MATHEMATICAL PREDICTIVE MODELS FOR COOLING PONDS AND LAKES

PART B: USER'S MANUAL AND APPLICATIONS OF MITEMP
PART C: A TRANSIENT ANALYTICAL MODEL FOR SHALLOW COOLING PONDS

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MATHEMATICAL PREDICTIVE MODELS FOR COOLING PONDS AND LAKES

PART B: USER'S MANUAL AND APPLICATIONS OF MITEMP

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PART C: A TRANSIENT ANALYTICAL MODEL FOR SHALLOW COOLING PONDS

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ABSTRACT

In Part B a computer code, "MITEMP: M.I.T. Transient Temperature Prediction Model for Natural Reservoirs and Cooling Impoundments," is presented as a feasible and efficient tool for the prediction of transient performance of man-made impoundments. Particular emphasis is placed on waste heat dissipation from steam-electric power stations. The code allows the simulation of the physical regime (temperature and flow patterns) of impoundments as a function of design and for long time periods. The code contains the following elements: (1) Natural Deep Lake and Reservoir Model, (2) Deep Stratified Cooling Pond Model, (3) Shallow Vertically Mixed Dispersive Cooling Pond Model, and (4) Shallow, Vertically Mixed Recirculating Cooling Pond Model.


The user's manual presented herein gives a detailed description of the computational structure of MITEMP and discusses input and output requirements. The application to several case studies is presented. A complete code listing is given in the appendix, as are some sample computations.

In Part C, an analytical model is developed to predict the transient performance of shallow, vertically mixed cooling ponds. This model is suggested as an aid in the initial design or screening process, eliminating the need for repeated use of MITEMP for long term simulations. When a candidate design(s) is selected, its long term performance can be analyzed with the more precise MITEMP.
ACKNOWLEDGMENT

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PART C: TRANSIENT ANALYTICAL MODEL FOR SHALLOW COOLING PONDS

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PART B: USER'S MANUAL AND APPLICATIONS OF MITEMP
I. INTRODUCTION

The design of man-made impoundments for industrial, agricultural, domestic or recreational water utilization requires efficient and accurate planning tools. Part B of this report describes the structure and application of a computer model which allows the ready simulation of the physical regime (temperature and flow patterns) of impoundments as a function of their design for any required length of time. The major application of the computer model is in the design and simulation of cooling lakes or ponds for the dissipation of waste heat from steam-electric generating plants. A particular component of the computer model, however, is the prediction of natural stratification conditions in lakes or reservoirs (i.e., in the absence of artificial heat loading).

In the earlier report (Part A), a classification of impoundments in terms of their temperature structure and flow pattern has been developed, the mathematical basis for predictive models for the various impoundment classes has been derived and the verification of these models with available field and laboratory data has been demonstrated.

Based upon this background, a flexible and multipurpose computer code entitled "MITEMP: M.I.T. Transient Temperature Prediction Model for Natural Reservoirs and Cooling Impoundments" has been assembled. MITEMP contains the following sub-models:

(1) Natural Deep Lake and Reservoir Model

(2) Deep Stratified Cooling Pond Model

(3) Shallow, Vertically Mixed Dispersive Cooling Pond Model

(4) Shallow, Vertically Mixed Recirculating Cooling Pond Model
Figure 1-1: Hierarchical Structure of MITEMP and Decision Criteria
1.1 **Review of Pond Classification**

The choice of appropriate sub-model depends on three parameters as illustrated in Figure 1-1. These parameters include the heat loading $\phi$ (MWt/acre), the pond number $P$ (dimensionless), and the horizontal aspect ratio $L/W$ (dimensionless). The physical basis for these parameters is summarized briefly below; a more complete discussion of the physical basis, supported by laboratory and field measurements, can be found in Chapters 2 and 3 of Part A or in Jirka and Watanabe (1980a).

The parameter $\phi$ allows one to distinguish between ponds whose hydrothermal structure is influenced primarily by natural forces such as surface wind stress ($\phi < 0.1$ to $0.2$ MWt/acre) as opposed to power plant circulation ($\phi > 0.1$ to $0.2$ MWt/acre).

The pond number is defined as

$$P = \left( \frac{f_i Q_o^2}{4\beta\Delta T_o g H^3 W^2} \frac{D_v^3 L}{W} \right)^{1/4}$$

where $L =$ pond length along flow path, $W =$ flow path width ($W = A/L$), $A =$ pond surface area, $H =$ pond depth, $Q_o =$ condenser flow rate, $\Delta T_o =$ condenser temperature rise, $D_v =$ volumetric dilution produced by vertical entrance mixing, $f_i =$ interfacial friction factor, $\beta =$ coefficient of thermal expansion and $g =$ acceleration of gravity. $P$ represents the ratio of the surface layer thickness $h$ to the total pond depth $H$, where $h$ is derived as the heated water depth necessary to circulate the condenser flow across the pond by buoyant gravitational convection.

