit the same degree of stratification. In the Vicksburg District, the Arkansas lakes stratify 9-10 months of the year (Figure 5). The Mississippi lakes stratify either 4-5 months (Figure 6). The degree of stratification is dependent upon such factors as geographical location, climatology, hydrology, depth, volume, surface area, discharge facilities, and other physical configurations of the lake.

The classical representation of three-layer lake temperature stratification is shown in Figure 7. The upper zone is called the epilimnion. The middle zone is called the metalimnion. The lower zone is called the hypolimnion.

The epilimnion is usually well mixed and contains sufficient dissolved oxygen to permit fish reproduction and growth. Oxygen is available at the air-water interface, and wind supplies the mixing force.

The metalimnion is the region of temperature change or gradient. The plane of maximum rate of decrease in temperature is called the thermocline. Under conditions of strong stratification, the metalimnion is extremely stable and acts as a barrier to complete lake mixing.

The hypolimnion consists of the densest, coldest water in the lake. There is some evidence that mixing does occur in the hypolimnion, but since it is cut off from the epilimnion by the metalimnion, its supply of dissolved oxygen is limited. Organic decomposition in this region exerts an oxygen demand, and the region may go anoxic. Oxygen levels frequently drop below levels required to support fish life.

Figure 8 demonstrates a stratification pattern for a one-year period. During early spring, the lake may be isothermal throughout. On into spring the epilimnion begins to warm due to surface heat transfer across the air-water interface and advection due to warmer inflows. The amount of energy required to mix the lake is now increasing rapidly. As summer approaches, solar radiation increases, directing more energy into the epilimnion, and stratification becomes evident. The temperature of the hypolimnion remains virtually unchanged. By mid-summer, three distinct temperature regions are detectable. The metalimnion is well established, and provides a definite barrier to mixing. In lakes deeper than thirty meters, very little temperature increase is noted in the hypolimnion. In large lakes of less than thirty meters depth, the hypolimnion temperature may rise up to 15°C higher than early spring readings. Thermal stratification persists until late summer or early fall. At this point inflow temperatures and solar radiation are declining. Surface waters start to cool, and wind action and convection drive mixing down into the metalimnion. This barrier to mixing deteriorates until the temperatures and densities of the upper regions approach those of the hypolimnion. As the upper regions cool, the energy required for mixing lessens, until wind action is sufficient to mix the lake from water surface to hypolimnion. At this point the density balance is extremely "fragile" and mixing influences bring about the fall turnover, when water from the hypolimnion is displaced and moved upward by water being driven down from the upper regions. The lake may then become thoroughly mixed, or isothermal (5).

SELECTION OF MATH MODEL

During the past few years, several thermal analysis math models have been developed and applied. The model selected for use in this study is called ECOTHERM. ECOTHERM is the thermal analysis portion of WESECO, an ecosystem model being developed by the Environmental Lab, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. WESECO is an updated version of the WQRRS model developed by Water Resources Engineers, Inc., and subsequently modified by the Hydrologic Engineering Center, Davis, California. WESECO and ECOTHERM are intended for use in modeling lakes which are bouyancy-dominated with long detention times (7).

The decision to use ECOTHERM was based on the following considerations: (1) ECOTHERM, as a third-generation model, includes certain refinements which make it applicable to a variety of lakes; and (2) the use of ECOTHERM would provide the base for future development of ecosystem models for lakes in the Vicksburg District.

Required input parameters for using ECOTHERM are shown in Table III. Hydrologic data was available from records of the Vicksburg District. Meteorological data was obtained from the National Weather Service, Ashville, North Carolina.

Required calibration coefficients are shown in Table IV.

ECOTHERM provides a procedure for examining the balance of thermal energy imposed on an impoundment, coupled with the placement, interaction, routing, and withdrawal of flows in the impoundment. This energy balance and hydrodynamic activity are used to predict the changes in vertical temperature profiles with respect to time. The model includes computational methods for simulating heat transfer at the air-water interface, heat advection due to flow, outflow, and wind-induced mixing, and the internal dispersion of thermal energy (Figure 9). The model is based on the division of the lake into discrete horizontal layers or control slices, as shown in Figure 10.

ECOTHERM is based on the following assumptions:

A. Isotherms, or lines of equal temperature, are parallel to the water surface in the lateral and longitudinal directions (ID model).
B. Internal advection between layers and heat transfer occur only in the vertical direction.
C. Inflow and outflow from the lake occur as a uniform horizontal distribution within each layer.
D. Internal dispersion of thermal energy is accomplished by combining molecular diffusion, turbulet diffusion, and thermal convection into an eddy or effective diffusion coefficient.

It should be noted that ECOTHERM is still in the developmental stage. This study utilized the model in its middle stages of development. Solution techniques used for this study may or may not still be applicable in the final version of the model, estimated to be published in fiscal year 1979.

MODEL CALIBRATION, VERIFICATION

As shown previously, the ECOTHERM model requires the determination of coefficients of surface heat exchange distribution and turbulent mixing. For Lake Greeson and Sardis Lake, calibration runs were made for 1972 and 1968, respectively. In separate studies on each lake, coefficients were adjusted and the simulation was repeated until the predicted temperature profiles corresponded in shape and range to those observed in field studies of the lakes for the same time frame. The results of the calibration simulations are shown in Figures 11 and 12.

Using coefficients determined in the calibration analysis, verification studies were performed using Lake Greeson models for 1973, 1974, 1975, and 1976, and Sardis Lake models for 1966, 1967, 1969, and 1970. The results of two of the verification runs are shown in Figures 13 and 14.

The Sardis Lake model produced good verification results for the four years examined. The Lake Greeson model was verified for 1975 and 1976, but poor agreement between observed and predicted temperature profiles was noted for 1973 and 1974, as demonstrated in Figure 15.

DISCUSSION

Results of the calibration and verification simulations were analyzed to determine why the Lake Greeson model could not be verified for 1973 and 1974. Examination of average monthly inflows and discharges for the study years, shown in Figures 16 and 17, shows that both inflows and discharges were significantly above average during the early portions of those years, reflecting the floods of 1973 and 1974.

Examination of average monthly inflows and discharges for Sardis Lake during the study years, shown in Figures 18 and 19, shows above average inflows and discharges for 1969 and 1970.

The above average inflows and discharges apparently affected the Lake Greeson models to a greater degree than the Sardis Lake models. A possible explanation for this is in the method of discharge from each lake. Lake Greeson is used for power generation, and its discharges are of high volume but intermittent frequency. Sardis Lake, which is used for flow augmentation, has discharges of high volume and sustained frequency. Input to the model was performed on a daily time step. In the case of Sardis, a discharge of 100 cfs might have actually been 100 cfs for each moment of that day. A discharge input of 100 cfs for Greeson might actually have been 2400 cfs for a one-hour period, averaged to 100 cfs over a 24-hour day. This representation of existing conditions might not be sufficiently accurate for model simulation. A shorter time step, six hours for example, might provide better representation of existing conditions, but would increase substantially the volume of input and work effort required.

In all simulations on both lakes, a "superheating" phenomenon was experienced in calibration attempts. This superheating ranged from 2 - 5° C, and could not be predicted by varying any of the calibration coefficients. This superheating was observed in the spring and summer of each year.

Meteorological data from Little Rock, Arkansas, was used as input to the Lake Greeson models; meteorological data from Memphis, Tennessee, was used in the Sardis Lake models. It is possible that this data reflected the "heat island effect" of large cities like Little Rock and Memphis. These urban developments would be expected to record higher air temperatures during the spring and summer period than the air temperatures observed in the rural locations of Lake Greeson and Sardis Lake.

For model simulations, an adjustment was made to cool Lake Greeson input air temperatures by 2° C throughout the year. No air temperature adjustment was made for Sardis Lake simulations, however. As a result, surface water temperatures for Lake Greeson are in close agreement (observed with predicted), while Sardis Lake observed and predicted water temperatures parallel each other in the spring and summer period, varying by 2 - 5° C.

MODEL APPLICATION

Utilizing the calibrated and verified Lake Greeson models for 1972 and 1976, an application was made to a Lake Greeson water supply problem.

Lake Greeson is a deep (51 meters), cold-water-release lake which exhibits strong stratification throughout 9-10 months of the year.

The discharge outlet centerline elevation is fixed at 28 meters measured from the lake bottom. Discharges are drawn from under the thermocline during the spring and summer of each year. Discharge temperatures are considerably below natural stream temperatures for this period, as simulated in Figure 20.

The Arkansas Game and Fish Commission has asked the Vicksburg District to consider modifying the discharge configuration to draw water from a higher elevation, above the thermocline, in order to release warmer water to the receiving stream. If this is done, Arkansas Game and Fish hopes to establish a warmwater fishery in the Little Missouri River below the dam.

The following alternatives were considered:

A. Trashrack Modifications.

The discharge outlets at Lake Greeson are in the face of the dam. They are covered by trashracks to prevent debris from entering the penstocks and damaging the turbines. These trashracks extend from just below the outlet invert up to elevation 47 meters.

In order to draw water from a higher elevation, it was proposed to plate over the trashracks with fixed steel plates, or bulkheads, up to elevation 37 meters. Above elevation 37 meters, the plates would be manually adjustable, such that openings could be fixed at centerline elevations of 44 meters and 41 meters. Figure 21 details the proposed bulkhead/trashrack modifications.

An additional restriction on reservoir operations would be required by this alternative. To prevent cavitation from occurring between the bulkheads and the face of the dam, approximately three meters of head would have to be maintained above the uppermost submerged bulkhead elevation. At the lower setting, this means that the lake water could not be down below 40 meters (9).

To examine this alternative, simulations of the calibrated Lake Greeson models for 1972 and 1976 were reported, with the centerline outlet elevation raised from 28 meters to 41 meters. Results of the simulation for 1976 are shown in Figure 22.

B. Selective Withdrawal.

A second alternative to the cold-water-release problem would be to construct a selective withdrawal structure over the discharge outlets. The structure would have several adjustable openings, such that water could be drawn from any one of a range of elevations, or combinations of elevations, to meet desired water quality objectives both within the lake and downstream of the dam.

To simulate selective withdrawal operations, runs were again made with calibrated models for Lake Greeson for 1972 and 1976. For these simulations, the model was allowed to vary the outlet elevation daily, through a range of outlets at elevations 44, 41, 38, 35, and 29 meters. Target discharge temperatures were set equal to simulated inflow temperatures. Results of the simulation for 1976 are shown in Figure 23.

ANALYSIS OF APPLICATION

Both proposed alternatives, trashrack modification and selective withdrawal, will apparently result in warmer discharges, approaching the temperature of the inflowing stream. This would tend to elevate temperatures downstream of the dam and aid in the establishment of a warmwater fishery.

The predicted effect on the thermal structure of the lake is shown in Figure 24. Releasing warmer discharges will have a tendency to elevate the thermocline, reducing the size of the epilimnion significantly. An overall cooling of the lake is also predicted when the lake returns to an isothermal condition.

CONCLUSIONS

This version of ECOTHERM can be utilized to model variations in lake temperature profiles on bouyancy-dominated lakes with relatively constant discharges. Increasing modeling difficulty is encountered, however, when increasing discharges are coupled with erratic periods of short-term discharge.

On the model application to the water quality problem for Lake Greeson discharges, both the trashrack modification and selective withdrawal would apparently obtain the desired water quality objective of increasing discharge temperatures to a point approaching inflow temperatures. A schedule of gate-change operations can be derived from the model's selection of elevations in the selective withdrawal mode. However, the model predicted that the increase in temperature of the releases may be at the expense of the lake's productive epilimnion, possibly reducing the fishery habitat potential of the lake.

Both alternatives should be examined further as potential solutions to achieving the water quality objective of releasing warmer water from Lake Greeson, as both will apparently accomplish that objective. However, the possible detrimental effect on lake fishery habitat which may accompany either of these methods should be fully evaluated.

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ACKNOWLEDGEMENTS

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The writer also expresses gratitude to personnel of the Environmental Lab, U.S. Army Engineer Waterways Experiment Station, for computer program assistance.

