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THERMAL POLLUTION MODEL
Volume VI. User's Manual for
One-dimensional Numerical Model

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VERIFICATION AND TRANSFER OF THERMAL POLLUTION MODEL

VOLUME VI: USER'S MANUAL FOR ONE-DIMENSIONAL NUMERICAL MODEL

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PREFACE

Emphasis continues to be placed on the use of digital computers in solving nonlinear hydrodynamic and thermodynamic equations of fluid flow. This publication of the thermal pollution group at the University of Miami presents the solution of one such problem. This problem deals with the use of a numerical one-dimensional model in predicting the temperature profiles of a deep body of water. Although this model can be applied to most lakes, a specific site (Lake Keowee, S. C.) application has been chosen and described in detail. The programs are written in fortran V and could be modified by the user. Some of these modifications are suggested either in the text or in the specific programs.

A detailed derivation of the equations integrated has been left out; however, to improve readability of the final equations, the meaning of the terms and variables occurring in these equations are included.

This research was performed at the thermal pollution laboratory at the University of Miami. Funding was provided by the National Aeronautics and Space Administration (NASA-KSC) and the Environmental Protection Agency (EPA-RTP).

ABSTRACT

A user's manual for a one-dimensional thermal model is described. The model is essentially a set of partial differential equations which are solved by finite difference methods using a high speed digital computer. The main equations integrated are discussed. The programs are written in fortran V and an example problem is discussed in detail.

CONTENTS

FIGURES

SYMBOLS

z	Vertical coordinate measured upward from deepest point of the lake. As a subscript it marks the vertical components of a vector.
h	Depth of lake
$A(z)$	Horizontal cross-sectional area at height Z
$I(z)$	Bottom-surface source of mass per unit area
$Q(z)$	Bottom-surface source of heat per unit area
T	Temperature (°C)
ρ	Density of water
V_z	Vertical velocity
K_z	Eddy diffusivity
K_{zo}	Eddy diffusivity under neutral condition
$W^* = (\tau_s/\rho)$	Friction velocity
σ_1	Empirical constant
R_i	Richardson number
α_v	Volumetric coefficient of expansion of water
τ_s	Surface shear stress
C_p	Heat capacity
$H(z)$	Heat source/unit volume
A_1	Average value of W^*
B_1	Half of the annual variation W^*
C_1, C_2, C_3, C_4, C_5	Phase angles
ϕ_o	Solar radiation incident on the water surface
A_2	Average value of ϕ_o
B_2	Half the annual variation of ϕ_o
η	Extinction coefficient
β	Absorption coefficient
Q_p	Volumetric discharge
ΔT	Condenser temperature change
T_D	Discharge temperature
q_s	Surface heat flux
K_s	Surface heat exchange coefficient
T_E	Equilibrium temperature
A_3	Average value of T_E
B_3	Half the annual variation of T_E
T_s	Surface temperature
q_B	Bottom surface heat flux
B	Lake surface radius
$\frac{dA}{dz}$	Area variation with depth

ACKNOWLEDGMENTS

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The authors express their sincere gratitude for the technical and managerial support of Mr. Roy A. Bland, the NASA-KSC project manager of this contract, and the NASA-KSC remote sensing group. Special thanks are also due to Dr. Theodore G. Brna, the EPA-RTP project manager, for his guidance and support of the experiments, and to Mr. S. B. Hager, Chief Engineer, Civil-Environmental Division, and Mr. William J. McCabe, Assistant Design Engineer, both from the Duke Power Company, Charlotte, North Carolina, and their data collection group for data acquisition. The support of Mr. Charles H. Kaplan of EPA was extremely helpful in the planning and reviewing of this project.

SECTION 1

INTRODUCTION

It is important that the thermal behavior of heated discharges and their receiving basins be clearly understood.

A numerical model that can be used for predicting the seasonal thermocline of a deep body of water is very useful in studying the environmental impact of thermal discharges from power plants. This is not only required for existing power plants but also for planned units. Thus, a predictive capability is essential to the licensing procedure. Monitoring programs cannot satisfy these needs, but from time to time, play a vital role in the calibration and verification of mathematical models.

The one-dimensional, thermal numerical model, described in this manual, features the effects of area change with depth, nonlinear interaction of wind-generated turbulence and buoyancy, absorption of radiative heat flux below the surface, thermal discharges and the effects of vertical convection caused by discharge. The main assumption in the formulation of this model is horizontal homogeneity.

This model can be applied to most stratified deep bodies of water. This stratification has a seasonal cycle and is an important natural characteristic of a body of water. The body of water could be divided into any number of slices. The temperature of each slice is predicted by the model. The surface slice exchanges heat with the environment of known climatic conditions while the bottom slice is assumed perfectly insulated. Condenser cooling water is extracted from any one of the slices and heated by the power plant. The discharge is injected into a slice of the same temperature as the dischage.

The main function of the model is the prediction of the temperature profiles in a deep body of water for any number of annual cycles. However, predictions connot be made on hourly basis - a feature usually handled by a more sensitive three-dimensional model. This is the main limitation of the model.

The procedure used in writing this manual is as follows:

Description and flow chart of the main program are given in Section 3, where the subroutines are also described. In the next section, a list of the variables and dimensions are given. The next three sections show how a typical run is prepared, executed and plotted. An example case is discussed in Appendix A, while Appendix B gives the fortran source program listings.

SECTION 2

RECOMMENDATIONS

The main disadvantage of a one-dimensional thermal model lies in the fact that resolution is sacrificed for computational speed. Three dimensional models are bulky and time consuming but have much better resolution, however, when long term simulations are necessary, a one-dimensional model is recommended.

The model described here can be modified to include the single effects of the various quantities involved in the surface heat transfer phenomenon rather than using the equilibrium temperature concept. This is particularly recommended for the user who is interested in modeling the long term effects of one (for example, evaporation) of the quantities involved in the surface heat transfer processes.

Furthermore, the model can be easily adapted to handle connected multiple domains. This recommendation is discussed in the text.

SECTION 3

PROGRAM DESCRIPTION AND FLOW CHART

DESCRIPTION OF PROGRAM ALGORITHM

Background

A view of an idealized deep body of water is shown in Figure 1. This basin is divided into eleven slices. The inner nine slices are of equal thickness, DZ, while the top and bottom slices are of thickness DZ/2. The thickness, DZ, is determined from the depth of the basin and the number of slices used. The temperature of each slice is as shown in Figure 1; the horizontal lines correspond to the center of each slice.

The condenser cooling water (CCW), if any, could be taken from any slice. In Figure 1, the CCW is extracted from the center of Slice 2 which is at temperature T_3. The discharge temperature, T_D, is the sum of T_3 and the increase in temperature through the condenser. T_D is injected into a slice of equal temperature or treated as a surface outfall if T_D is greater than the highest temperature of the basin.

The basin also gains or loses heat from the surface as a result of changing climatic conditions which are required as input data. These could vary every time step, daily or monthly.

Algorithm

The problem is an initial value problem, so the values of dependent variables are assumed known initially. The governing and associated equations are discussed in the next section. The governing equation is parabolic and mathematically represents a diffusion process with vertical convection.

The values of the dependent variables at successive time steps are obtained by using a forward-time Dufort-Frankel scheme.

The sequence in which calculations are performed is as follows: (Refer to Summary of Variables - next section.)

1. The dependent variables, T, K_Z, W*, A_V, ρ, T_E and K_S, are initialized. The area of each slice is calculated and then the time step

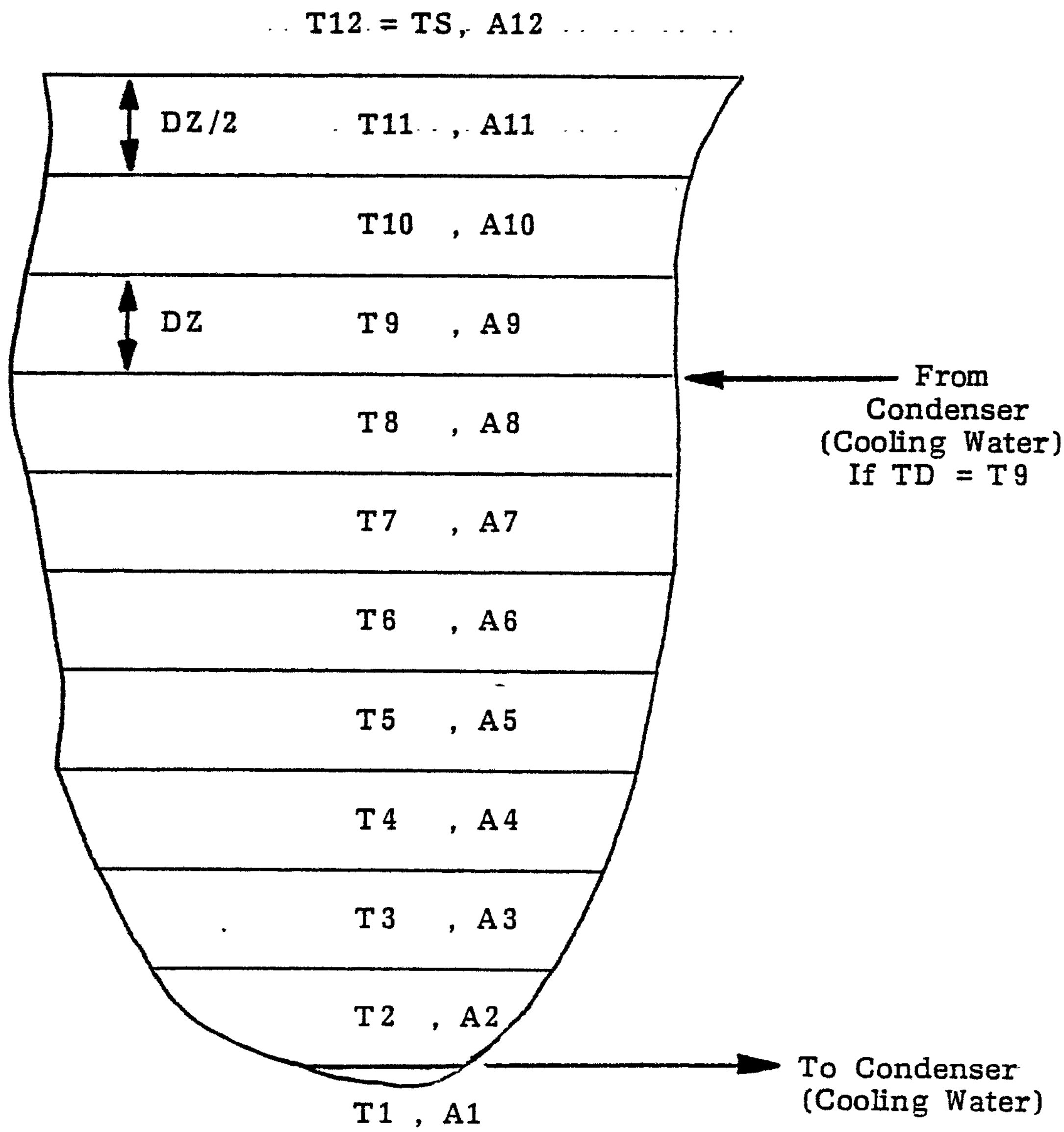

Figure 1. Idealized deep body of water

is calculated. The heading of the beginning year is printed. The values of the variables, K_Z, W*, A_V, ρ, T_E and K_S, are then calculated. The temperatures of the slices are finally calculated. If the temperature profile is unstable, mixing of the unstable portion of the profile is undertaken.