Thus the tendency for vertical stratification increases as $P$ decreases.
A criterion of $\Phi < 0.5$ is used to distinguish deep (vertically stratified) from shallow (vertically well-mixed) cooling ponds.

The aspect ratio $L/W$ describes the tendency for lateral recirculation and thus inefficient use of the pond's surface area, in shallow cooling ponds. Such recirculation is more likely in a shallow pond than in a deep pond because of the tendency of density currents to provide full utilization of the surface area in the deep pond. A criterion of $L/W < 3$ to 5 is used to distinguish laterally recirculating from longitudinally dispersive shallow ponds.

The four sub-models whose classification depends on $\Phi$, $\Phi$ and $L/W$ are illustrated in Figure 1-2 and are described briefly below. A more complete description is provided in Chapters 4 and 5 of Part A and in Jirka and Harleman (1979).

The temperature distribution in a natural deep lake or reservoir (Figure 1-2a) is assumed to be distributed vertically, i.e. $T(z)$. The depth of the well-mixed surface layer is computed as a function of time in response to wind mixing and surface cooling using the algorithm described originally in Octavio et al (1977) and modified by Bloss and Harleman (1979). Temperatures in the hypolimnion respond to vertical advection created by submerged withdrawal (if any), absorption of solar radiation, mixing of river inflow and vertical diffusive mixing. User-specified input parameters are used to describe the last three processes.

A deep stratified cooling pond (Figure 1-2b) is assumed to consist of two regions: a vertically well-mixed surface layer whose temperature is a function of horizontal position and a sub-surface zone whose temperature is a function of depth. This structure is similar to that of
Figure 1-2 Schematics of Hydrothermal Structure of Sub-Models in MITEMP
a natural deep lake or reservoir except that the depth of the surface layer is computed as a function of the discharge conditions (depth \( h = \frac{P}{H} \)) and has horizontal temperature variation due to heat loading and consequent atmospheric cooling along the flow path. Temperatures in the sub-surface layer respond to the same processes which are present in a natural deep lake as reservoir. However, the condenser flow rate is typically larger than most river flows and the condenser intake will be more deeply submerged than the outlets of most lakes and many reservoirs, leading to a greater contribution from the vertical advection term. As a consequence, sub-surface temperatures in a deep stratified cooling pond may not be as sensitive to the specification of coefficients describing vertical diffusion, river inflow mixing and solar radiation absorption.

Shallow, vertically mixed ponds with longitudinal dispersion (Figure 1-2c) are characterized by a one dimensional (longitudinal) temperature distribution which results mainly from surface cooling and longitudinal dispersion; the latter is computed as a function of the pond loading and geometry. In addition, a small entrance mixing region may be present near the inlet; the fraction of the pond area devoted to entrance mixing is a user-specified input.

In a shallow, vertically mixed pond with lateral recirculation (Figure 1-2d) the flow is divided into two regimes: a forward flowing jet zone of width \( qW \) and a reverse flowing return zone of width \( (1-q)W \). Entrainment from the return flow zone to the jet zone is characterized by a dilution factor \( D_s \). Parameters \( q \) and \( D_s \) are user-specified inputs whose
values typically fall in the ranges of $0.25 < q < 0.40$ and $1.5 < D_s < 3.0$.
The program also computes longitudinal dispersion in each zone but this process is generally of secondary importance relative to the mixing caused by entrance dilution.

It should be recognized that a particular design, or a range of contemplated designs or design modifications, may yield values of the parameters $\phi$, $P$ and $L/W$ which place the pond in an inbetween classification, i.e. $\phi \sim 0.1$ to 0.2, $P \sim 0.5$ or $L/W \sim 3$ to 5. In this case it may be prudent to perform simulations under both classifications and consider either average or worst case performance. It should also be clear that the classification systems can be used to guide initial pond design.

For example, it is clear from linearized steady-state analysis (see Appendix B of Part A, Part C, or Jirka and Watanabe (1980b)) or from parametric sensitivity studies with the MITEMP model (Adams, et al., 1978), that shallow ponds with longitudinal dispersion are the most efficient; lateral entrance mixing associated with shallow recirculating ponds, or vertical entrance mixing associated with deep stratified ponds, may significantly decrease pond performance.

1.2 Use of MITEMP

The program MITEMP can be used to simulate the hydrothermal performance of ponds classified according to the scheme discussed above. This simulation is facilitated by the following program features:

(a) Multicomponent Cooling Lakes: Because existing or proposed cooling impoundments can be comprised of a series of ponds separated by baffles or dikes, MITEMP has been set-up to simulated up to five ponds
in series; each pond may be classified separately in one of the four classes discussed above.

(b) **Open or Closed Cycle Operation:** Because cooling lakes or ponds may be operated in either open cycle (once-through) or closed cycle modes, MITEMP has the capability to simulate either of these conditions. In the open cycle mode, the user provides an input time series of condenser flow rates and temperatures, while in a closed cycle mode, data is provided on condenser flow rate and temperature rise.