Table I

Authorized Project Purposes, Vicksburg District Lakes (1)

Project			Purposes					
Lake	Main Tributary	River Basin	(1) Flood Control	(2) Low Flow Augmentation	(3) Power Generation	(4) Fish and Wildlife	(5) Recreation	(6) Water Supply
Sardis	Little Tallahatchie	Yazoo	x	x		x	x	
Arkabutla	Coldwater	Yazoo	x	x		x	x	
Grenada	Skuna & Yalobusha	Yazoo	x	x		x	x	
Enid	Yocona	Yazoo	x	x		x	x	
DeGray	Caddo	Ouachita	x		x	x	x	x
Ouachita	Ouachita	Ouachita	x	x	x	x	x	
Greeson	Little Missouri	Ouachita	x		x	x	x	

Table II

Water Temperature Data Availability (3)

Year	Lake Greeson Number of Inflow Temperatures	Lake Greeson Number of Temperature Profiles	Sardis Lake Number of Inflow Temperatures	Sardis Lake Number of Temperature Profiles
65	-	35	9	46
66	-	40	22	39
67	-	25	22	23
68	-	7	12	12
69	-	-	12	12
70	-	-	12	12
71	5	5	9	9
72	9	9	-	-
73	10	10	3	2
74	24	12	18	3
75	52	9	33	2
76	52	9	37	2

Table III

ECOTHERM Input Parameters (4)

Input Parameters	Units	Update Frequency	Data Source
Inflow	M^3/Sec	Daily	Vicksburg District
Discharge	M^3/Sec	Daily	Vicksburg District
Inflow Temperature	°C	Daily	Vicksburg District
Initial Temperature Profile	°C/M	Initial Entry	Vicksburg District
Stage-Area Relationship	M-M^2	Initial Entry	Vicksburg District
Effective Width at Outlet Structure	M-M	Initial Entry	Vicksburg District
Effective Length	M	Initial Entry	Vicksburg District
Longitude	Degrees	Initial Entry	Vicksburg District
Latitude	Degrees	Initial Entry	Vicksburg District
Wind Speed	Km/Hr	Daily	National Weather Service
Air Temperature	°C	Daily	National Weather Service
Cloud Cover	Fraction	Daily	National Weather Service
Atmospheric Pressure	mb	Daily	National Weather Service
Dewpoint Temperature	°C	Daily	National Weather Service

Table IV

Model Calibration Coefficients (7)

Coefficient	Definition	Area of Influence	Approximate Range	Units	Type Adjustment
CDENS	Critical Density	Inflow	0.002 - 0.2	Kg/M^3	Fine
BB	Evaporation Coefficient	Epilimnion	10^{-10} - 10^{-9}	Dimensionless	Fine
TURB	Atmospheric Turbidity	Epilimnion	2 - 5	Dimensionless	Fine
EXCO	Extinction Coefficient	Epilimnion	0.4 - 3.5	1/Meter	Fine
SURF	Surface Fraction (Heat)	Surface	0.4 - 0.9	Dimensionless	Fine
GSWH	Critical Stability	Hypolimnion, Metalimnion	10^{-6} - 10^{-2}	1/$Second^2$	Coarse
A1	Diffusion Coefficient	Surface	10^{-6} - 10^{-4}	M^2/Second	Coarse
A2	Diffusion Coefficient	Hypolimnion	10^{-7} - 10^{-3}	M^2/Second	Coarse
A3	Diffusion Coefficient	Metalimnion	-1.0 - -0.5	Dimensionless	Coarse

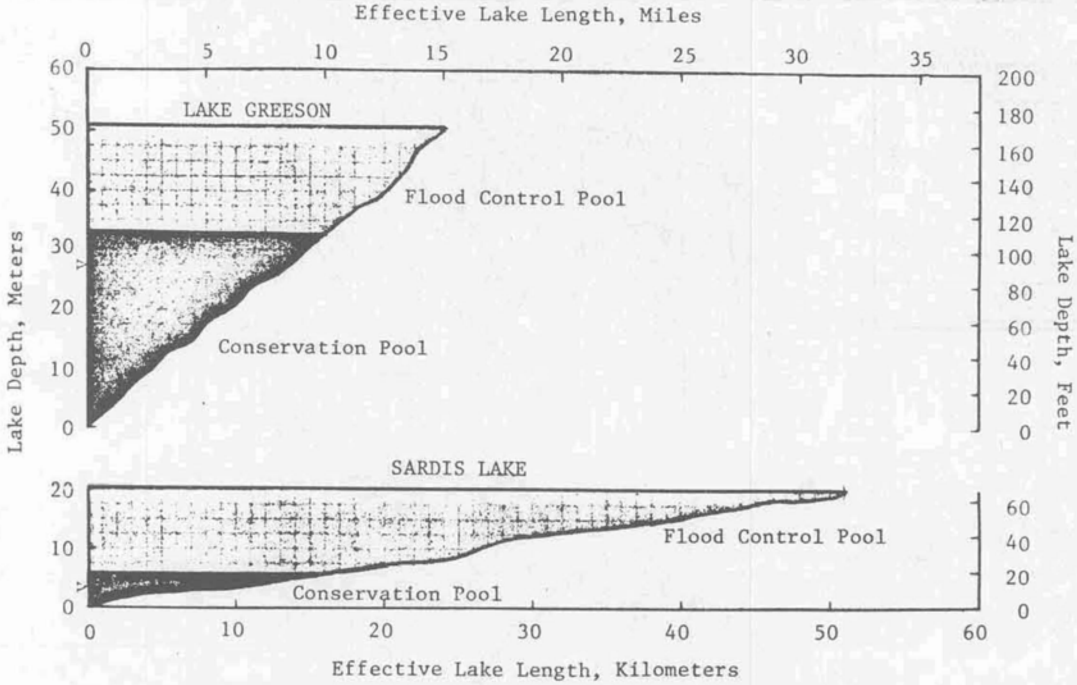

FIGURE 1. Length versus Depth Relationships for Lake Greeson and Sardis Lake. >denotes outlet elevation (2).

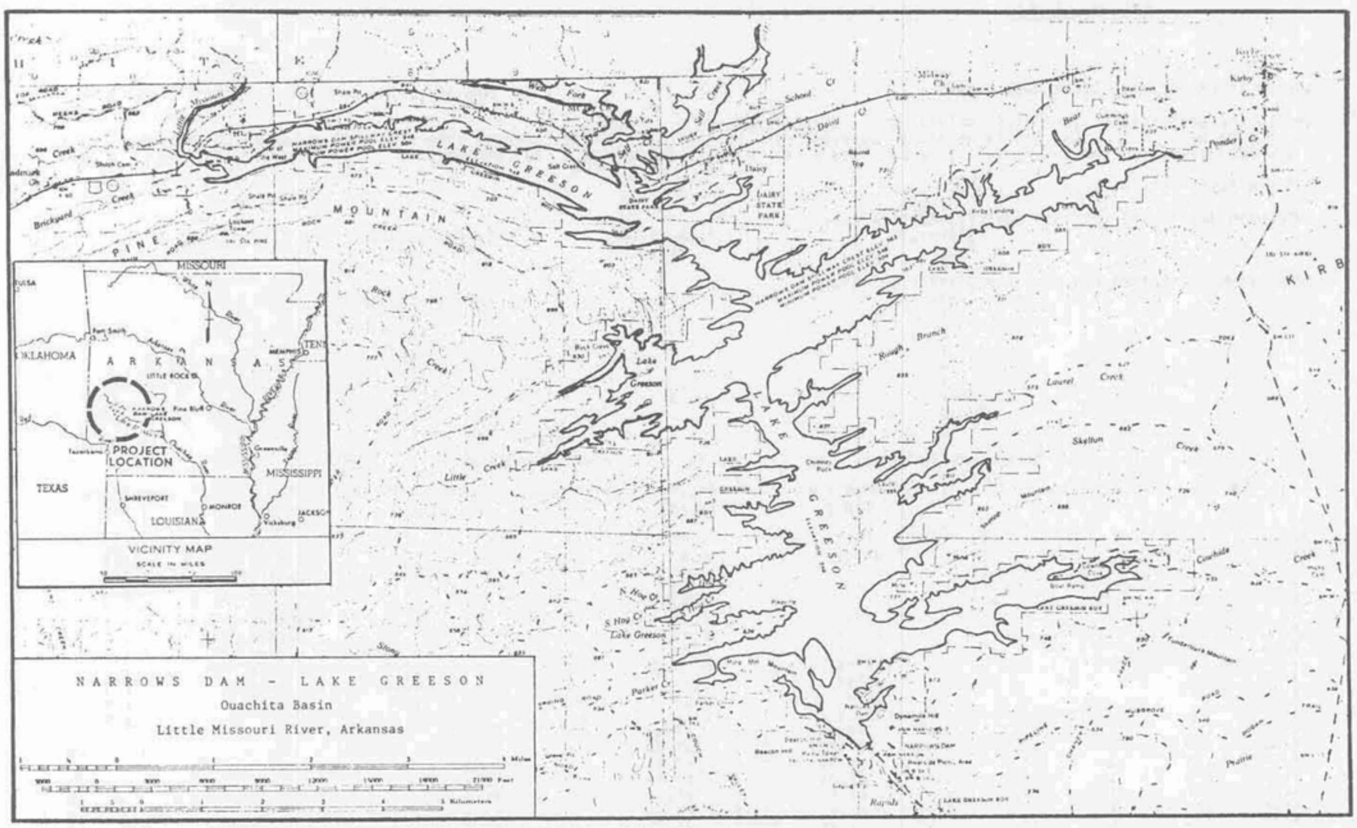

FIGURE 2. Map of Narrows Dam - Lake Greeson, Ouachita Basin, Little Missouri River, Arkansas.

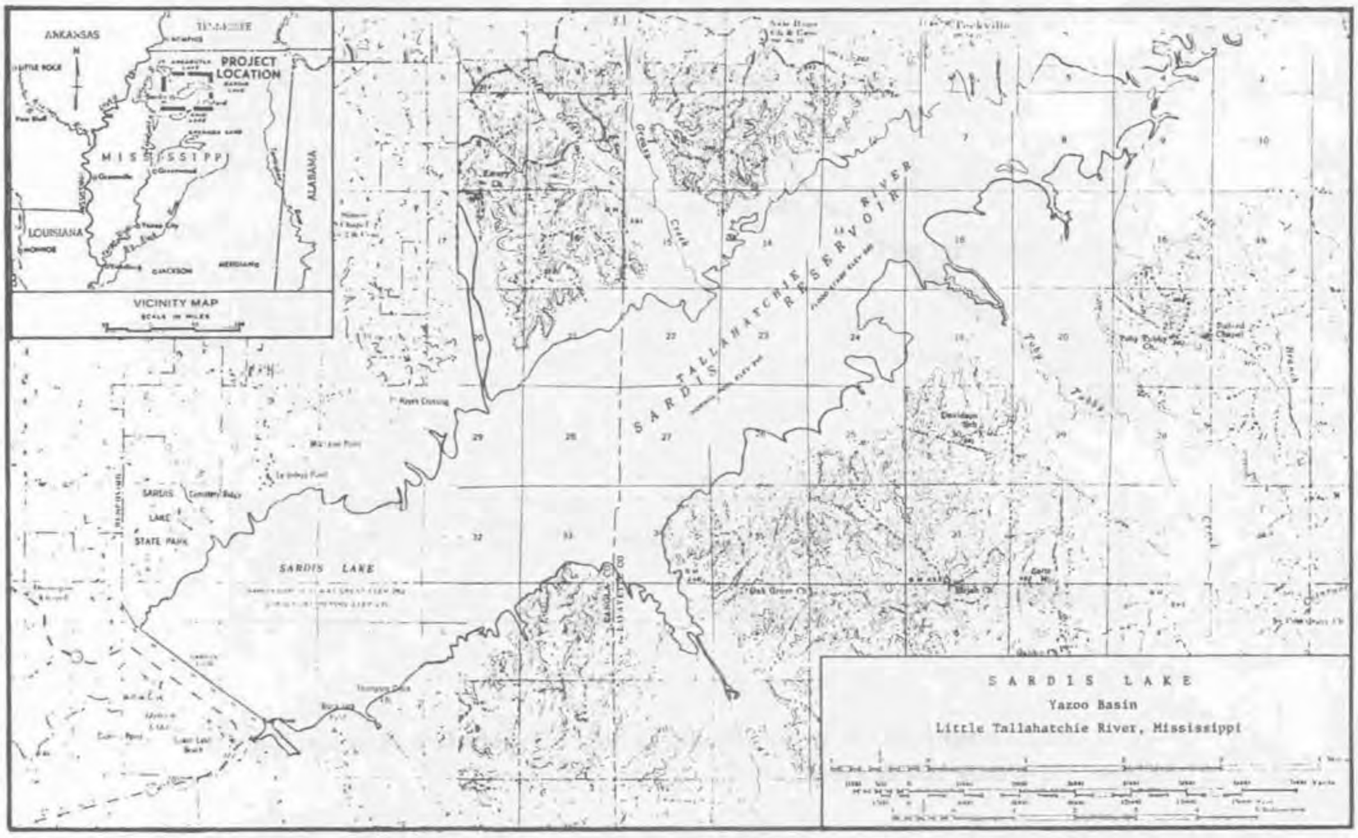

FIGURE 3. Map of Sardis Lake, Yazoo Basin, Little Tallahatchie River, Mississippi.