2. During the next time step, the temperatures are updated, and the dependent variables are calculated again.

3. The values of the temperature T, eddy diffusivity K_Z, number of days and surface heat transfer coefficient K_S are printed every time step, every day or normally at the end of each month. At the end of the present year, the title of the new year is printed and computions continue as listed above. These steps are shown in a flow chart, Figure 2. The results are stored on a magnetic tape and plotted when necessary.

Description of Main and Subprograms

The fortran calculation programs consist of a main program (NASA) and seven subroutines (YEARS, EQUIL1, STORE, CCW, SMOOTH, MIXIT and AREAS).

1. MAIN: The main program handles the input data, calls the subroutines and does the temperature calculations. Two alternatives are given for handling the input data; these are either read through cards or in-data files or through a block-data arrangement given at the beginning of the main program. For users interested in the block-data package, the following caution is necessary: Whenever a data or set of data is changed, the main program must be recompiled!

2. YEARS: This subroutine prints the year heading. It is called at the beginning of a new year.

3. EQUIL1: This subroutine reads the dewpoint temperature, wind speed and solar radiation. It then computes the surface heat transfer coefficient and the equilibrium temperature. Depending on how the data has been averaged (e.g. days, months or years); it is called as often as needed.

4. STORE: This subroutine stores the calculated data on magnetic tape designated as Unit 8. The stored data could be read by the plotting subroutine called READER. This subroutine and other plot programs are described later.

5. CCW: This subroutine supplies the condenser cooling water data. The data is also converted to the required units by this subroutine.

6. SMOOTH: This subroutine finds the largest value of the eddy dif-

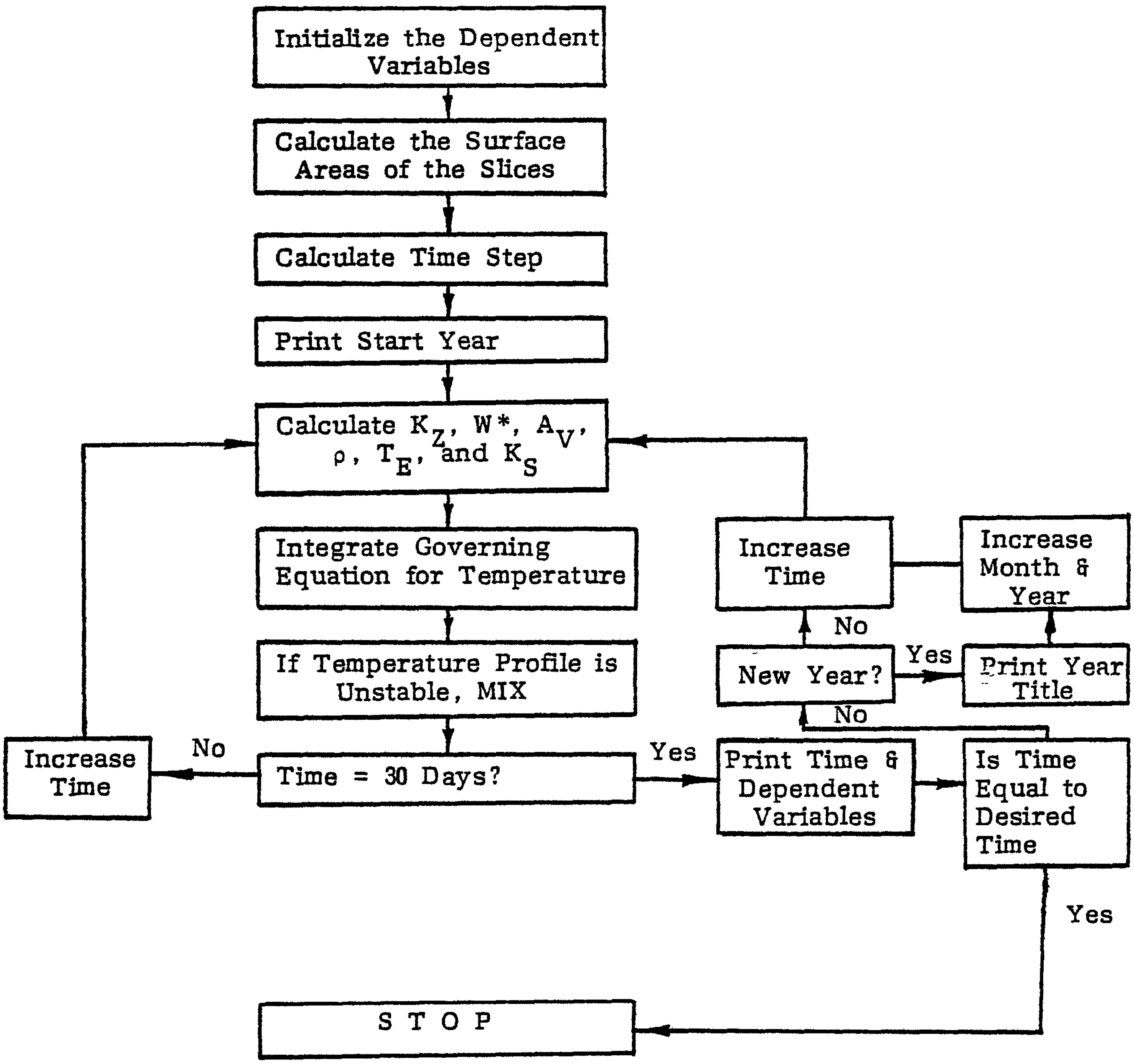

Figure 2. Flow chart (calculation)

fusivity and uses it to calculate the variable time step. It also smoothens the calculated eddy diffusivity for unstable temperature gradients. It is called every time step.

7. MIXIT: This subroutine looks for unstable temperature gradients and mixes or stabilizes the temperatures. It is also called every time step.

8. AREAS: This subroutine handles the surface areas of each slice and converts the values to the required units. It is called only once at the beginning of the computations.

9. INPUT: This is an in-data element containing all input data.

SECTION 4

DESCRIPTION OF PROGRAM SYMBOLS

Introduction

The programs have been written to calculate, as a function of depth, thermal diffusivity and temperature profiles over complete annual cycles. The equation integrated is

$$A_{(Z)}\frac{\partial}{\partial t}(\rho C_p T) = \frac{\partial}{\partial Z}(\rho C_p A_{(Z)} K_Z \frac{\partial T}{\partial Z}) - \frac{\partial}{\partial Z}(\rho C_p A_{(Z)} T V_Z) + QA' + A_{(Z)} H_{(Z)} \tag{1}$$

The above equation requires two boundary conditions and one ititial condition.

The initial condition is an input quantity supplied by the user and equals the homothermal temperature of the basin. The boundary conditions are:

1. At the surface;

$$K_Z \frac{\partial T}{\partial Z}\Big|_{Z=h} = K_S (T_E - T_S) \tag{2}$$

where Z = vertical coordinate measured from the deepest point
T_E = equilibrium temperature
T_S = surface temperature
K_S = surface heat exchange coefficient

2. At the bottom;

Perfect insulation is assumed,

$$\frac{\partial T}{\partial Z}\Big|_{Z=0} = 0 \tag{3}$$

Calculations of the temperature profiles are made by numerical integration of Equation (1). Calculations start with the homothermal conditions and a forward explicit scheme is used.

Each time step, the surface temperature, T_S = T12, is calculated and then the temperature of each slice is calculated. Solar radiation is absorbed at the surface slice and the unabsorbed portion is transmitted exponentially to the slices below.

The empirical relations involved in this manual are summarized below. A full discussion is given in the final report, Lee et al. (1980).

Description of Main Variables

1. Density, ρ, fortran variable - ROW:

$$\rho = A_1 + B_1T + C_1T^2 \tag{4}$$

where A_1 = density at 0°C
= 1.02943 gm/cc
B_1 = constant
= -0.00002
C_1 = constant
= -0.0000048

2. Eddy diffusivity, K_Z, fortran variable = XKZ

$$K_Z = K_{ZO}(1 + \sigma_1 R_i)-1 \tag{5}$$

and

$$R_i = \frac{\alpha_V g z^2}{W^{*2}} \frac{\partial T}{\partial Z} \tag{6}$$

where R_i = Richardson number
σ_1 = 0.1, an empirical constant, fortran variable - SIGMA
g = acceleration due to gravity, fortran variable - G
W* = friction velocity, fortran variable - FRVEL
= (τ_s/ρ)

$$\alpha_V = A_2 + B_2(T - 4) + C_2(T - 4)^2 \tag{6a}$$

fortran variable for α_V, AV

where A_2 = 0, volumetric coefficient of expansion at 4°C, fortran variable - A1
B_2 = constant, fortran variable - A2
= 1.538×10^{-5}
C_2 = constant, fortran variable - A3
= -2.037×10^{-7}

α_V can also be estimated by using Equation (4).

where K_{ZO} = eddy diffusivity under neutral condition (varies with time), fortran variable - XKZO

$$K_{ZO} = A_3 + B_3 \sin\left(\frac{2\pi}{365}t + C_3\right) \quad \text{(t is in days)} \tag{6b}$$

where A_3 = average value of K_{ZO}, fortran variable - R9
B_3 = half annual variation of K_{ZO}, fortran variable - R10
C_3 = phase angle, fortran variable - R8

3. Heat source, H, fortran variable - F6

$$H = \eta(1 - \beta)A_{(Z)}\phi_o \exp(-\eta(Z - h)) \tag{7}$$

where β = 0.5, fraction of the solar radiation absorbed at the surface
η = 0.75, solar radiation absorption coefficient
ϕ_o = net solar radiation reaching the water surface (input variable), fortran variable - HSOL

SECTION 5

PREPARATION OF INPUT DATA

The input data is stored in an in-data file - INPUT. Alternatively, it could be punched on cards. The input data is read in with an open format. The main variables read are: dewpoint temperature, wind speed and solar radiation. In some cases where the dewpoint temperature is not available, the relative humidity, air temperature and a pschometric chart are used to find the dewpoint temperature. If this involves a lot of chart reading, subroutine EQUIL1 could be modified and the dewpoint temperature calculated from a known equation supplied by the user. If the latter case is used, then the input data base is enlarged to read air temperature, relative humidity, wind speed and solar radiation. A detailed input list of the constants is given in Appendix A.