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STATUS AT END OF SIMULATION HOUR  4128                                          THIS IS JULIAN DAY 172, COMPUTATION INTERVAL  1

AVERAGE METEOROLOGICAL QUANTITIES FOR THIS COMPUTATION PERIOD:
  CLOUD COVER           0.56  AIR PRESSURE,MB  1080.68  WIND SPEED,KPH      15.51  DRYBULB TEMP,DEGC:  29.2  DEWPOINT TEMP,DEGC: 21.5
  S/W RAD,KC/M2/HR    197.9   L/W RAD,KC/M2/HR   355.8  VAPOR PRESSURE,MB   25.6  SAT.VAP.PRES,MB     49.4  EVAP.RATE,M/HR      0.0003

SURFACE ELEVATION,M:  12.3

INFLOWING QUANTITIES FOR THIS COMPUTATION INTERVAL:
                                    TRIBUTARY                INFLOW,M3/SEC           TEMPERATURE,DEG C
                                        1                        5.7                      27.72

OUTFLOWING QUANTITIES FOR THIS COMPUTATION INTERVAL:
                                      PORT                    LAYER                 OUTFLOW,M3/SEC
                                        1                       2                        0.
                                        2                       3                       50.97
                                        3                       3                        0.
                                        4                       4                        0.
                                        5                       2                        0.
                                        6                       3                        0.
                                        7                       3                        0.
                                        8                       4                        0.

                         TOTAL OUTFLOW,M3/SEC              50.97     OUTFLOW TEMPERATURE DEG C     27.68

  0    5   10   15   20   25   30   35     TEMPERATURE    S/W RADIATION  LAYER INFLOW   LAYER OUTFLOW DIFFUSION COEF      ELEVATION
                                              DEG C         KC/M2/HR        M3/SEC         M3/SEC          M2/HR               M

 12                                 E*        32.01           9.97           0.             1.39          0.1704              11.5
 11                                 E*        32.01           1.30           0.             3.56          0.1281              10.5
 10                                 E*        32.01           0.18           0.             5.05          0.0858               9.5
  9                                 E*        31.67           0.02           0.             6.73          0.0435               8.5
  8                        D       *          29.88           0.00           0.             8.80          0.0012               7.5
  7                       D  *                25.63           0.00           5.66           7.49          0.0012               6.5
  6                       D*                  24.09           0.00           0.             5.82          0.0024               5.5
  5                       D*                  23.70           0.00           0.             4.08          0.0036               4.5
  4                      D *                  23.56           0.00           0.             2.91          0.0036               3.5
  3                      D*                   23.47           0.00           0.             2.66          0.0036               2.5
  2                      D*                   23.40           0.00           0.             2.41          0.0036               1.5
  1                      D*                   23.36           0.00           0.             0.08          0.                   0.5
 4128      172        1       12.3      5.7    27.72     51.0     27.66      2        51.0                                            NO
 4152      173        1       12.3     11.3    27.63     51.0     27.66      2        51.0                                            NO
 4176      174        1       12.3     25.5    26.78     51.0     27.61      2        51.0                                            NO
 4200      175        1       12.2     31.1    27.21     51.0     27.59      2        51.0                                            NO
 4224      176        1       12.2     22.7    26.98     51.0     27.66      2        51.0                                            NO
 4248      177        1       12.2     41.1    26.19     94.9     27.59      3        94.9                                            NO
 4272      178        1       12.1     17.0    25.96    117.5     27.31      3       117.5                                            NO
 4296      179        1       12.0     17.0    28.58    116.1     27.26      3       116.1                                            NO
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FIGURE 4. ECOTHERM Model Sample Output (4).

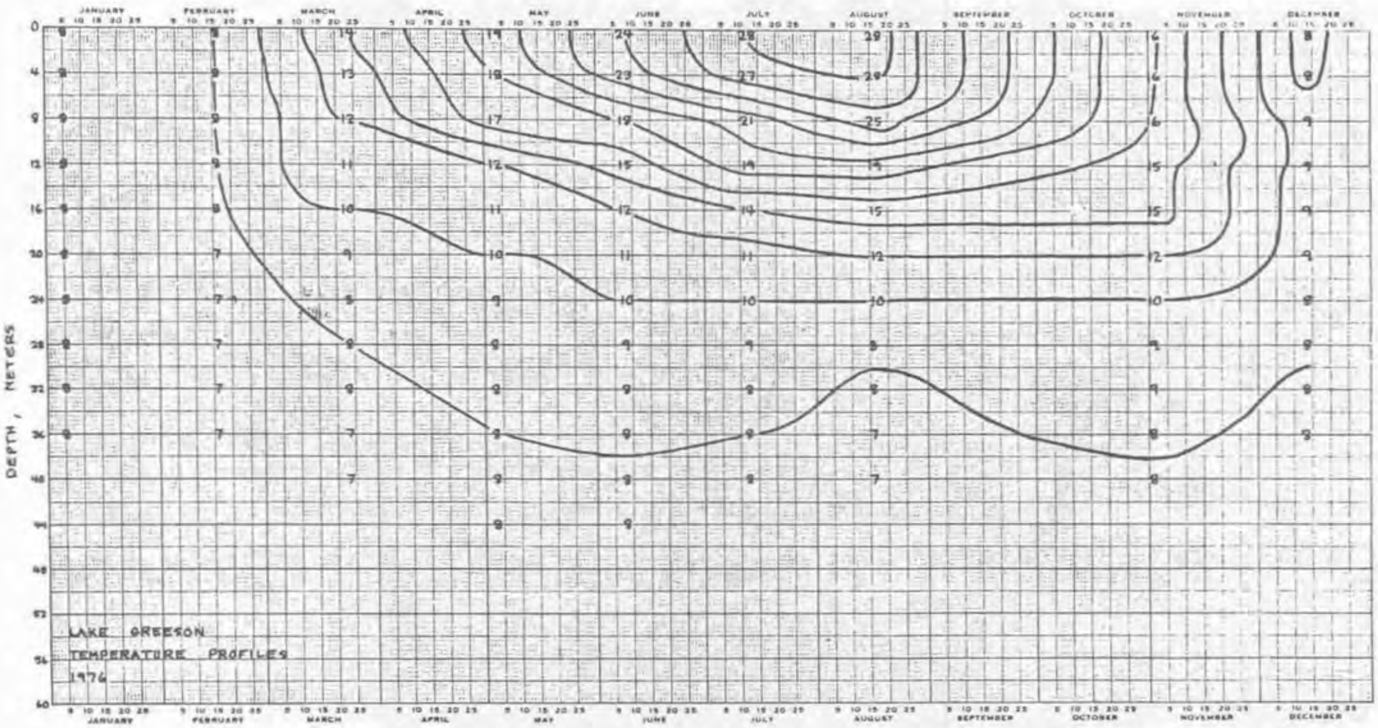

FIGURE 5. Lake Greeson Temperature Profiles, 1976 (3).

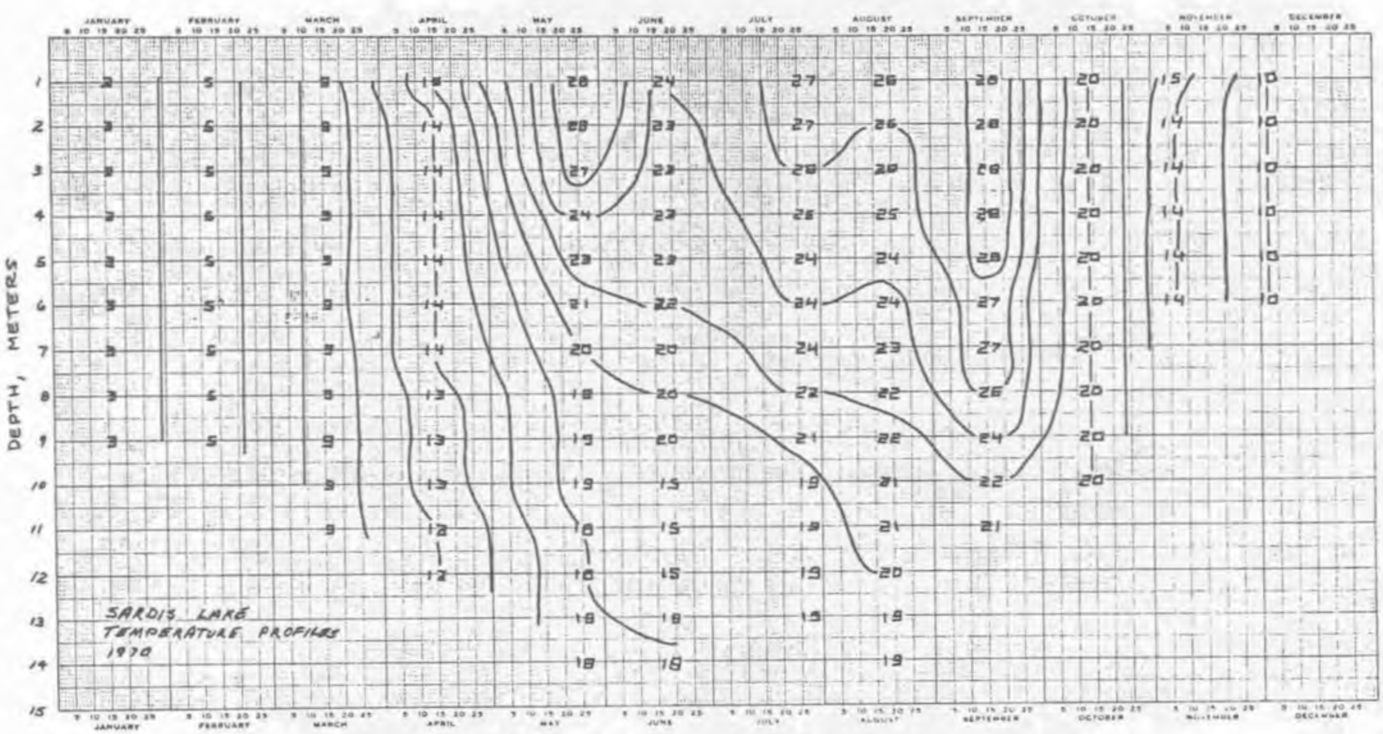

FIGURE 6. Sardis Lake Temperature Profiles, 1970 (3).