SECTION 6

PLOTTING PROGRAMS AND EXECUTION ELEMENTS

DESCRIPTION OF PROGRAMS

The fortran plotting routine consists of one main program (PLOTTER) and one subroutine (READER).

PLOTTER: This program calls the calcomp fortran subroutines (refer to a Calcomp plotting manual for details) and the subroutine (READER) which reads the calculated results from a magnetic tape designated as Unit 8. (See Item A.4.) A flow chart is shown in Figure 3.

READER: Reads the calculated data stored on Unit 8 (magnetic tape).

Execution Elements

Two execution elements are used, one for executing the calculated results and the other for executing the plots.

DO-IT: This element compiles and prints the main program (NASA) and then prepares an entry point table, maps the necessary programs and subprograms, calls the in-data element containing the input data and finally, executes the calculations. This is done as follows for a UNIVAC 1100 computer at the University of Miami.

Only one magnetic tape is necessary.

1. @ ASG, AX FILE.

   The 'FILE' is assigned for the run.

2. @ ASG, T 8., 16N, TAPENAME

   A magnetic tape file named '8.' is being assigned. The tape is 9-track, and the reel number is 'TAPENAME'. The calculated results are stored on this tape.

3. @ PRT, S FILE.NASA

   The main program is printed.

4. @ PACK FILE.

   The 'FILE' is packed.

5. @ PREP FILE.

   The entry point table is prepared.

6. @ MAP, S

7. IN FILE.NASA

8. LIB FILE.

9. END

10. @ XQT

11. @ ADD FILE.INPUT

12. @ FIN

PLOT-IT: Similar to DO-IT, but handles the plotting executions. For a UNIVAC 1100 computer the following cards are necessary. Two magnetic tapes are necessary.

1. @ ASG, AX FILE.

2. @ ASG, T 8., 16N, TAPENAME

3. @ ASG, T 11., 16, PLOTTAPE

   A magnetic tape file named '11.' is being assigned. The tape is 7-track, and the reel number is 'PLOTTAPE'. The plots are stored on this tape.

4. @ PRT, S FILE.PLOTTER

   The plot program is printed.

5. @ PACK FILE.

6. @ PREP FILE.

7. @ MAP, S

8. IN FILE.PLOTTER

9. LIB FILE.

10. END

11. @ XQT

12. @ ADD FILE.INPUT

13. @ FIN

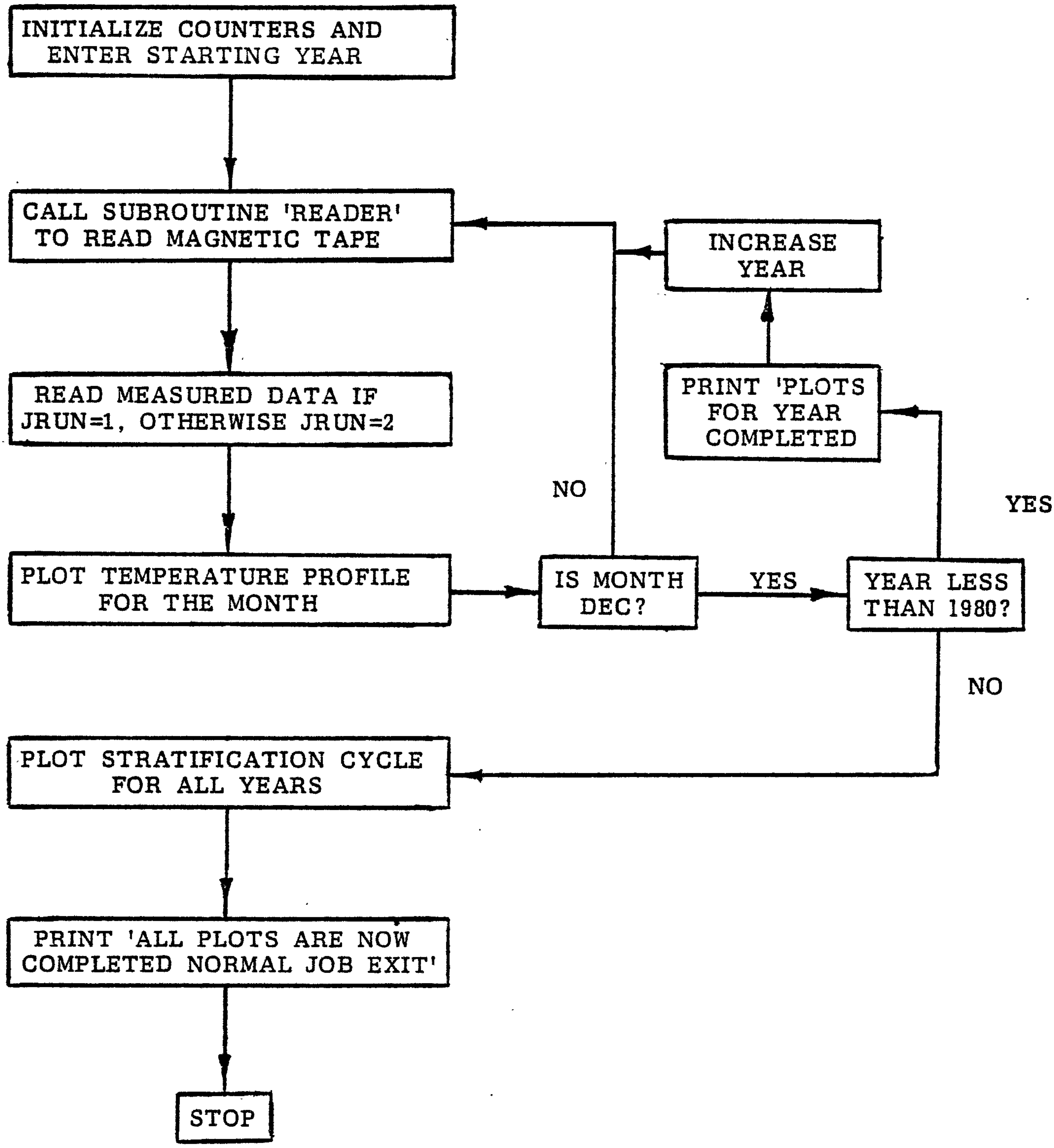

Figure 3. Flow chart (plots)

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Lee, S. S., Sengupta, S. and E. V. Nwadike. Verification of a One-Dimensional Model for the Seasonal Thermocline at Lake Keowee. NASA Contract NAS 10-9410. 1980.

APPENDIX A

APPENDIX A

EXAMPLE PROBLEM

The model described in this manual was verified using monthly-averaged data supplied by Duke Power Company for Lake Keowee, South Carolina. Accordingly, the data discussed below apply to Lake Keowee.

SITE DESCRIPTION

Lake Keowee is located 40 km west of Greenville, South Carolina. It is the source of cooling water for Oconee Nuclear Station (ONS). It was formed from 1968 through 1971 by damming the Little and Keowee rivers. A connecting canal (maximum depth 30.5 m) joins the two main arms of the lake. Flow out of the lake is through the Keowee Hydro Station. Lake Keowee also exchanges water with Lake Jocassee-pumped storage station. The three-unit ONS with a net capacity of 2580 Mwe started operating in July 1973. ONS operated on annual gross thermal capacity factors of 11, 28, 69 and 59% in the years 1973 through 1976, respectively. From 1977 to 1979 the factors varied from 65 to 75%. A map showing the geometry of the lake is given in Figure 4.

PROBLEM STATEMENT

Calculation of Parameters and Input Data

1. The fortran variable DM(I, J) is a two-dimensional array containing the temperatures at the connecting channel between Lake Keowee and the Jocassee-pumped storage station. The data is averaged monthly. The units are in degrees Celcius (°C). I is the year counter and J is the month counter. The inputs for the first year are punched on the first card, the next year on the next card, and so on. Accordingly, each card contains twelve inputs in open format (real floating point numbers).

2. The following fortran variables/constants are also read in with open format, five on one card.

   IYEAR: starting year - 1971 (could be changed).

   DZ: thickness of an inner slice (ft) - (maximum depth of lake)/(10.0).

   XKZL: lower limit of the eddy diffusivity (ft^2/day) - corresponds to

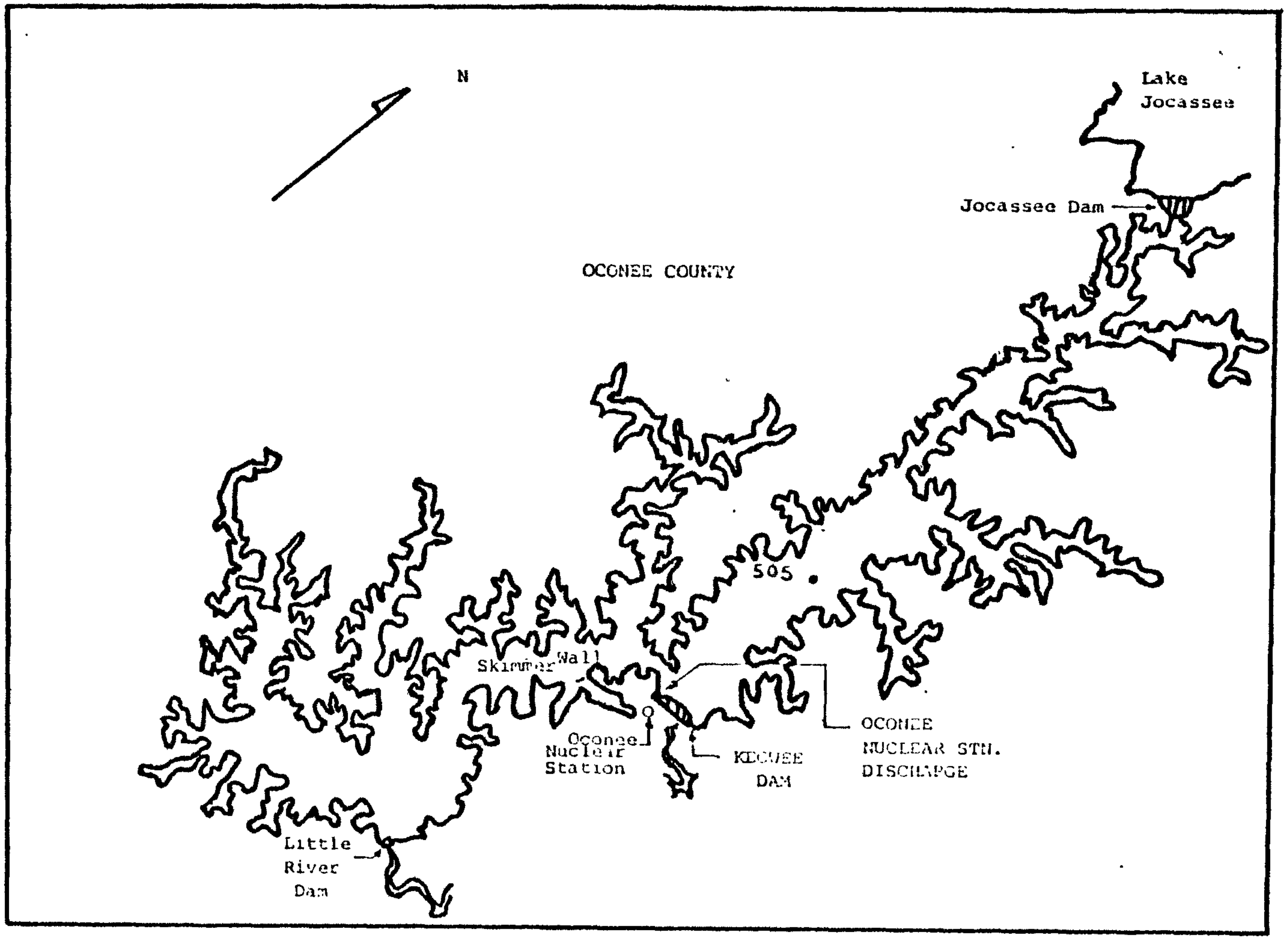

Figure 4. Lake Keowee

the thermal diffusivity of solid water (15 ft^2/day).