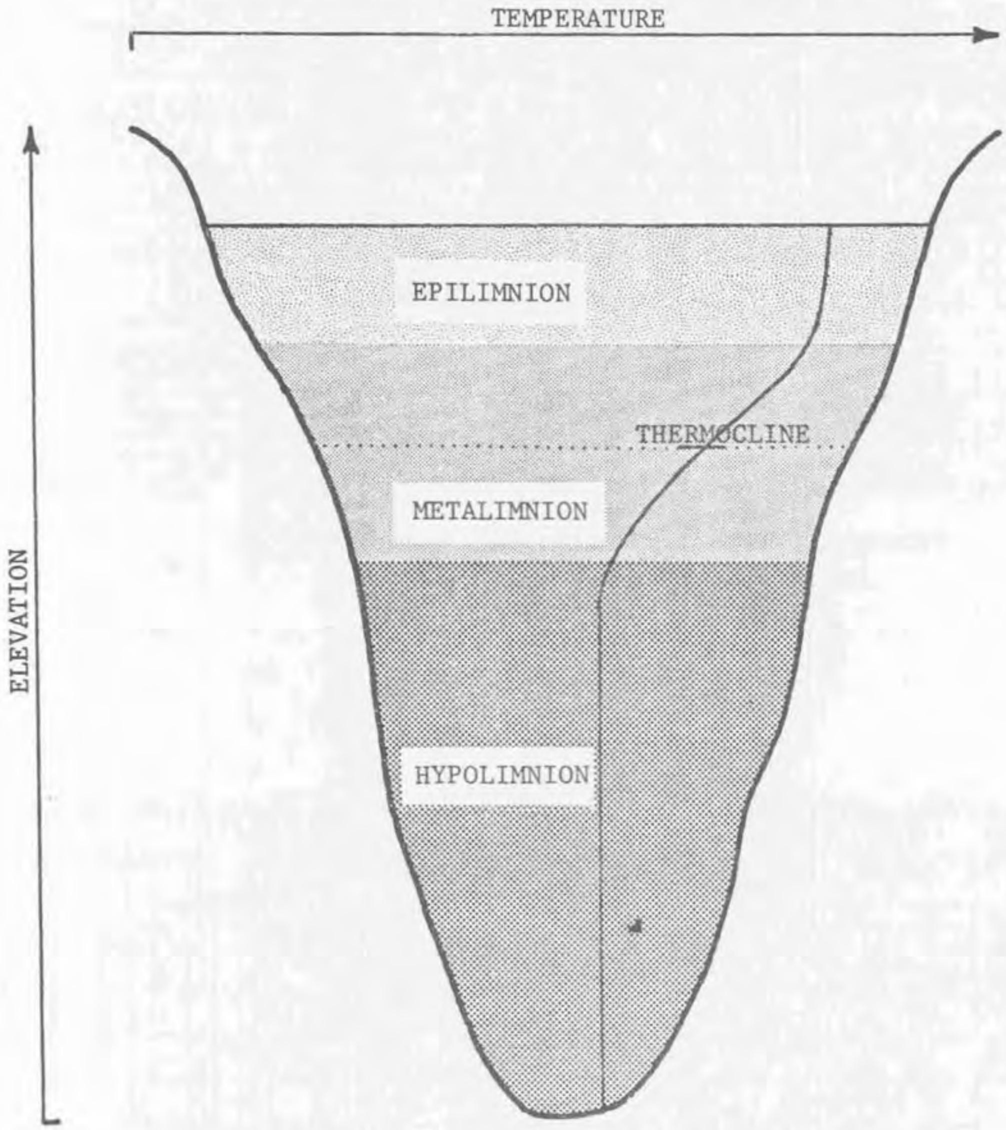

FIGURE 7. Schematic Representation of Strong Temperature Stratification in a Lake (6).

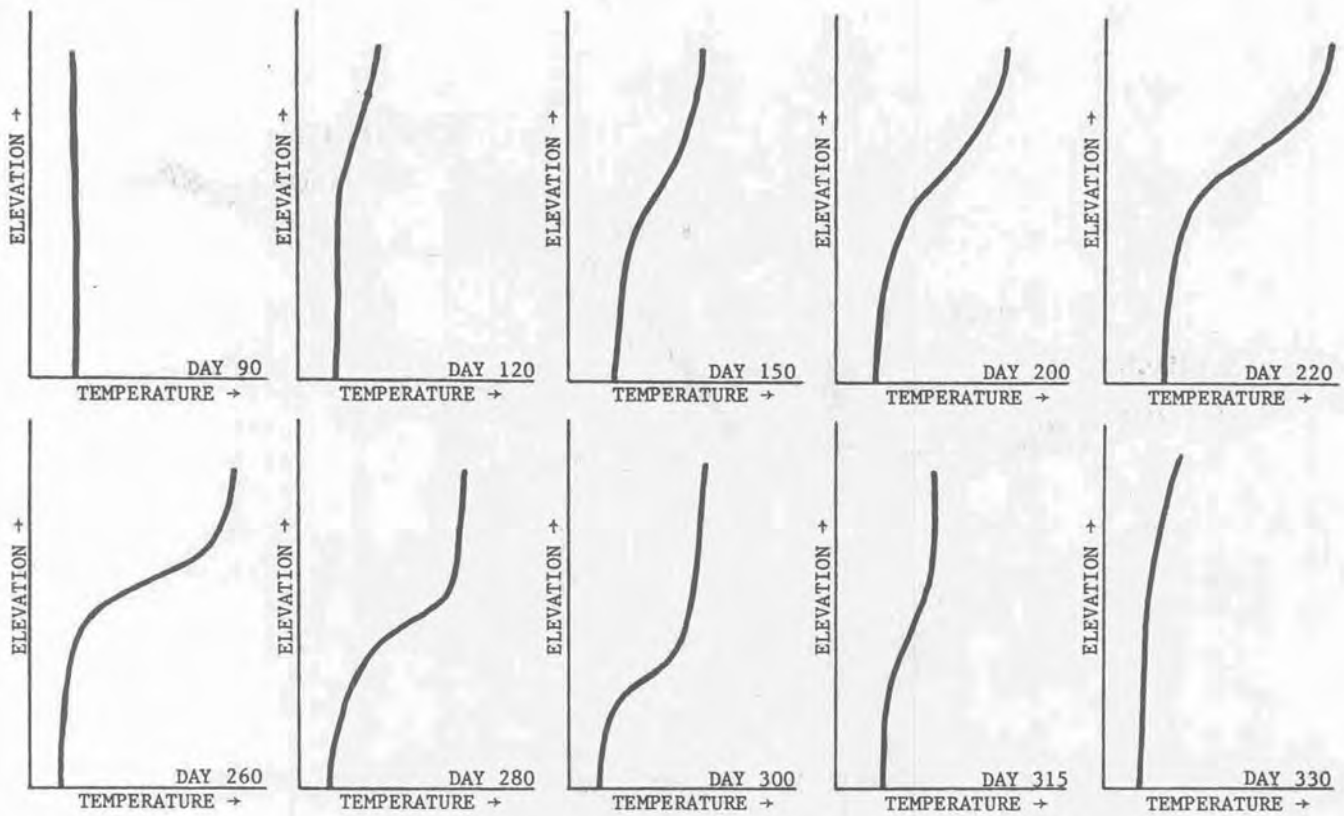

FIGURE 8. Characteristic Annual Pattern of Thermal Stratification for a Deep Water Lake in the Southeastern United States.

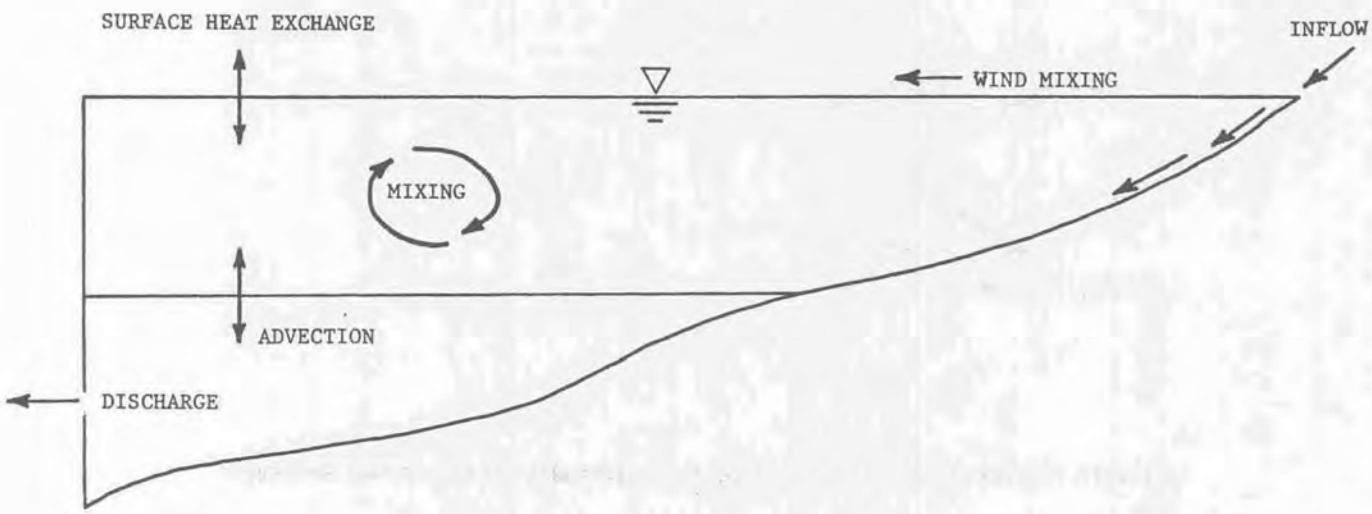

FIGURE 9. Schematic of Mixing and Heating Mechanisms in a Lake (5).

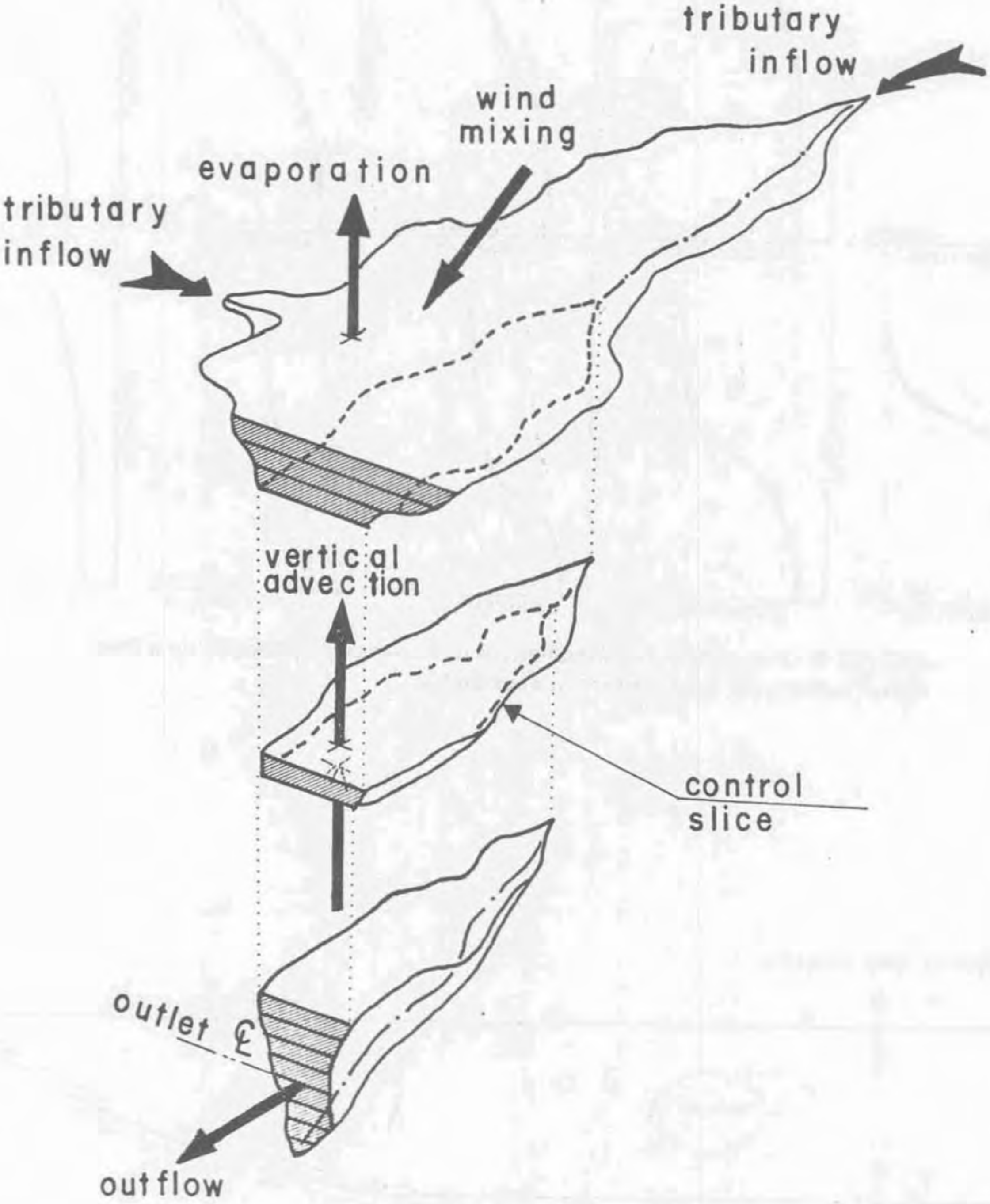

FIGURE 10. Geometric "Control Slice" Representation of a Stratified Reservoir (8).