H: maximum depth of lake, ft (150 ft).

G: acceleration due to gravity (ft/sec^2).

PI: π = 3.1415926.

A1: corresponds to A2 in Equation (6a); A1 = 0 $°C^{-1}$.

A2: corresponds to B2 in Equation (6a); A2 = 1.538 x 10^{-5} °C.

A3: corresponds to C2 in Equation (6a); A3 = -2.037 x 10^{-7} °C.

A4: corresponds to A1 in Equation (4); A4 = 1.02943 gm/cc °C.

A5: corresponds to B1 in Equation (4); A5 = 0.00002 gm/cc °C.

A6: corresponds to C1 in Equation (4); A6 = -0.0000048 gm/cc $°C^2$.

(NOTE: The units for A4 through A6 are automatically converted to consistent units in the main program.)

TO: homothermal temperature of lake (initial condition); TO = 7.8 °C.

C_p: specific heat; C_p = 1.8 BTU/lb °C.

SIGMA: see Equation (5); SIGMA = σ_1 = 0.1.

**R6,R7,R8: the friction velocities (τ_s/ρ) are calculated for the whole period and fitted into a sine curve: (friction velocity OMEGA)

$$W^* = R6 + R7 \sin\left(\frac{2\pi}{365}\text{time} + R8\right)$$

where R6 = average value of W*, 0.1 ft/sec.
R7 = average value of the half annual variations of W*, 0.025 ft/sec.
R8 = phase angle, 2.61 radians
TIME is in days, not specified.

R8,R9,R10: correspond to C3, A3, and B3 of Equation (6b) respectively; R9 = 800 ft^2/day and R10 = 200 ft^2/day.

DATA1: 0 or 1 (see below).

3. The next set of inputs is the dewpoint temperatures, wind speed and

**Alternatively, friction velocity could be read in as monthly averages. If this alternative is followed, then DATA1 = 1, otherwise DATA1 = 0.

solar radiation. These can either be punched on cards or stored in an in-data element. They are read every month. Each card contains three members. For example: for January-March 1971 (Lake Keowee), the data are

3.0, 6.69, 167.0

0., 9.3, 264.4

6.3, 9.28, 264.4

The first number on each line (each card) is the dewpoint temperature in °C. The second one is the wind speed in ft/sec. The third quantity is the solar radiation in BTU/ft^{2}day. If DATA1 = 1, a fourth number must be included on each line (every card). This fourth quantity is the computed friction velocity for each month.

NOTE: The in-data element described above is called INPUT. (See Fortran Source Program Listing, Appendix B.)

Sample Output and Sample Plots

```
                                                        ****************
                                                        *              *
                                                        * YEAR = 1971  *
                                                        *              *
                                                        ****************
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   JAN.      1971
   30       6.28    155.13
   30       7.80      7.80      7.80      7.80      7.80      7.80      7.80      7.80      7.80      7.80      7.80      7.80
 801.70   801.70    801.70    801.70    801.70    801.70    801.70    801.70    801.70    801.70    801.70    801.70
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   FEB.      1971
   60      12.19    165.52
   60       7.39      7.39      7.39      7.39      7.39      7.39      7.39      7.39      7.39      7.39      7.39      7.39
 701.57   701.57    701.57    701.57    701.57    701.57    701.57    701.57    701.57    701.57    701.57    701.57
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   MARCH     1971
   90      17.77    164.02
   90       7.59      7.60      7.60      7.62      7.66      7.77      7.95      8.16      8.34      8.46      8.56      8.65
 627.60   570.80    444.33    276.63    159.26     97.70     73.28     76.81    114.63    221.20    416.75    595.37    627.60
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   APRIL     1971
  120      17.02    182.29
  120       7.71      7.71      7.73      7.60      7.92      8.14      8.55      9.35     10.52     11.22     11.49     11.68
 600.01    18.45     18.45     18.45     18.45     18.45     18.45     18.45     18.45     30.93    126.19    497.51    600.01
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   MAY       1971
  150      28.42    183.08
  150       7.79      7.79      7.63      7.93      8.12      8.50      9.21     10.59     13.25     17.65     18.43     18.64
 625.90    15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     19.22    340.56    625.90
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   JUNE      1971
  180      27.07    213.15
  180       7.92      7.92      7.99      6.15      8.47      9.11     10.31     12.50     16.34     22.31     22.89     23.16
 698.61    15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     17.12    440.35    698.61
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   JULY      1971
  210      27.15    204.74
  210       8.14      8.14      8.24      6.51      9.03     10.01     11.77     14.71     19.39     23.83     24.17     24.34
 798.29    15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     32.60    622.68    798.29
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   AUG.      1971
  240      24.32    202.42
  240       8.48      8.48      8.64      9.04      9.77     11.15     13.40     16.93     22.14     24.21     24.46     24.59
 898.42    15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     98.53    771.14    898.42
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   SEPT.     1971
  270      18.66    201.52
  270       8.98      8.98      9.20      9.74     10.73     12.42     15.07     18.94     22.67     22.98     23.07     23.12
 972.39    15.00     15.00     15.00     15.00     15.00     15.00     15.00     15.00     26.45    425.09    926.57    972.39
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   OCT.      1971
  300       8.31    167.98
  300       9.63      9.63      9.92     10.58     11.76     13.67     16.45     19.45     19.71     19.76     19.77     19.77
 999.99    15.00     15.00     15.00     15.00     15.00     15.00     15.00     20.81    304.77    871.89    996.95    999.99
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   NOV.      1971
  330       8.73    168.76
  330      10.42     10.42     10.74     11.48     12.74     14.23     14.23     14.23     14.23     14.23     14.23     14.23
 974.11    15.00     15.00     15.00     15.00     15.00     23.46    830.29    974.11    974.11    974.11    974.11    974.11
      .0          .0          .0      .0      .0      .0      .0      .0      .0      .0      .0      .0
MONTH IS   DEC.      1971
  360       3.59    132.35
  360      11.46     11.47     11.58     11.95     11.96     11.96     11.96     11.96     11.96     11.96     11.96     11.96
 901.40   171.92     92.91     30.78     48.07    716.19    901.40    901.40    901.40    901.40    901.40    901.40    901.40
```

Figure 5. Sample output - Lake Keowee, 1971

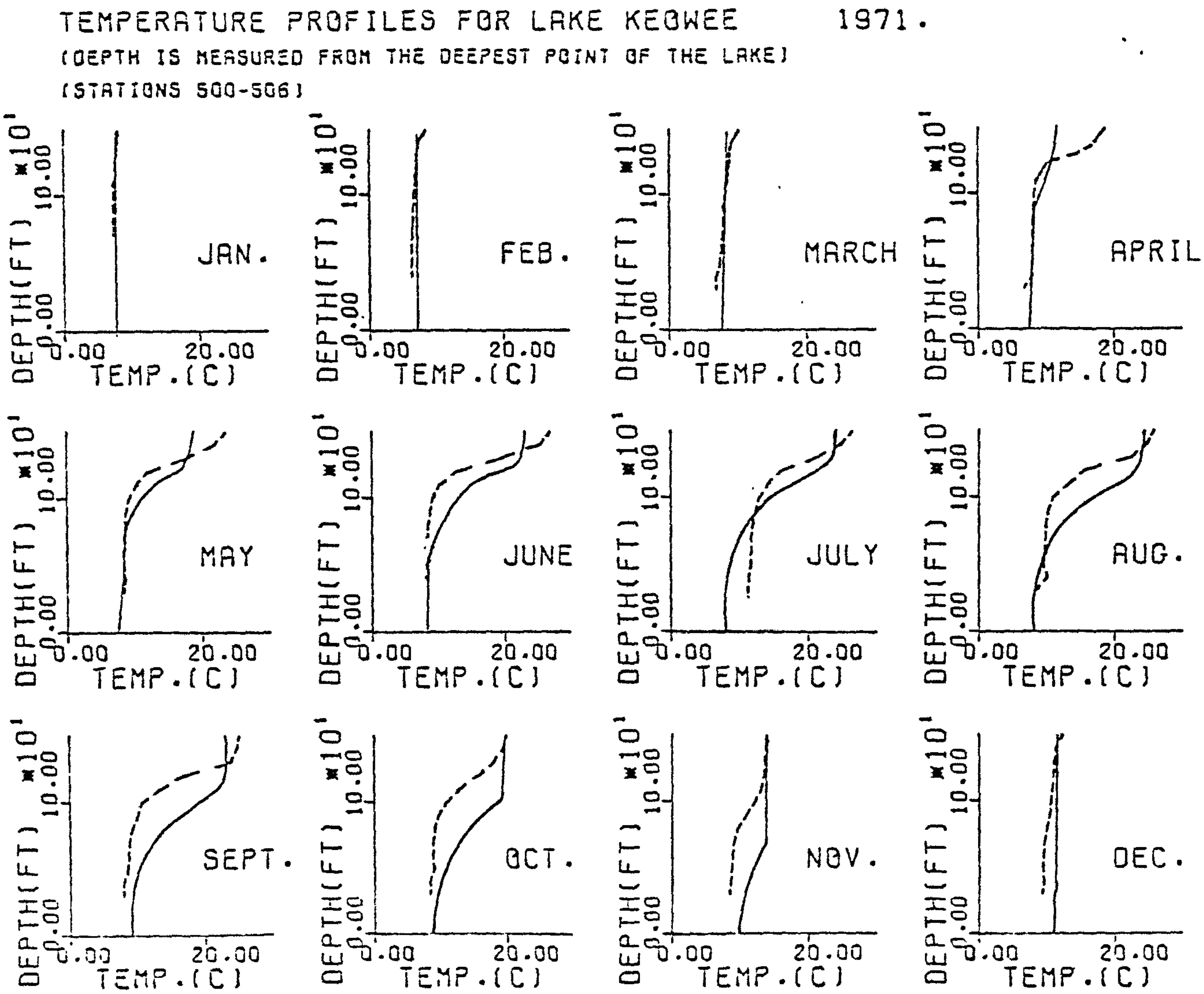

Figure 6. Sample plots - measured average temperature profiles (Stations 500-506) vs predicted temperature profiles, Lake Keowee, 1971

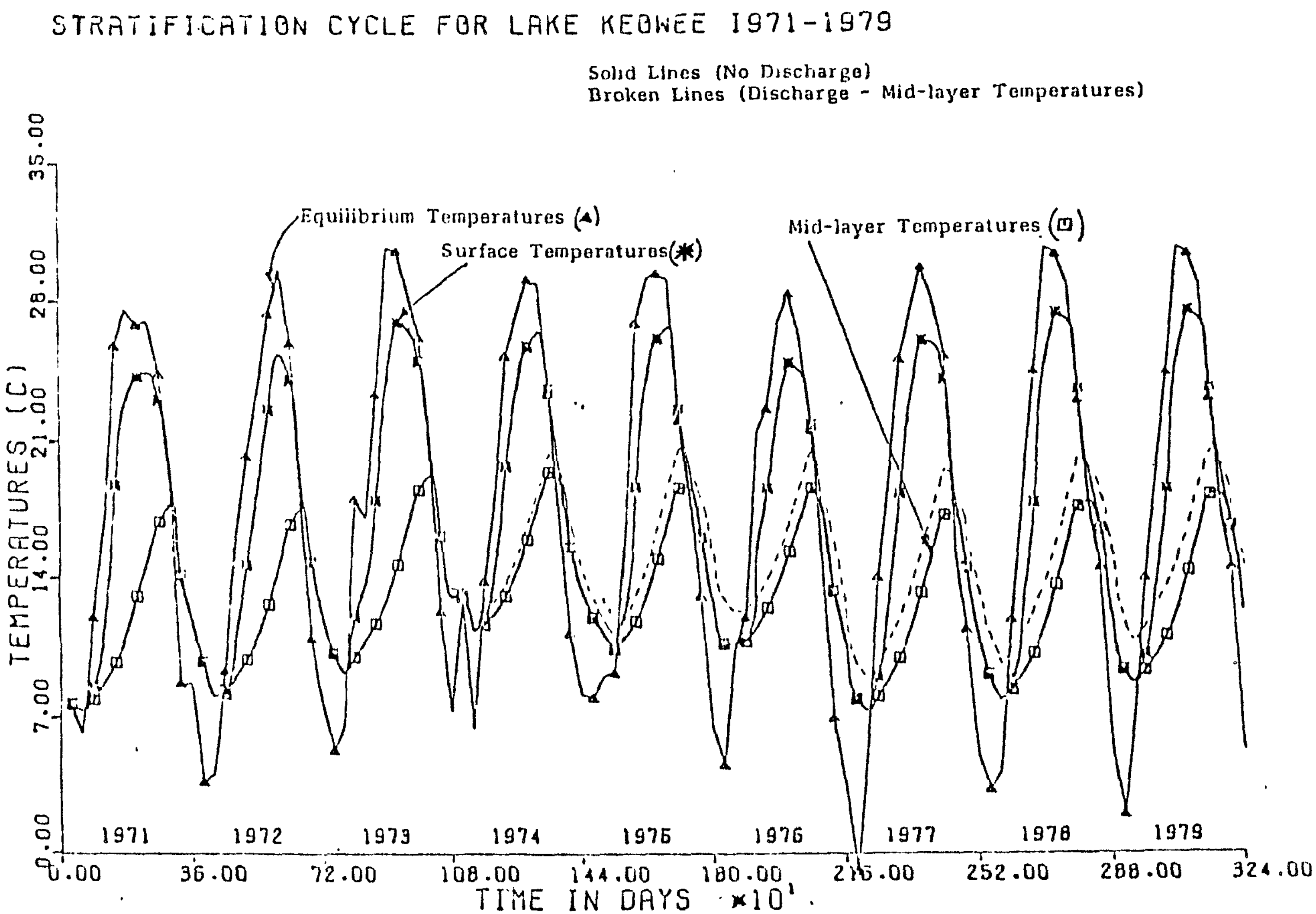

Figure 7. Sample plot

APPENDIX B

FORTRAN PROGRAM LISTING

```
NASA SYM CREATED ON 12 AUG 80 AT 14:17:05
C      ONE DIMENSIONAL MODEL FOR THE SEASONAL THERMOCLINE
C
C
       DIMENSION T(20),AV(20),CB(20),Z(20),A(20),XKZ(20),ROW(20),TN(20)
       DIMENSION DM(20),T2(20),XTDD(10,360)
       DIMENSION DELTEM(12),QP(12)
       CHARACTER*6 MONTHS(12)
C
C
       DATA(MONTHS(J),J=1,12)/'JAN.','FEB.','MARCH','APRIL','MAY','JUNE',
      C'JULY','AUG.','SEPT.','OCT.','NOV.','DEC.'/
C
C
C      IF YOJ NEED TO STORE RESJLTS ON MAGNETIC TAPE READ JRJN=1
C      OTHERWISE JRUN=2.
C
       READ 1,JRUN
       READ 1,IYEAR,DZ,XKZL,H,G
       READ 1,PI,A1,A2,A3,A4
       READ 1,A5,A6,T0,CP,SIGMA
       READ 1,R6,R7,R8,R9,R10
1      FORMAT()
       MMI=0
         Z(1)=0.
       JIM=1
       TDD=0.
       DVE=0.
       CALL AREAS(A)
       J=1
       JW=1
       JJ=0
       NDAYS=0
       NDAYS1=0
        TIME=0.
       TIME1=0.
       TIME2=0.
       TIME3=0.
        TIME4-0.
        TE=T0
        DO 20 I=1,12
        T(I)=T0
         T2(I)=T0
  20      CONTINJE
          DO 22 I=2,11
          Z(I)=DZ/2.+(I-2)*DZ
```

```
 22      CONTINUE
       Z(12)=H
      DT=(0.4*DZ**2)/1000.0
      QP2=574.07383*(60.**2)*24.
      CALL YEARS(SELTEM,QQPP,IYEAR)
      CALL CCW(QP,DELTEM,IYEAR,DT)
       N=0
       OMEGA=2.*PI/360.
       T(12)=TO
       T12=TO
      JTOT=1
      MJ=1
      ROW(12)=(A4+A5*T(12)+A6*(T(12))**2)*62.4
      ROWCP=ROW(12)*CP
      CALL EQUIL1(TN,TE,XK,TDEW,WIND,HSOL)
 33   IF(MJ.EQ.1)DELTM2=DM(1)-T(7)
      FRVEL=(R6+R7*SIN(OMEGA*TIME+R8))**2
      XKZO=(R9+R10*SIN(OMEGA*TIME+R8))
       AV(1)=A1+A2*(T(1)-4.)+A3*(T(1)-4.)**2
       XKZ(1)=XKZO*(1+SIGMA*AV(1)*G*((H-Z(1))**2)*
     1(3.*T(1)+T(3)-4.*T(2))/(2.*DZ*FRVEL))**(N-1)
       DO 90 I=2,11
       AV(I)=A1+A2*(T(I)-4.)+A3*(T(I)-4.)**2
       XKZ(I)=XKZO*(1+SIGMA*AV(I)*G*((H-Z(I))**2)*
     1(T(I+1)-T(I-1))/(DZ*FRVEL))**(N-1)
         ROW(I)=(A4+A5*T(I)+A6*(T(I))**2)*62.4
 90      CONTINUE
      ROW(12)=(A4+A5*T(12)+A6*(T(12))**2)*62.4
      AV(12)=A1+A2*(T(12)-4.)+A3*(T(12)-4.)**2
      XKZ(12)=XKZO*(1+SIGMA*AV(12)*G*((H-Z(12))**2)*
     1    (3.*T(11)+T(9)-4.*T(10))/(1.5*DZ*FRVEL))**(N-1)
      ROWCP=ROW(12)*CP
      CALL SMOOTH(XKZ,XKZU,XKZL,NDAYS1,TN12,T12,T,DT1,DZ)
 902  DO 989 I=1,12
      IF(XKZ(I).LT.XKZL)XKZ(I)=XKZL
      IF(XKZ(I).GT.XKZO)XKZ(I)=XKZO
 989  CONTINUF
      DO 91 I=2,11
      F1=DT/(ROW(1)*CP*A(I))
      F2=((ROW(I)+ROW(I+1))/2.*(A(I)+A(I+1))/2.
     1*(XKZ(I)+XKZ(I+1))/2.*(T(I+1)-T(I))-((ROW(I)
     2+ROW(I-1))*(A(I)+A(I+1))/4.*(XKZ(I)
     3+XKZ(I-1))/2.*(T(I)-T(I-1))))/(DZ**2)
      IF(IYEAR.LE.1973)DELTM2=0.0
      IF(IYEAR.LE.1973)QP2=0.0
 777  F3=ROW(I)*DELTEM(JW)*CP*QP(JW)
      F31=ROW(I)*DELTM2*CP*QP2/A(I)
      F41=(ROW(I)*CP*QP2/(1.5*DZ))*DELTM2*(T(I+1)-T(I-1))
      F4=(ROW(I)*CP*QP(JW)/(1.5*DZ))*DELTEM(JW)*(T(I+1)-T(I-1))
      IF(T(I+1).LE.T(I-1))F4=(ROW(I)*CP*QP(JW)/(1.5*DZ))*DELTEM(JW)
```

```
      IF(T(I+1).LE.T(I-1))F41=(ROW(I)*CP*QP2/(1.5*DZ))*DELTM2
      F5=T(I)
      F6=0.5*(EXP(-0.75*(H-Z(I))))*(HSOL)
      F7=-0.75*A(I)
      F8=-F6*F7
      TD=T(8)+DELTEM(JW)
      IF(I.LT.8)XAK=0.
      IF(I.GE.8)XAK=1.
       IF(T(1).GT.TD)XM=0.
       IF(T(1).LE.TD)XM=1.
      TD2=DELTM2+T(5)
      IF(T(I).GT.TD2)XM1=0.
      IF(T(1).LE.TD2)XM1=1.
      IF(I.LE.5)XTK=1.
      IF(I.GT.5)XTK=1.
       TN(I)=(F2+F3+XAK*XM*F4+XM1*F41+F31*XTK+F8)*F1+F5
91     CONTINUE
      TN(1)=T(2)
      TM=(TN(12)+TDEW)/2.0
      FW=9.2+0.46*(WIND**2)
      BETA=0.35+0.015*TM+0.0012*(TM**2)
      XK=(4.5+0.05*TN(12)+BETA*FW+0.47*FW)*4.232*(9./5.)
      TE=TDEW+HSOL/XK
       CONS1=(1.5*XK*DZ)/(ROWCP*XKZ(12))
      TE11=TN(11)
      TE10=TN(10)
      SHEAT=(ROWCP*DELTEM(JW)*QP(JW))/(A(12)*XK)
       IF(TD.GT.TN(12))GO TO 14
       GO TO 15
14     TN(12)=(4.*TN(11)-TN(10)+CONS1*TE+SHEAT*CONS1)/(3.+CONS1)
       GO TO 16
15     TN(12)=(4.*TN(11)-TN(10)+CONS1*TE)/(3.+CONS1)
16    TS=TN(12)
      CALL MIXIT(TN,A)
      TIME=TIME+DT
      TIME2=TIME2+DT
      TIME3=TIME3+DT
      TIME4=TIME4+DT
      TIME5=TIME5+DT
      DO 929 I=1,12
      T2(I)=TN(I)
929   CONTINUE
      T12=T(12)
600   TN12=TN(12)
601    DO 92 I=1,12
       T(I)=TN(I)
92     CONTINUE
       J=J+1
       TIME1=TIME1+DT
       IF(NDAYS.GE.360)TIME3=TIME3-360.0
```

```
      IF(NDAYS.GE.360)TIME2=TIME2-360.0
      IF(NDAYS.GE.360)TIME=TIME-360.0
      IF(NDAYS.GE.360)TIME4=TIME4-360.0
      IF(NDAYS.GE.360)TIME5=TIME5-360.0
      IF(NDAYS.GE.360)JJ=0
      IF(NDAYS.GE.360)JW=1
      IF(IYEAR.GT.1979)GO TO 99
      IF(NDAYS.GE.360)IYEAR=IYEAR+1
      IF(NDAYS.GE.360)CALL CCW(QP,DELTEM,IYEAR,DT)
      IF(NDAYS.GE.360)CALL YEARS(SELTEM,QQPP,IYEAR)
      IF(NDAYS.GE.360)JTOT=JTOT+1
      IF(NDAYS.GE.360)JIM=JIM+1
      IF(TIME4.GE.1.0)GO TO 501
      GO TO 502
  501 MMI=MMI+1
      XTDD(JIM,MMI)=TD
      TIME4=TIME4-1.
  502 CONTINUE
      IF(NDAYS.GE.360)NDAYS=0
      DO 66 I=2,10
      CB(I)=(T(I+1)-T(I))/15.
   66 CONTINUE
      CB(1)=(T(2)-T(1))/7.5
      CB(11)=(T(12)-T(11))/7.5
      IF(TIME1.GE.30.) GO TO 98
      TDD=TDD+TD
      DVE=DVE+1.
      GO TO 33
   98 NDAYS=TIME2
      TDD=TDD/DVE
      PRINT 988,(QP(JWJ),JWJ=1,12)
  988 FORMAT(1X,12F10.1)
      TIME4=0.
      MMI=0
      JJ=JJ+1
      JW=JW+1
      NDAYS1=TIME3
      MJ=MJ+1
      DELTM2=DM(MJ)-T(5)
      IF(MJ.GE.12)MJ=1
  313 CONTINUE
      DO 700 I=1,12
  700 T(I)=TN(I)
      IF(JRUN.EQ.2)GO TO 111
      CALL STORE(T,AV,CB,Z,A,XKZ,ROW,TN,DM,TZ,MONTHS,T2,QP,
     CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
     CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
     CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J)
```

```
  111 CONTINUE
      CALL EQUIL1(TN,TE,XK,TDEW,WIND,HSOL)
      PRINT 920,MONTHS(JJ),IYEAR
  920 FORMAT(2X,'MONTH IS',2X,A6,2X,I4)
      PRINT 101,NDAYS,TE,XK
  101 FORMAT(1X,I6,2F9.2)
      WRITE(6,9) NDAYS,(T(I),I=1,12)
      WRITE(6,7) XKZ0,(XKZ(I),I=1,12)
      IF((IYEAR.EQ.1973.AND.NDAYS.GE.210).OR.(IYEAR.GT.1973))
     CWRITE(6,18)TDD,DELTEM(JW-1)
   18 FORMAT(1X,'THE AVERAGE MONTHLY DISCH. TEMP. = ',F5.2,5X,
     C'DELTA-T = ',F5.2)
   12 FORMAT(1X,11F10.2)
    9 FORMAT(1X,I6,12F9.2)
    7 FORMAT(1X,13F9.2)
      TIME1=TIME1-30.0
      TDD=0.
      DVE=0.
      IF(IYEAR.GT.1979)GO TO 99
       GO TO 33
   99 PRINT 921,J
  921 FORMAT(2X,'TOTAL NUMBER OF COMPUTATIONS =',I15,' X 12')
      END FILE 8
      STOP
       END
```

```
APEAS SYM CREATED ON 12 AUG 80 AT 13:05:27
C     THIS SUBROUTINE CONTAINS THE AREAS OF