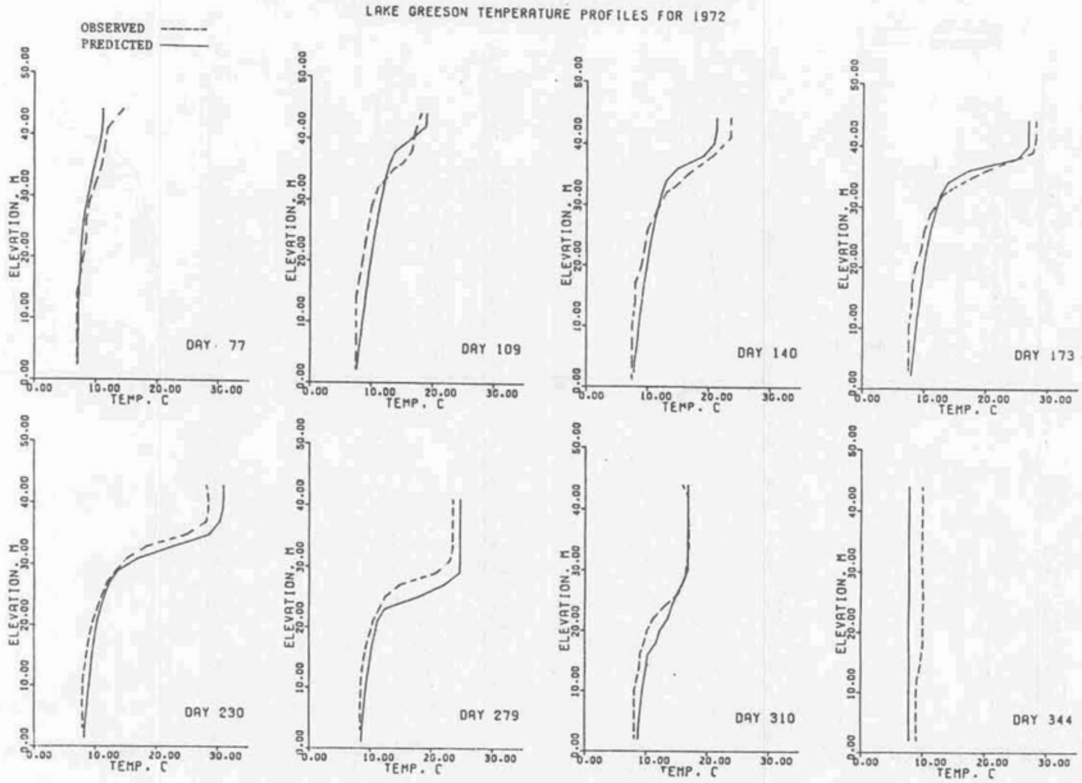

FIGURE 11. Calibration Results for Lake Greeson, 1972.

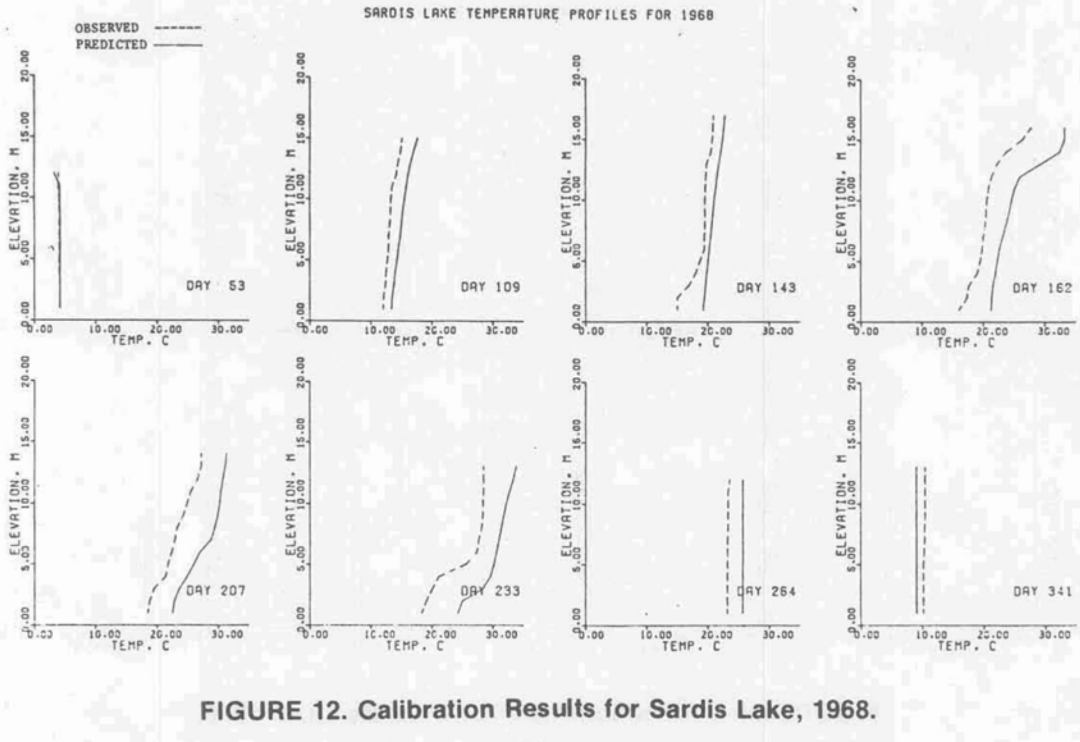

FIGURE 12. Calibration Results for Sardis Lake, 1968.

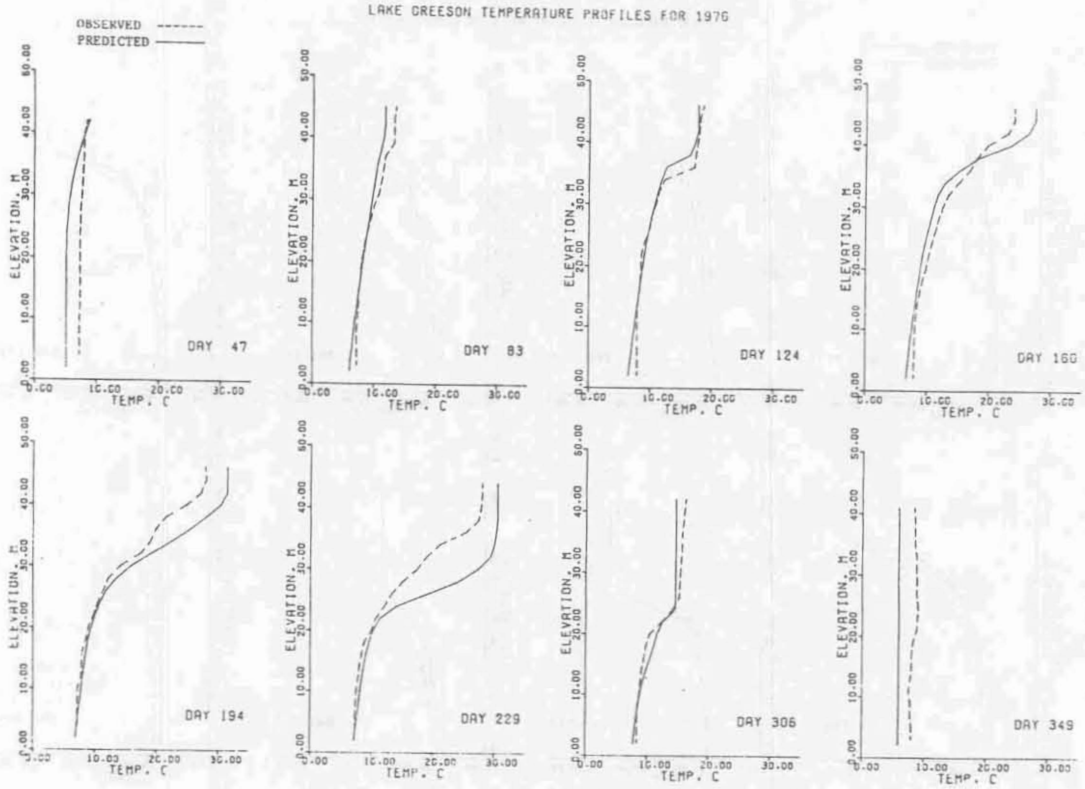

FIGURE 13. Verification Results for Lake Greeson, 1976.

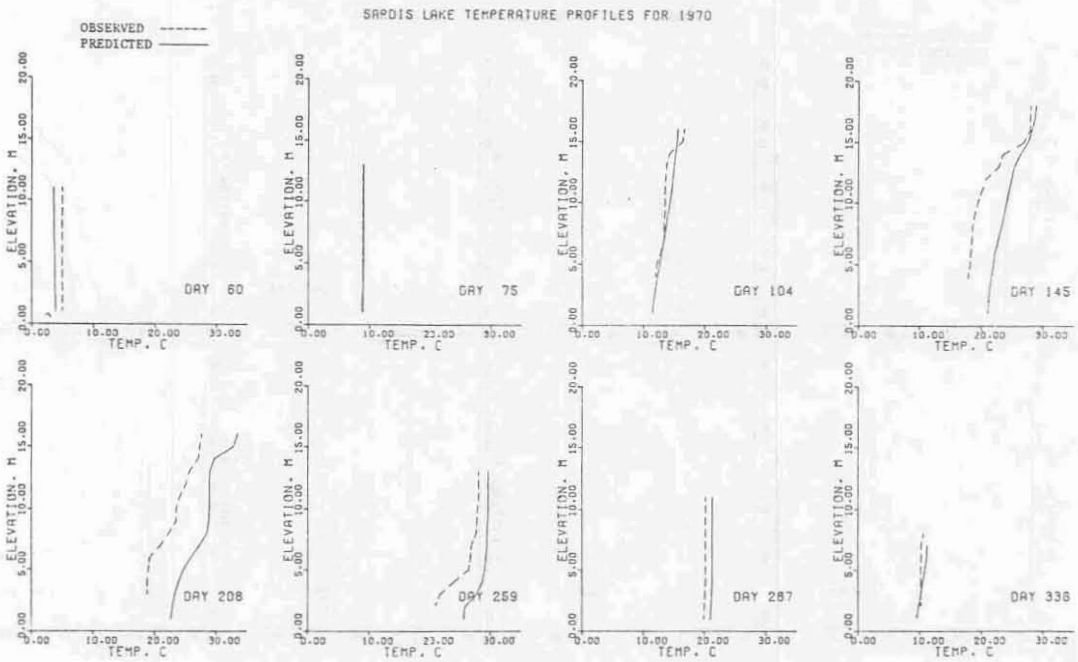

FIGURE 14. Verification Results for Sardis Lake, 1970.

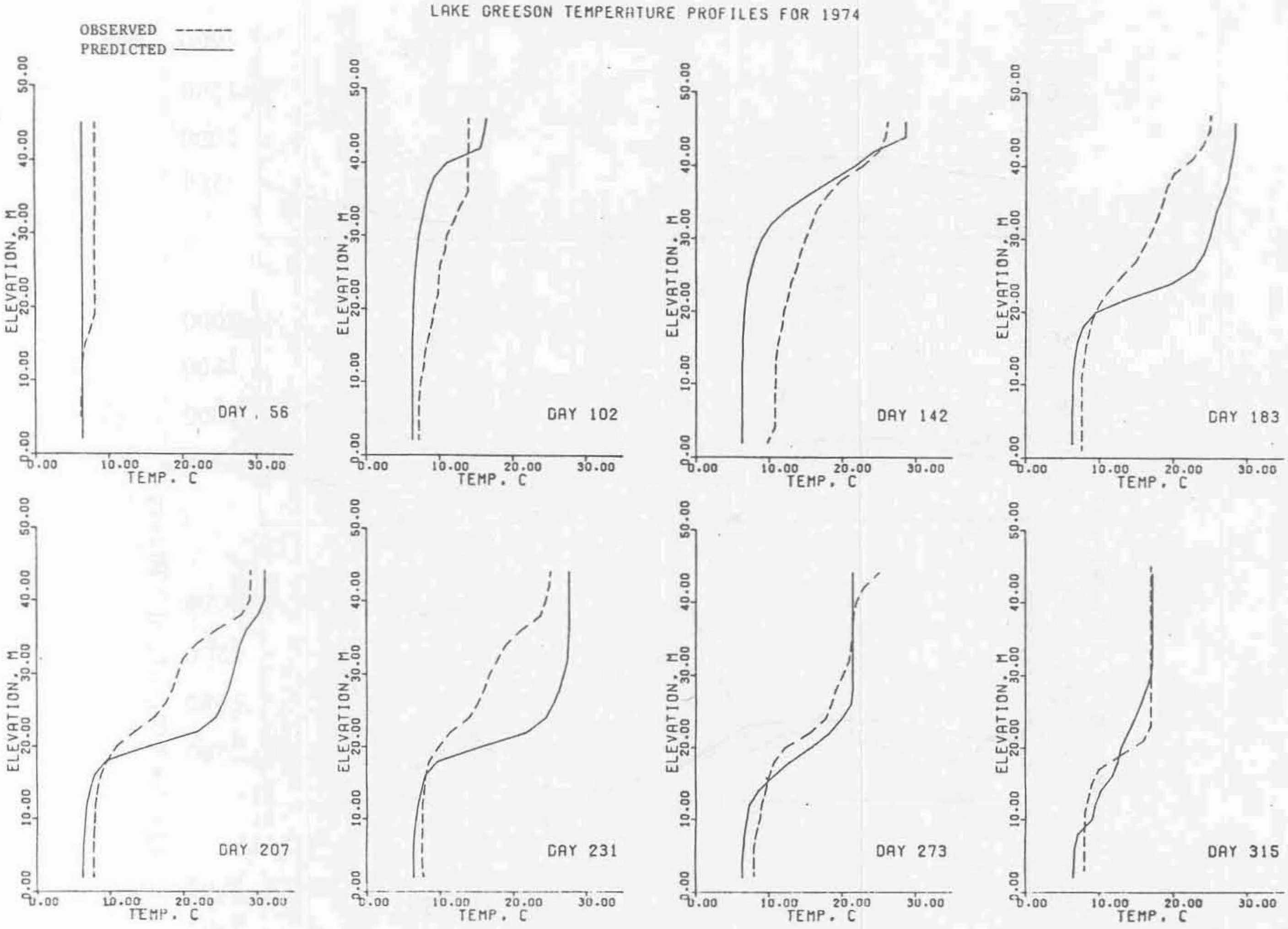

FIGURE 15. Verification Results for Lake Greeson, 1974.

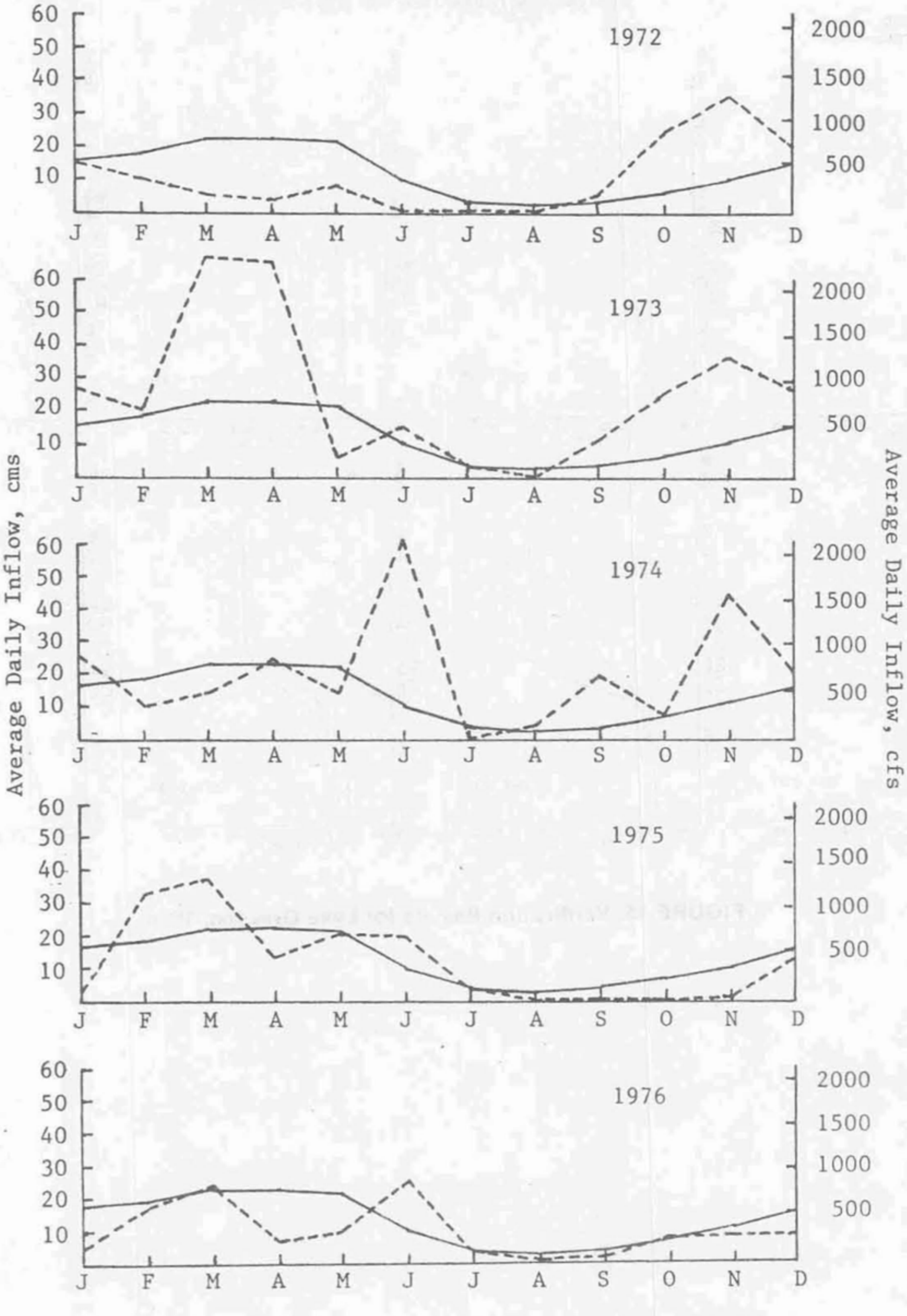

FIGURE 16. Lake Greeson Average Inflows for Period of Study, 1972-76 (Dotted Line) as Compared with Average Inflow for Period of Record, 1953-76 (Solid Line) (2).

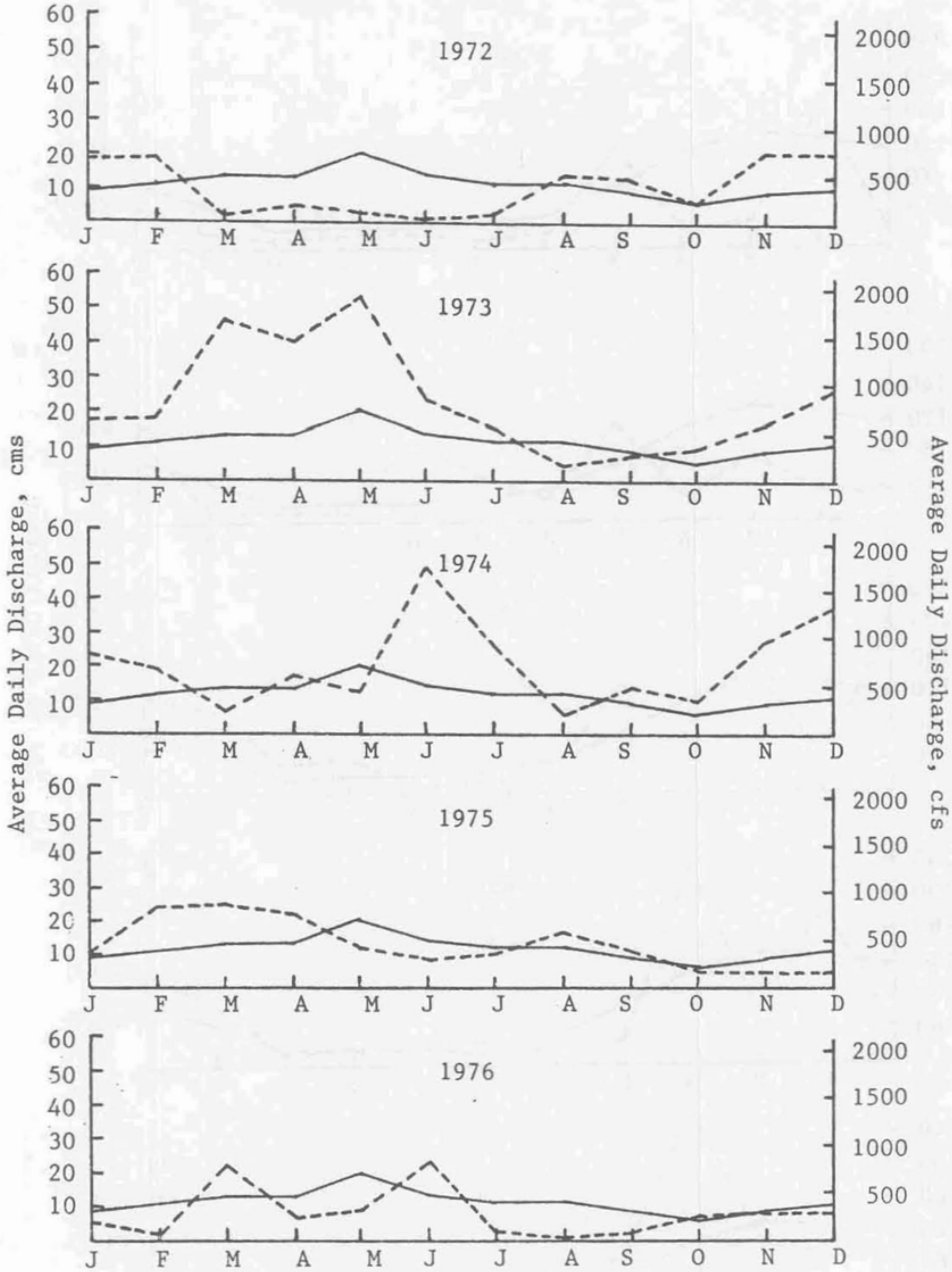

FIGURE 17. Lake Greeson Average Discharges for Period of Study, 1972-76 (Dotted Line) as Compared with Average Discharge for Period of Record, 1953-76 (Solid Line) (2).

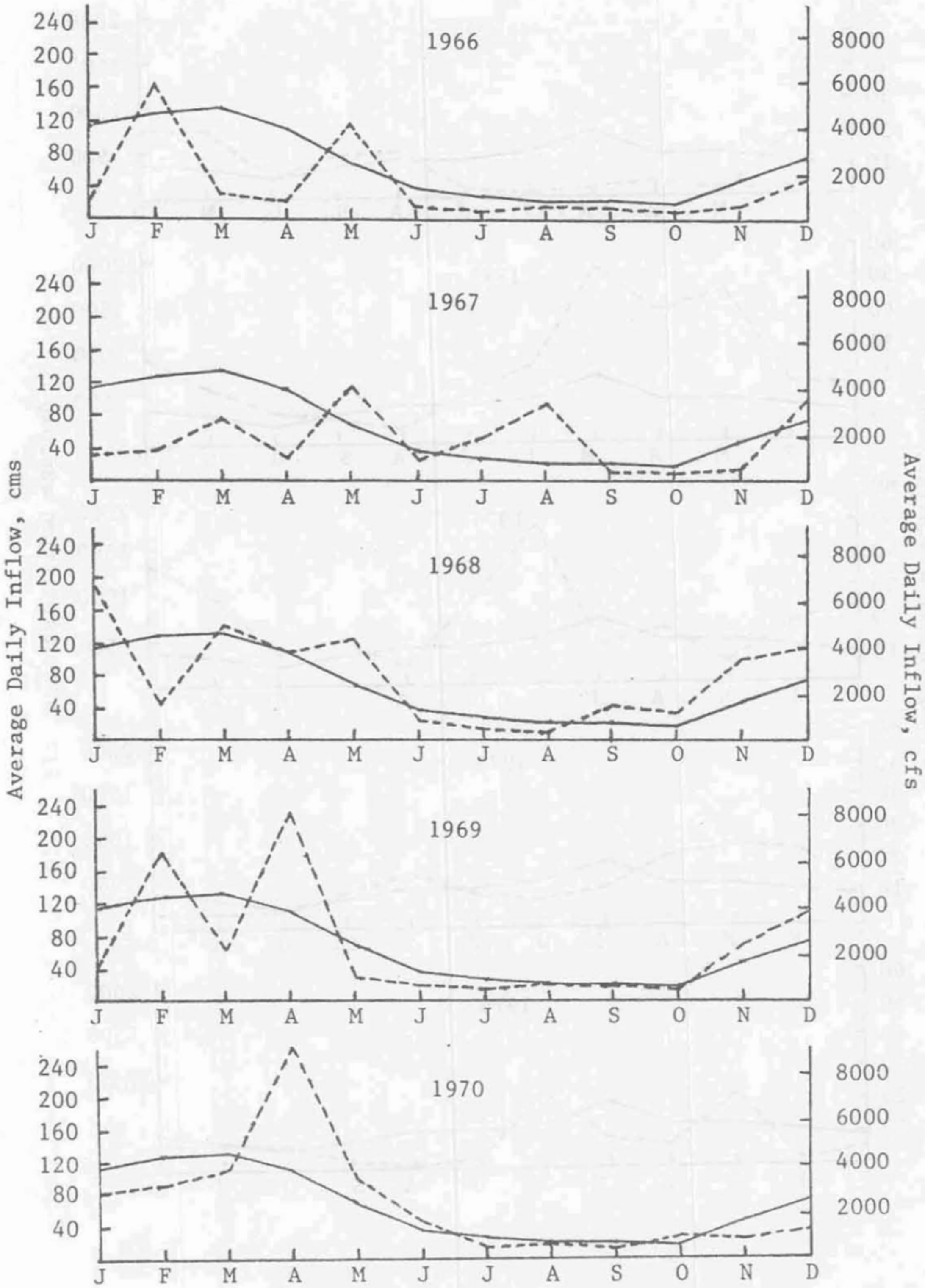

FIGURE 18. Sardis Lake Average Inflows for Period of Study, 1966-70 (Dotted Line) as Compared with Average Inflows for Period of Record, 1947-76 (Solid Line) (2).