C     A DOMAIN (LAKE KEOWEE), AT TWELVE
C     HORIZONTAL CROSS-SECTIONS.
C
C
      SUBROUTINE AREAS(A)
      DIMENSION A(20)
      ACONS=10.**8
      A(1)=0.0325*ACONS
      A(2)=0.055*ACONS
      A(3)=0.200*ACONS
      A(4)=0.550*ACONS
      A(5)=1.125*ACONS
      A(6)=1.8*ACONS
      A(7)=2.575*ACONS
      A(8)=3.55*ACONS
      A(9)=4.70*ACONS
      A(10)=5.825*ACONS
      A(11)=7.25*ACONS
      A(12)=8.008*ACONS
      RETURN
      END
```

```
CCW SYM CREATED ON 12 AUG 80 AT 13:00:09
C       THIS SUBROUTINE CONTAINS THE CONDENSER
C       COOLING WATER. ASSUMES THAT COMPUTATIONS
C       START IN 1971.
C
C
C
        SUBROUTINE CCW(QP,DELTEM,IYEAR,DT)
        DIMENSION QP(12),DELTEM(12)
        IF(IYEAR.GT.1979)GO TO 11
        IYEA=IYEAR-1970
        ACOST=10.0
        GO TO(1,1,3,4,5,6,7,8,9),IYEA
1       DO 10 I=1,12
        QP(I)=0.0
10      DELTEM(I)=0.0
        GO TO 11
3       DO 12 I=1,6
        QP(I)=0.0
12      DELTEM(I)=0.0
        QP(7)=1890.2*ACOST
        QP(8)=1910.3*ACOST
        QP(9)=2170.7*ACOST
        QP(10)=2232.5*ACOST
        QP(11)=2170.7*ACOST
        QP(12)=3284.6*ACOST
        DELTEM(7)=5.3
        DELTEM(8)=4.6
        DELTEM(9)=5.3
        DELTEM(10)=7.3
        DELTEM(11)=7.7
        DELTEM(12)=4.1
        GO TO 11
4       QP(1)=3069.3*ACOST
        QP(2)=3069.4*ACOST
        QP(3)=2976.9*ACOST
        QP(4)=2807.3*ACOST
        QP(5)=2164.6*ACOST
        QP(6)=4171.8*ACOST
        QP(7)=5334.6*ACOST
        QP(8)=4727.1*ACOST
        QP(9)=5961.4*ACOST
        QP(10)=4953.4*ACOST
        QP(11)=4202.1*ACOST
        QP(12)=5225.6*ACOST
        DELTEM(1)=4.2
        DELTEM(2)=7.4
        DELTEM(3)=8.4
        DELTEM(4)=8.0
        DELTEM(5)=2.7
        DELTEM(6)=6.0
        DELTEM(7)=5.0
        DELTEM(8)=4.8
        DELTEM(9)=5.8
        DELTEM(10)=3.5
        DELTEM(11)=7.9
        DELTEM(12)=5.9
        GO TO 11
5       QP(1)=4612.4*ACOST
        QP(2)=3694.9*ACOST
        QP(3)=5456.8*ACOST
        QP(4)=5570.8*ACOST
        QP(5)=6494.3*ACOST
        QP(6)=6574.2*ACOST
        QP(7)=7104.2*ACOST
        QP(8)=7510.1*ACOST
        QP(9)=7201.6*ACOST
        QP(10)=6993.4*ACOST
```

```
      QP(11)=7467.1*ACOST
      QP(12)=6850.9*ACOST
      DELTEM(1)=6.3
      DELTEM(2)=4.8
      DELTEM(3)=6.2
      DELTEM(4)=6.3
      DELTEM(5)=6.8
      DELTEM(6)=8.8
      DELTEM(7)=8.3
      DELTEM(8)=7.8
      DELTEM(9)=7.4
      DELTEM(10)=7.7
      DELTEM(11)=8.5
      DELTEM(12)=9.4
      GO TO 11
6     QP(1)=6069.3*ACOST
      QP(2)=4440.2*ACOST
      QP(3)=4874.3*ACOST
      QP(4)=4272.1*ACOST
      QP(5)=3970.7*ACOST
      QP(6)=5197.6*ACOST
      QP(7)=5830.0*ACOST
      QP(8)=7248.3*ACOST
      QP(9)=6785.4*ACOST
      QP(10)=5637.8*ACOST
      QP(11)=5809.2*ACOST
      QP(12)=4914.8*ACOST
      DELTEM(1)=10.6
      DELTEM(2)=7.3
      DELTEM(3)=7.1
      DELTEM(4)=5.1
      DELTEM(5)=5.8
      DELTEM(6)=9.3
      DELTEM(7)=7.4
      DELTEM(8)=8.5
      DELTEM(9)=8.0
      DELTEM(10)=7.8
      DELTEM(11)=6.7
      DELTEM(12)=8.4
      GO TO 11
7     QP(1)=5045.8*ACOST
      QP(2)=4985.2*ACOST
      QP(3)=5113.5*ACOST
      QP(4)=6013.6*ACOST
      QP(5)=6302.4*ACOST
      QP(6)=4385.3*ACOST
      QP(7)=5038.6*ACOST
      QP(8)=5708.9*ACOST
      QP(9)=6964.0*ACOST
      QP(10)=6754.7*ACOST
      QP(11)=4697.6*ACOST
      QP(12)=5854.6*ACOST
      DELTEM(1)=12.5
      DELTEM(2)=11.4
      DELTEM(3)=10.4
      DELTEM(4)=11.4
      DELTEM(5)=9.4
      DELTEM(6)=8.4
      DELTEM(7)=7.4
      DELTEM(8)=5.0
      DELTEM(9)=5.0
      DELTEM(10)=3.8
      DELTEM(11)=6.2
      DELTEM(12)=7.9
      GO TO 11
8     QP(1)=6176.7*ACOST
      QP(2)=6444.6*ACOST
      QP(3)=5195.7*ACOST
      QP(4)=4811.8*ACOST
      QP(5)=4984.2*ACOST
      QP(6)=5659.9*ACOST
      QP(7)=7058.6*ACOST
```

```
      QP(8)=7914.9*ACOST
      QP(9)=6557.3*ACOST
      QP(10)=7407.4*ACOST
      QP(11)=6065.1*ACOST
      QP(12)=6503.5*ACOST
      DELTEM(1)=9.0
      DELTEM(2)=11.0
      DELTEM(3)=13.2
      DELTEM(4)=9.7
      DELTEM(5)=10.1
      DELTEM(6)=8.1
      DELTEM(7)=7.9
      DELTEM(8)=7.5
      DELTEM(9)=7.6
      DELTEM(10)=6.2
      DELTEM(11)=8.4
      DELTEM(12)=7.2
      GO TO 11
    9 QP(1)=7207.7*ACOST
      QP(2)=7319.9*ACOST
      QP(3)=7419.5*ACOST
      QP(4)=7275.8*ACOST
      QP(5)=4189.1*ACOST
      QP(6)=5381.2*ACOST
      QP(7)=4733.3*ACOST
      QP(8)=4733.3*ACOST
      QP(9)=4733.3*ACOST
      QP(10)=4733.3*ACOST
      QP(11)=4733.3*ACOST
      QP(12)=4733.3*ACOST
      DELTEM(1)=10.3
      DELTEM(2)=10.4
      DELTEM(3)=9.6
      DELTEM(4)=9.9
      DELTEM(5)=8.2
      DELTEM(6)=7.1
      DELTEM(7)=5.0
      DELTEM(8)=5.0
      DELTEM(9)=5.0
      DELTEM(10)=5.0
      DELTEM(11)=5.0
      DELTEM(12)=5.0
   11 RETURN
      END
```

```
EQJIL1 SYM CREATED ON 11 JUN 80 AT 11:00:00
          SUBROUTINE EQUIL1(TN,TE,XK,TDEW,XTN,XTE,XXK,WIND,HSOL)
          DIMENSION TN(20),XTN(20)
2         READ(5,1)TDEW,WIND,HSOL
1         FORMAT()
          WIND=WIND*0.45
          HSOL=HSOL*3.6855
          TM=(TN(12)+TDEW)/2.0
          FW=9.2+0.46*(WIND**2)
          BETA=0.35+0.015*TM+0.0012*(TM**2)
          XK=4.5+0.05*TN(12)+BETA*FW+0.47*FW
          XK=XK*4.232*(9./5.)
          TE=TDEW+HSOL/XK
          XTM=(XTN(12)+TDEW)/2.0
          XFW=9.2+0.46*(WIND**2)
          XBETA=0.35+0.015*XTM+0.0012*(XTM**2)
          XXK=4.5+0.05*XTN(12)+XBETA*XFW+0.47*XFW
          XXK=XXK*4.232*(9./5.)
          XTE=TDEW+HSOL/XXK
          RETURN
          END
```

```
INPJT SYM CREATED ON 12 AJG 80 AT 13:01:13
3.0,6.69,167.0
0.,9.3,264.4
6.3,9.28,264.4
7.5,8.72,457.
17.2,7.5,480.5
18.8,5.65,478.
20.,6.48,409.
19.44,5.75,428.2
18.33,5.77,329.
13.88,7.02,261.3
2.88,7.53,247.7
5.5,8.3,147.7
1.67,6,69,178.
-2.22,9.26,257.6
1.11,9.20,352.5
6.67,8.72,448.
11.11,7.53,433.6
13.13,7.95,564.3
18.77,6.64,493.8
22.22,6.07,453.5
18.8,5.47,386.3
11.5,7.17,298.1
5.9,7.13,220.9
4.,6.8,148.
1.,7.22,162.7
-1.,7.3,279.5
10.,7.1,348.5
7.7,8.44,449.3
14.3,6.83,449.5
20.25,3.04,507.7
22.2,5.32,496.9
21.7,5.1,391.6
20.8,6.803,338.4
13.5,7.1,341.7
7.2,8.14,247.6
3.2,5.6,154.
8.2,5.8,191.4
0.,5.8,226.9
6.3,7.7,326.1
10.7,8.73,397.7
17.2,6.8,436.
17.8,6.98,559.3
21.,5.2,459.5
21.,5.87,480.
17.5,6.74,339.2
10.2,5.7,302.5
6.0,7.2,231.1
3.8,6.9,181.9
3.0,6.393,191.4
3.5,7.614,226.9
2.2,9.6,326.1
7.2,7.6,397.7
17.5,4.8,436.
19.0,5.82,559.3
21.3,5.10,459.5
21.0,5.4,480.8
16.2,7.3,339.3
12.4,7.7,302.5
7.9,6.9,231.1
2.0,7.2,181.9
-1.0,7.4,209.8
3.2,8.5,310.9
3.9,7.9,338.6
11.2,7.6,496.9
14.0,7.3,448.4
18.3,6.4,460.2
19.8,5.9,488.3
18.0,6.65,480.4
15.4,7.13,345.1
```

70	8.2,7.21,287.5
71	1.0,7.27,237.5
72	-1.5,8.2,195.0
73	-6.6,8.04,205.5
74	-2.78,8.4,317.6
75	6.0,7.7,328.5
76	10.2,7.6,427.3
77	15.4,6.2,473.
78	18.,6.7,543.3
79	20.2,5.8,551.8
80	20.7,5.4,423.9
81	18.7,5.3,350.7
82	9.2,7.2,286.6
83	7.0,7.5,196.2
84	0.4,7.2,178.2
85	-2.8,7.9,227.
86	-5.0,6.8,308.
87	1.2,7.6,408.
88	9.6,7.6,429.
89	14.,6.7,513.
90	19.4,4.7,598.
91	20.8,5.7,568.
92	20.8,5.1,461.
93	15.5,5.7,385.
94	9.3,6.6,369.
95	9.0,5.8,232.
96	0.4,7.3,191.
97	-3.33,8.6,208.
98	0.0,7.2,251.
99	5.0,7.9,373.
100	9.2,7.6,479.
101	14.,6.7,513.
102	19.4,4.7,598.
103	20.8,5.7,568.
104	20.8,5.1,461.
105	15.5,5.7,387.
106	9.3,6.6,369.
107	9.0,5.8,232.
108	0.4,7.3,191.
109	0.4,7.3,191.

```
MIXIT SYM CREATED ON 12 AUG 80 AT 13:26:57
C
C
C      THIS SUBROUTINE MIXES STABILIZES UNSTABLE
C      TEMPERATURE PROFILES.
C
C
       SUBROUTINE MIXIT(TN,A)
       DIMENSION TN(20),A(20)
100    DO 10 I=1,11
       IF(TN(I+1).GE.TN(I))GO TO 1
       IF((TN(I)-TN(I+1)).LT.0.0)GO TO 1
       TAV=(TN(I+1)+TN(I))/2.
       TN(I+1)=TAV
       TN(I)=TAV
1      CONTINUE
10     CONTINUE
       TMAX=AMAX1(TN(1),TN(2),TN(3),TN(4),TN(5)
      C,TN(6),TN(7),TN(8),TN
      C(9),TN(10),TN(11),TN(12))
       IF(TN(12).LT.TMAX)GO TO 100
300    RETURN
       END
```

```
PLOTTER SYM CREATED ON 12 AUG 80 AT 12:56:46
1          PARAMETER N=14,NN=12,NTIME=12,ND=110
2          DIMENSION IBUF(1000)
3          DIMENSION TEMP(50),DEEP(50),TEMPS(ND),DEEPS(ND),QP(NN),TZ(NN)
4          DIMENSION T(N),AV(N),CB(N),Z(N),XKZ(N),TEQ(ND),THF(ND),TSU(ND)
5          DIMENSION ROW(N),TN(N),DM(N),T2(N),A(N),ZED(ND)
6          DIMENSION E1(50),E2(50),E3(50),E4(50),E6(50),E5(50),
7         CE7(50),ED(50)
8          CHARACTER*6 MONTHS(N)
9          CHARACTER*6 IBCD
10         M=1
11         L=0
12   C
13   C
14   C     READ JRUN=1 IF YOU DESIRE PLOTS FOR MEASURED DATA
15   C     READ JRUN=2 IF YOU DO NOT.
16   C     NOTE : IF PLOTS FOR SEVEN STATIONS ARE NOT
17   C            AVAILABLE, LINES 35 TO 46 MUST BE MODIFIED
18         READ 100,JRUN,JYEAR
19   100   FORMAT()
20         ICOUNT=0
21         XZD=0.
22   5     J0=0
23         CALL PLOTS(IBUF,1000,11)
24         CALL PLOT(0.0,7.0,-3)
25         DO 1 I=1,NTIME
26         CALL READER(T,AV,CB,Z,A,XKZ,ROW,TN,DM,TZ,MONTHS,T2,QP,
27        CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
28        CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
29        CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J)
30         ICOUNT=ICOUNT+1
31         IF(ICOUNT.GT.96)GO TO 333
32         IF(JRUN.EQ.2)GO TO 200
33         READ(5,8)(DEEP(INK),TEMP(INK),INK=1,NSTOP)
34         DO 15 KL=1,50
35         READ(5,8) DEEP(KL),E1(KL),E2(KL),E3(KL),E4(KL),E5(KL),
36        CE6(KL),E7(KL)
37         READ(5,8)AE1,BE1,CE1,DE1,EE1,FE1,GE1,HE1,OE1
38         DEEP(KL)=AE1
39         E1(KL)=BE1
40         E2(KL)=CE1
41         E3(KL)=DE1
42         E4(KL)=EE1
43         E5(KL)=FE1
44         E6(KL)=GE1
45         E7(KL)=HE1
```

```
      ED(KL)=OE1
      IF(E3(KL).EQ.0.0)GO TO 16
      IF(DEEP(KL).EQ.(-1.))GO TO 16
      TEMP(KL)=(E1(KL)+E2(KL)+E3(KL)+E4(KL)+E5(KL)+E6(KL)+
     CE7(KL))/ED(KL)
      TEMP(KL)=E3(KL)
 15   CONTINUE
 200  CONTINUE
 16   NSTOP=KL-1
      IF(JRUN.EQ.2)GO TO 201
      DO 222 JIJ=1,50
      IF(DEEP(KL).EQ.(-1.))GO TO 223
      READ(5,8)AE1,BE1,CE1,DE1,EE1,FE1,GE1,HE1,OE1
      IF(AE1.EQ.(-1))GO TO 223
 222  CONTINUE
 223  CONTINUE
 201  CONTINUE
      CONS2=1./0.3048
      IF(JRUN.EQ.2)GO TO 202
      DO 9  INK=1,NSTOP
      DEEP(INK)=CONS2*DEEP(INK)
 9     DEEP(INK)=150.-DEEP(INK)
      DEEP(NSTOP+1)=0.0
      DEEP(NSTOP+2)=Z(NN)/1.5
      TEMP(NSTOP+1)=0.0
      TEMP(NSTOP+2)=30.0/1.5
 202  CONTINUE
 6    FORMAT()
 333  JO=JO+1
      L=L+1
      TSJ(L)=T(12)
      XZD=XZD+30.
      ZED(L)=XZD
      TEMPS(L)=TEMP(1)
      TEQ(L)=TE
      THF(L)=(T(7)+T(8))/2.
      IBCD=MONTHS(JO)
      Z(NN+1)=0.0
      Z(NN+2)=Z(NN)/1.5
      T(NN+1)=0.0
      T(NN+2)=30./1.5
      CALL AXIS(0.0,0.0,8HTEMP.(C),-8,1.5,0.0,T(13),T(14))
      CALL AXIS(0.0,0.0,9HDEPTH(FT),9,1.5,90.0,Z(13),Z(14))
      CALL FLINE(T,Z,-NN,1,0,0)
      IF(ICOUNT.GT.96)GO TO 444
      IF(JRUN.EQ.2)GO TO 203
      CALL DASHL(TEMP,DEEP,NSTOP,1)
 203  CONTINUE
 444  CALL SYMBOL(1.0,0.5,0.14,IBCD,0.0,6)
      CALL PLOT(2.25,0.0,-3)
```

```
      IF(JO.EQ.4.OR.JO.EQ.8)GO TO 3
      GO TO 1
    3 CALL PLOT(-9.0,-2.25,-3)
    1 CONTINUE
      CALL PLOT(-2.25,0.0,-3)
      CALL SYMBOL(-6.75,6.75,.14,41HTEMPERATURE PROFILES FOR LAKE KEOWEE
     C   ,0.0,41)
      P1=JYEAR
      MY=JYEAR
      CALL NUMBER(999.,999.,0.14,P1,0.0,0)
      CALL SYMBOL(-6.75,6.5,0.1,54H(DEPTH IS MEASURED FROM THE DEEPEST P
     COINT OF THE LAKE),0.0,54)
      CALL PLOT(8.0,-9.25,-3)
      PRINT 2,MY
    2 FORMAT(1X,'THE PLOTS FOR',I5,' ARE COMPLETE')
      IF(M.EQ.9)GO TO 6
      M=M+1
      JYEAR=JYEAR+1
      GO TO 5
    6 CALL PLOT(6.0,0.0,-3)
      DO 13 I=1,96
   13 DEEPS(I)=ZED(I)
      DEEPS(97)=0.0
      DEEPS(98)=3240.0/9.0
      TSU(109)=0.0
      TSU(110)=35./5.
      TEQ(109)=0.0
      TEQ(110)=35./5.
      THF(109)=0.0
      THF(110)=35./5.
      TEMPS(97)=0.0
      TEMPS(98)=35./5.
      ZED(109)=0.0
      ZED(110)=3240./9.
      CALL PLOT(0.0,2.0,-3)
      CALL AXIS(0.0,0.0,12HTIME IN DAYS,-12,9.0,0.0,ZED(109),ZED(110))
      CALL AXIS(0.0,0.0,16HTEMPERATURES (C),16,5.0,90.,TSU(109),TSU
     C(110))
      CALL FLINE(ZED,TSU,-108,1,2,11)
      CALL FLINE(ZED,TEQ,108,1,2,2)
      CALL FLINE(ZED,THF,-108,1,2,0)
      IF(JRUN.EQ.2)GO TO 204
      CALL DASHL(DEEPS,TEMPS,96,1)
  204 CONTINUE
```

```
C
C
C
C      CHANGE TITLES TO SUIT NEEDS (4 LINES)
C
C
       CALL SYMBOL(0.0,6.0,0.14,
     C46HSTRATIFICATION CYCLE FOR LAKE KEOWEE 1971-1979,0.0,46)
       CALL SYMBOL(0.0,0.10,0.10,87H    1971        1972        1973        1974
     C      1975        1976        1977        1978        1979,0.0,87)
       WRITE(6,7)
 7     FORMAT(1X,'ALL PLOTS ARE NOW COMPLETE',//,' NORMAL JOB  EXIT')
       CALL PLOT(15.0,0.0,-3)
       STOP
       END
```

```
READER SYM CREATED ON 12 AUG 80 AT 13:21:45
C
C
C      THIS SUBROUTINE READS THE MAGNETIC TAPE
C      CONTAINING THE COMPUTED RESULTS.
C
C
       SUBROUTINE READER(T,AV,CB,Z,A,XKZ,ROW,TN,DM,TZ,MONTHS,T2,QP,
      CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
      CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
      CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J,NCASE,SF,EDEPT,VOL)
       DIMENSION T(20),AV(20),CB(20),Z(20),A(20),XKZ(20),
      CROW(20),TN(20),DM(20),TZ(20),T2(20),QP(12)
       CHARACTER*6 MONTHS(12)
1      CONTINUE
       READ (8,END=1) (T(IJ),IJ=1,12),(AV(IJ),IJ=1,12),
      C(CB(IJ),IJ=1,12),(Z(IJ),IJ=1,12),(A(IJ),IJ=1,12),
      C(XKZ(IJ),IJ=1,12),(ROW(IJ),IJ=1,12),(TN(IJ),IJ=1,12),
      C(DM(IJ),IJ=1,12),(TZ(IJ),IJ=1,12),(MONTHS(IJ),IJ=1,12),
      C(T2(IJ),IJ=1,12),
      C(QP(IJ),IJ=1,12),
      CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
      CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
      CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J,NCASE,SF,EDEPT,VOL
       RETURN
       END
```

```
SMOOTH SYM CREATED ON 12 AUG 80 AT 14:34:30
C
C      THIS SUBROUTINE CORRECTS THE EDDY DIFFUSIVITY
C      IF VARIABLE TIME STEP IS REQUIRED, 'DT1' SHOULD
C      BE CHANGED TO 'DT' IN THE CALLING PROGRAM.
C
       SUBROUTINE SMOOTH(XKZ,XKZU,XKZL,NDAYS1,TN12,T12,T,DT1,DZ)
       DIMENSION XKZ(20),T(20)
       DO 93 I=1,12
       IF(XKZ(I).GT.XKZU) XKZ(I)=XKZU
       IF(XKZ(I).LT.XKZL) XKZ(I)=XKZL
   93  CONTINUE
       NEW=0
       DO 96 I=2,12
       IF(XKZ(I).EQ.XKZL)NEW=I
   96  CONTINUE
       IF(NEW.EQ.0)GO TO 77
       DO 55 I=1,NEW
       XKZ(I)=XKZL
   55  CONTINUE
   77  CONTINUE
       IF(NDAYS1.LE.60.OR.NDAYS1.GT.300) GO TO 29
       IF(TN12.GE.T12) GO TO 19
       IF(TN12.LT.T12) GO TO 39
   19  XMIN=AMIN1(XKZ(1),XKZ(2),XKZ(3),XKZ(4),XKZ(5),XKZ(6),XKZ(7),XKZ
      1(8),XKZ(9),XKZ(10),XKZ(11),XKZ(12))
       DO 82 I=1,12
       IF(XKZ(I).EQ.XMIN) GO TO 81
   82  CONTINUE
       GO TO 29
   81  IMIN=I
       DO 70 I=1,IMIN
       XKZ(I)=XKZ(IMIN)
   70  CONTINUE
       GO TO 29
   39  XMAX=AMAX1(XKZ(1),XKZ(2),XKZ(3),XKZ(4),XKZ(5),XKZ(6),XKZ(7),XKZ
      1(8),XKZ(9),XKZ(10),XKZ(11),XKZ(12))
       DO 62 I=1,12
          IF(XKZ(I).EQ.XMAX) GO TO 61
   62  CONTINUE
       GO TO 29
   61  IMAX=I
       DO 50 I=IMAX,12
       XKZ(I)=XKZ(IMAX)
   50  CONTINUE
   29  CONTINUE
  200  XMAX=AMAX1(XKZ(1),XKZ(2),XKZ(3),XKZ(4),XKZ(5),XKZ(6),XKZ(7),XKZ
      1(8),XKZ(9),XKZ(10),XKZ(11),XKZ(12))
       DT1=(0.4*DZ**2)/XMAX
       RETURN
       END
```

```
STORE SYM CREATED ON 12 AUG 80 AT 13:19:47 .
C
C
C      THIS SUBROUTINE STORES THE COMPUTED RESULTS ON
C      MAGNETIC TAPE.
C
C
       SUBROUTINE STORE(T,AV,CB,Z,A,XKZ,ROW,TN,DM,TZ,MONTHS,T2,QP,
      CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
      CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
      CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J,NCASE,SF,EDEPT,VOL)
       DIMENSION T(20),AV(20),CB(20),Z(20),A(20),XKZ(20),
      CROW(20),TN(20),DM(20),TZ(20),T2(20),
      CQP(12)
       CHARACTER*6 MONTHS(12)
       WRITE (8) (T(IJ),IJ=1,12),(AV(IJ),IJ=1,12),
      C(CB(IJ),IJ=1,12),(Z(IJ),IJ=1,12),(A(IJ),IJ=1,12),
      C(XKZ(IJ),IJ=1,12),(ROW(IJ),IJ=1,12),(TN(IJ),IJ=1,12),
      C(DM(IJ),IJ=1,12),(TZ(IJ),IJ=1,12),(MONTHS(IJ),IJ=1,12),
      C(T2(IJ),IJ=1,12),
      C(QP(IJ),IJ=1,12),
      CCP,SIGMA,R3,R4,R5,R6,R7,R8,R9,R10,QP2,FREVEL,ROWCP,DT,
      CXKZO,TE,NDAYS,TN12,T12,F1,F2,F3,F31,F41,F5,F6,F7,F8,TD,TD2,
      CNDAYS1,TIME,TIME2,TIME3,IYEAR,MJ,XK,TDD,J,NCASE,SF,EDEPT,VOL
       END FILE 8
       RETURN
       END
```