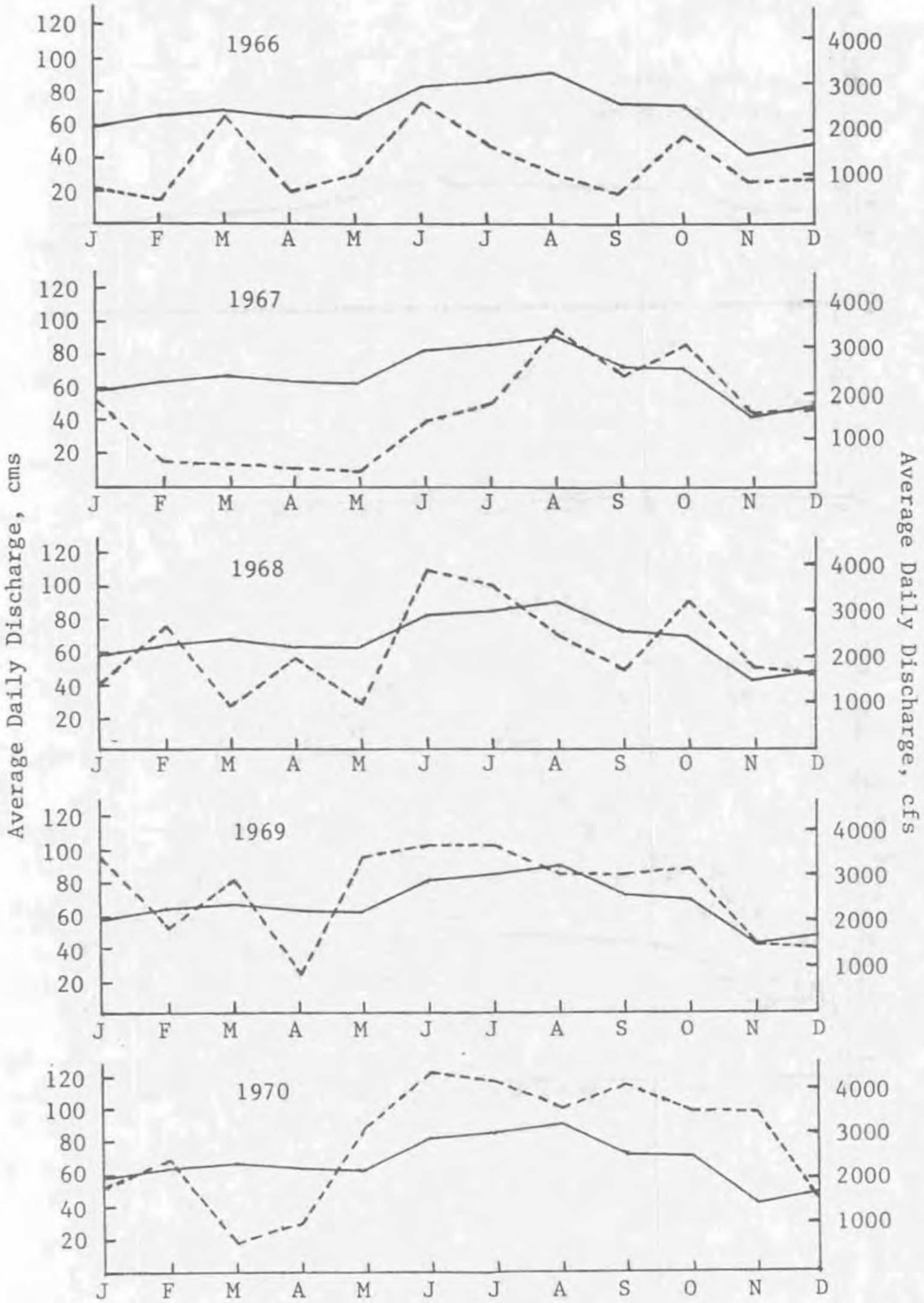

FIGURE 19. Sardis Lake Average Discharges for Period of Study, 1966-70 (Dotted Line) as Compared with Average Discharge for Period of Record, 1947-76 (Solid Line) (2).

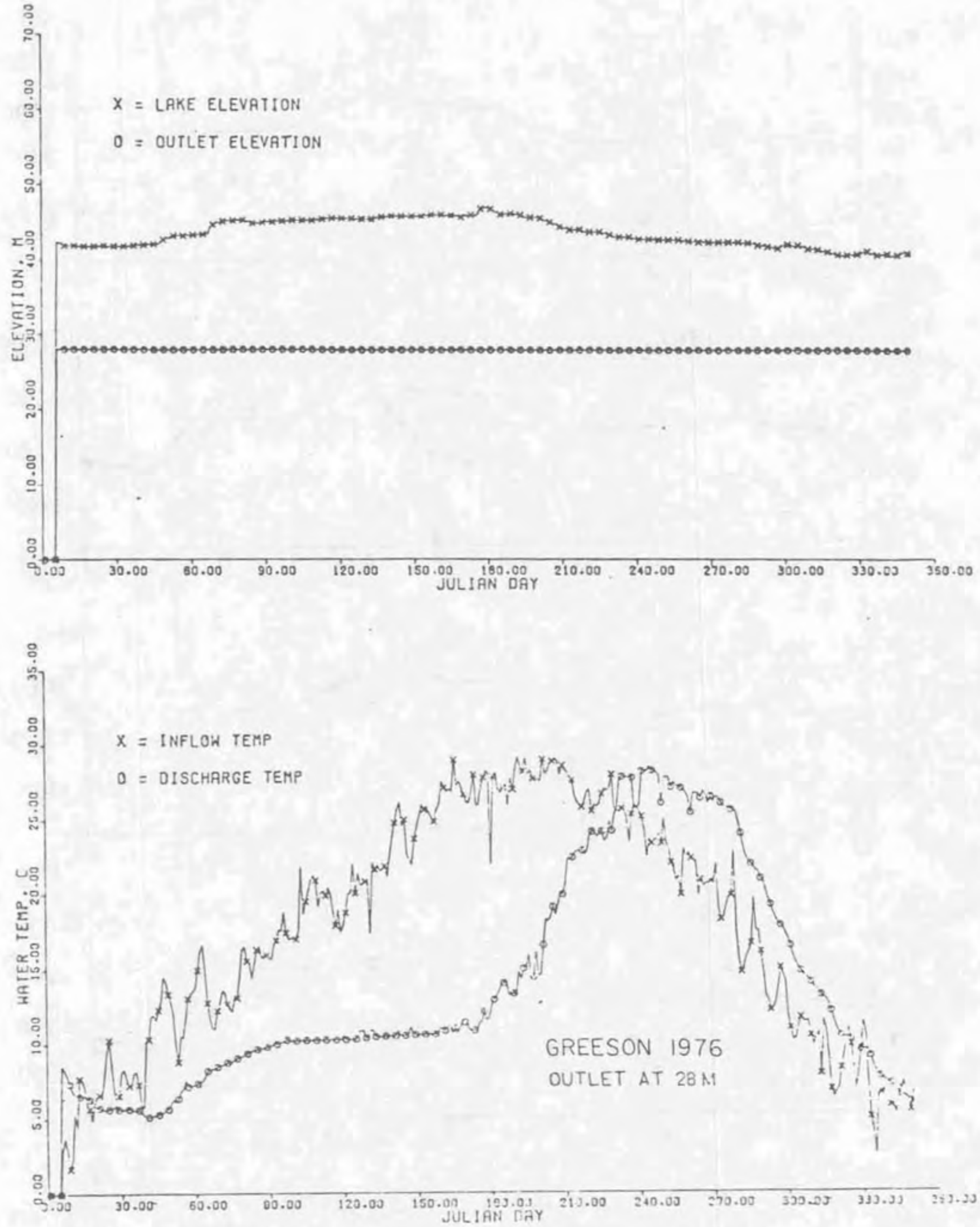

FIGURE 20. Simulated Lake Elevations, Discharge Outlet Elevation, Inflow Temperatures, and Discharge Temperatures for Lake Greeson, 1976, with Outlet Fixed at 28 Meters.

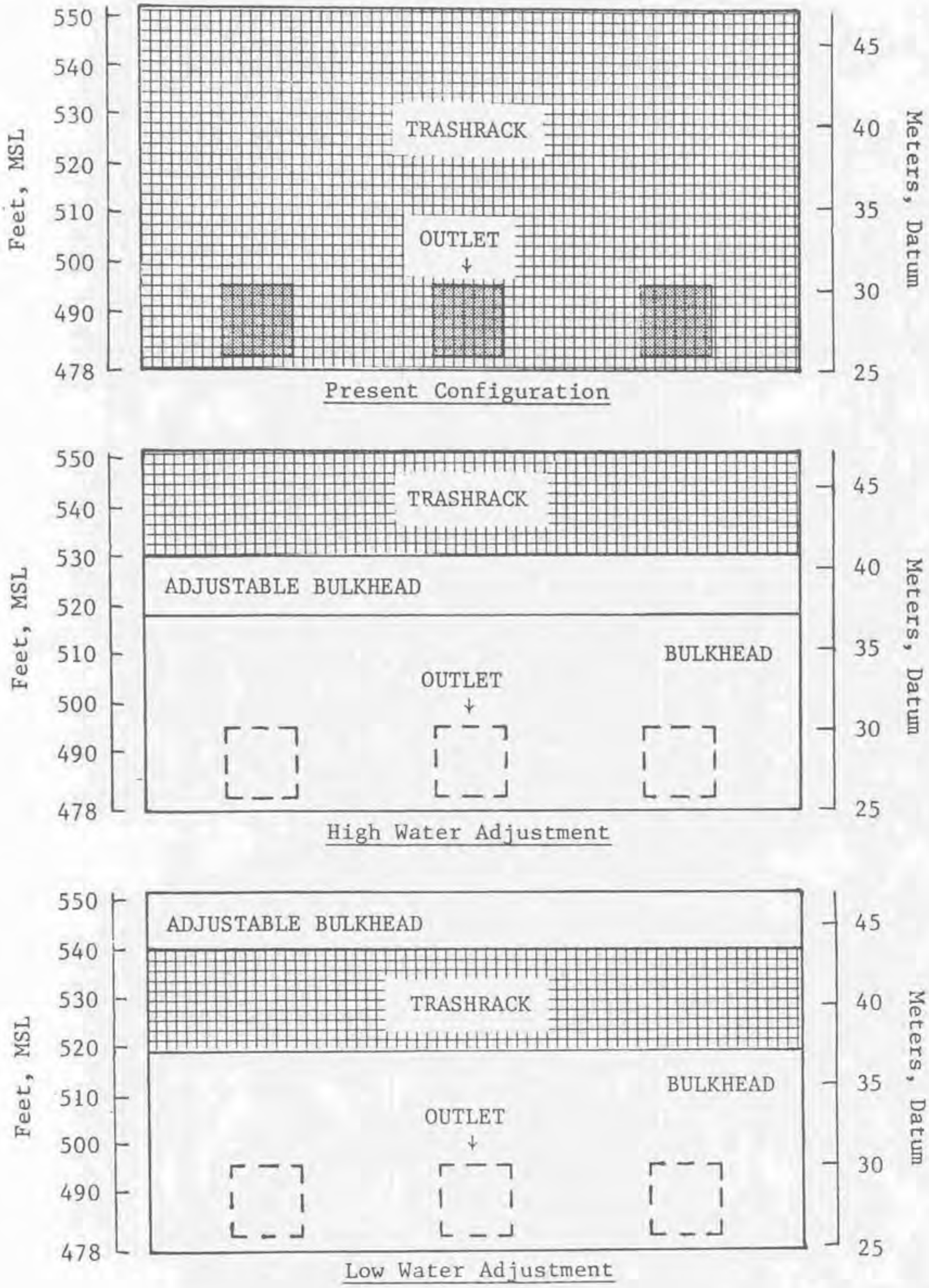

FIGURE 21. Combinations of Bulkheads and Trashracks for Use in the Powerhouse Intake Temperature Control System, Lake Greeson, Arkansas.