YEARS SYM CREATED ON 12 AUG 80 AT 13:10:03

```
C
C      THIS SUBROUTINE PRINTS THE YEAR TITLE.
C
C
      SUBROUTINE YEARS(SELTEM,QQPP,IYEAR)
      PRINT 99,IYEAR
99    FORMAT(59X,17('*'),/,59X,'*',15X,'*',/,59X,
     C'*',2X,'YEAR = ',I4,2X,'*',/,59X,'*',15X,'*'
     C,/,59X,17('*'))
      RETURN
      END
```

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT The six-volume report: describes the theory of a three-dimensional (3-D) mathematical thermal discharge model and a related one-dimensional (1-D) model, includes model verification at two sites, and provides a separate user's manual for each model. The 3-D model has two forms: free surface and rigid lid. The former, verified at Anclote Anchorage (FL), allows a free air/water interface and is suited for significant surface wave heights compared to mean water depth; e.g., estuaries and coastal regions. The latter, verified at Lake Keowee (SC), is suited for small surface wave heights compared to depth (e.g., natural or man-made inland lakes) because surface elevation has been removed as a parameter. These models allow computation of time-dependent velocity and temperature fields for given initial conditions and time-varying boundary conditions. The free-surface model also provides surface height variations with time. The 1-D model is considerably more economical to run but does not provide the detailed prediction of thermal plume behavior of the 3-D models. The 1-D model assumes horizontal homogeneity, but includes area-change and several surface-mechanism effects.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Mathematical Models		12A
Estuaries		08H,08J
Lakes		
Plumes		21B

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