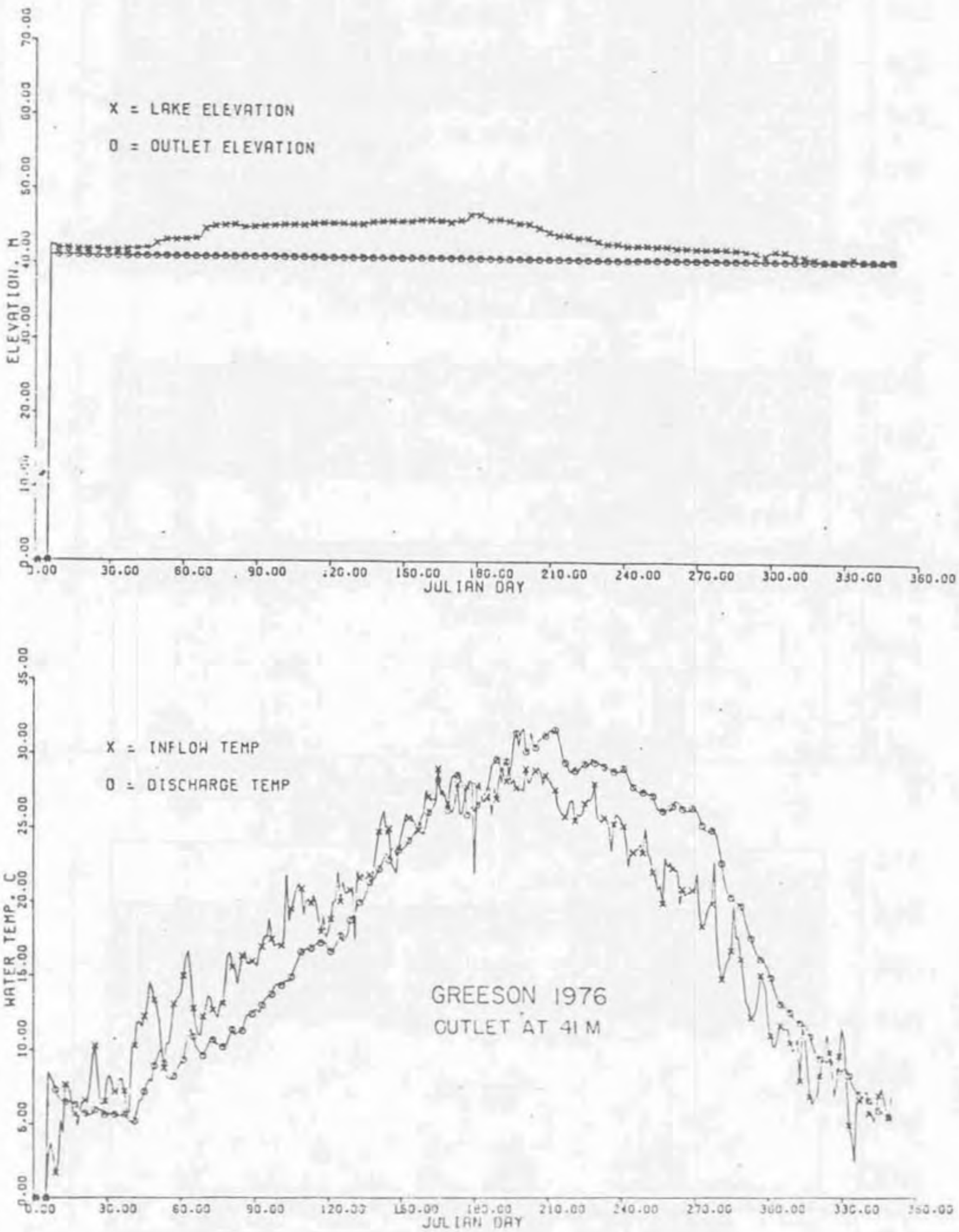

FIGURE 22. Simulated Lake Elevations, Discharge Outlet Elevation, Inflow Temperatures, and Discharge Temperatures for Lake Greeson, 1976, with Outlet Raised to 41 Meters.

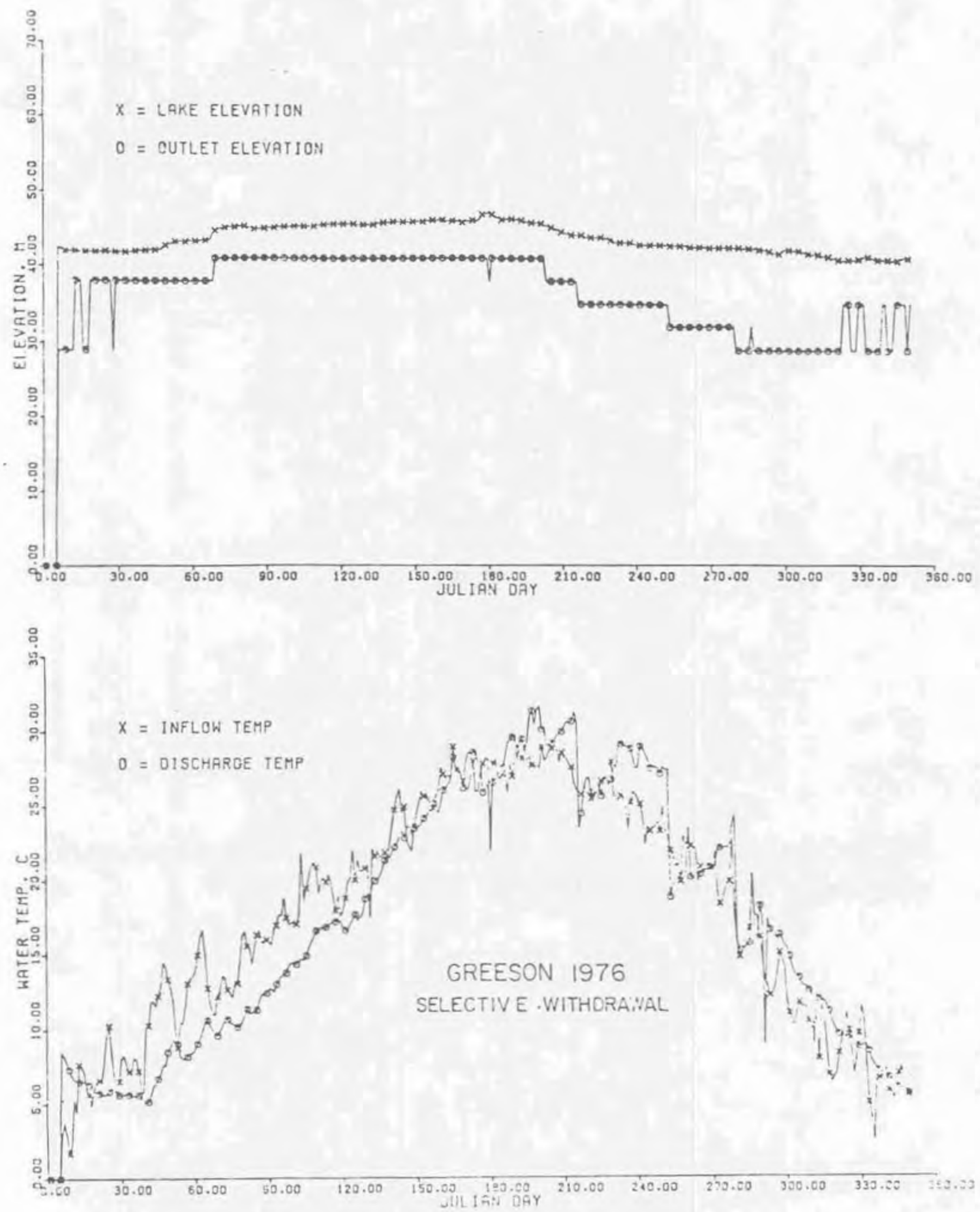

FIGURE 23. Simulated Lake Elevations, Discharge Outlet Elevations, Inflow Temperatures, and Discharge Temperatures for Lake Greeson, 1976, Under Selective Withdrawal Operation. (Inflow Temperatures = Target Temperatures).

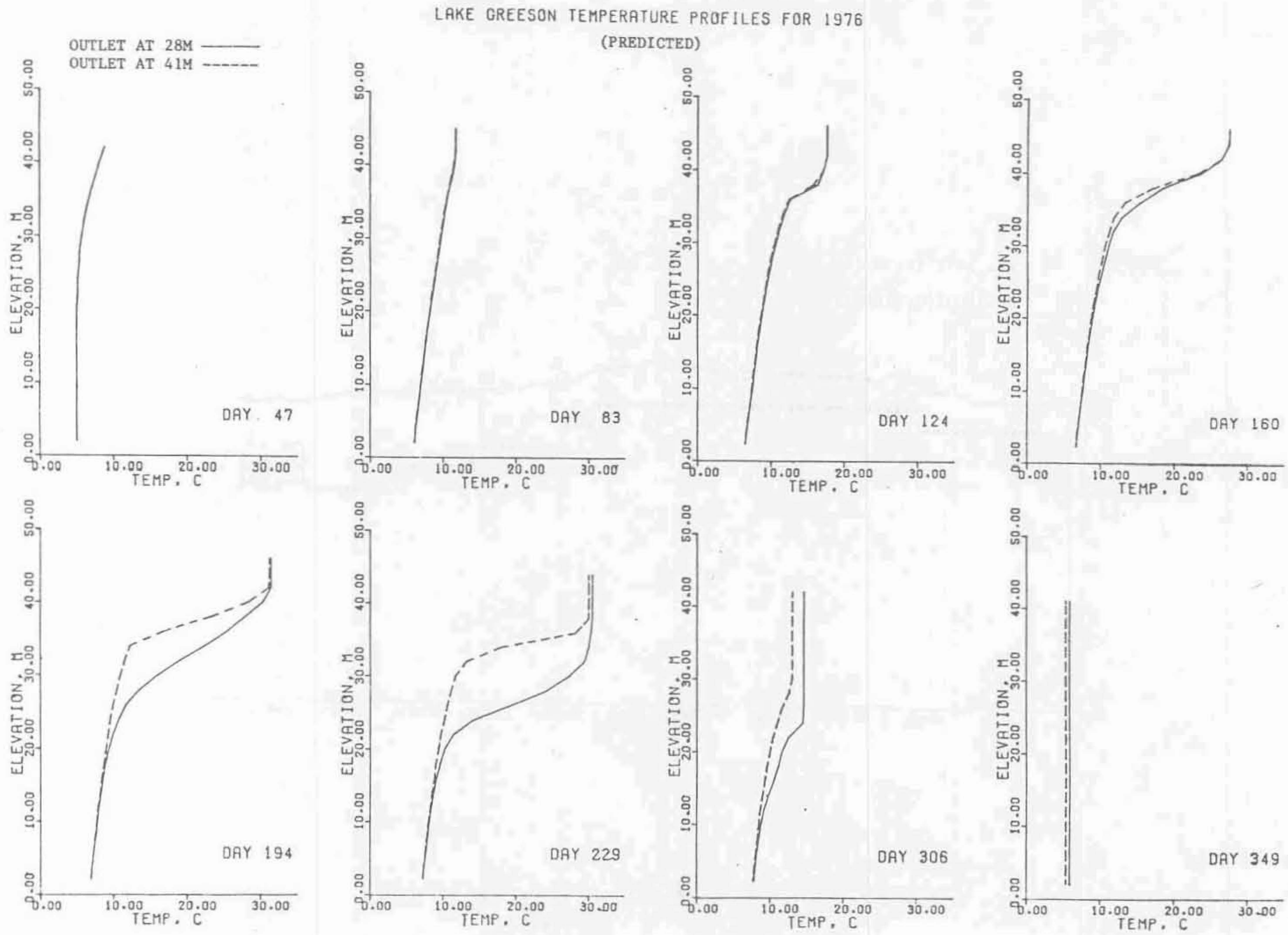

FIGURE 24. Comparison of Lake Greeson Simulations for 1976, with Outlet Elevations of 28 Meters and 41 Meters.