In general, MITEMP meets the stated objectives (see Section 1.2, Part A) for cooling lake analysis techniques in view of typical engineering, legal and biological requirements. These objectives are addressed here in brief.

(1) **Qualitative Correctness:** Application of the classification criteria insures that the "correct" conceptualization (i.e., model) is used for each particular case.

(2) **Predictiveness and Accuracy:** All the governing characteristics (i.e., model coefficients) can be estimated based on the physical features of the impoundment. Comparisons with available field data suggest that the model accuracy is within the 2°F (1°C) error band (for both mean value and standard deviation) which appears compatible with legal requirements and the state-of-the-art biological impact analysis.

(3) **Time Variability:** MITEMP can be run with a time scale of 3 hours to 1 day. This time step is short enough to adequately simulate weather fluctuations and plant transients, while filtering out events of a shorter duration which seem insignificant in view of the thermal inertia of water bodies. As coded, variable arrays allow a one year simulation of a deep stratified pond using one day time steps or a one year simulation of a vertically mixed pond using a 3 hour time step. Of course, variable dimensions can be changed to suit a user's need.
(4) **Spatial Resolution:** MITEMP allows one to differentiate the cooling (or natural) impoundment into major zones: namely the surface layer and the subsurface region. Within each zone, cumulative volume - temperature relationships are computed. Again, this procedure appears adequate in light of the governing requirements.

(5) **Computational Efficiency:** A typical MITEMP simulation of the most complex cooling lake configuration (i.e., the deep stratified cooling lake) requires approximately 6 sec of CPU time on a IBM 370/168 Computer for one year of simulation and one day time steps. Thus computational costs are sufficiently low to allow the simulation of design alternatives for long-term durations. (See Part C in this regard).

As with any planning model, MITEMP can be used either in a verification or prediction (or simulation) mode. In the verification mode, historical input data on meteorological, hydrological and plant operating conditions are used and the output (i.e., the computed temperatures) is compared to observed temperature distributions. In the prediction mode, the input data is given by either historic data series on meteorological and hydrological parameters or synthetically generated data series if sufficiently reliable on-site data is not available (see Jirka et al., 1977, for an example of the latter case). In addition, operating conditions (often full continuous load) must be specified. For preliminary design, especially of shallow cooling ponds, simulation can be considerably simplified using the analytical methods described in Part C of this report or in Adams and Koussis (1980).
1.3 Report Outline

A detailed description of the computational features of MITemp is given in Chapter 2. Ad hoc changes in the code can be made to allow the inclusion of site-specific conditions.

Chapter 3 gives user's instructions by listing the input requirements.

The application of the computer code to several case studies is discussed in Chapter 4. This illustrates the approaches taken in past cooling pond modeling work at the Parsons Laboratory in terms of classifying the impoundment, selecting the appropriate model and giving long-term predictions.

A complete listing of the computer code is given in Appendix A.

Numerical examples showing different input specifications and the resulting output are presented in Appendix B as a guideline and checkpoint for the prospective user.
II. STRUCTURE OF THE COMPUTER MODEL

In this chapter, the structure and function of each of the subroutines in the program are described. The general structure of the program is illustrated in Figure 2-1. A more detailed flow chart is shown in Figure 2-2. In this figure, programming sections are identified by the FORTRAN subroutine name.

2.1 Main Program

The main program is essentially a switchboard that controls which subroutines are called, and in what order, for each of the possible systems. This organization allows the user to break down the general model if desired and to reconstruct simpler models using only those subroutines required for the system of interest. The detailed flow chart given in Figure 2-2 is the flow chart for the main program.

2.2 Data Input Subroutines

Since specific system structures may not require all the possible types of input data, input data requirements have been divided into three groups, each of which is treated in a separate subroutine. All three subroutines contain conversion equations for use when the input data is in English units. Other aspects of the subroutines are described below.

2.2.1 Subroutine MET

Subroutines MET contains the data input statements that establish the structure of the system under consideration, i.e., the number of ponds, whether there is heat loading and the geometric classification of each pond. In addition, it contains all the meteorological data input statements.
Meteorological requirements consist of:

(1) air temperature,
(2) relative humidity,
(3) wind speed,
(4) short wave solar radiation (If measured values are not available, maximum clear sky short wave solar radiation values can be used in conjunction with cloud cover data.),
(5) long wave atmospheric radiation - or cloud cover (Measured values of atmospheric radiation are generally not available. However, they can be computed from the air temperature and cloud cover.)

Subroutine MET is called for all possible system structures. Its flow chart is shown in Figure 2-3.

2.2.2 Subroutine GEOM1

Subroutine GEOM1 contains the data input statements that establish the geometry and initial temperature distribution of the vertically well mixed portion of a cooling pond with horizontal temperature variation. For the first pond in the series, the data input statements for the flow rates and temperatures of the heated discharge are also included.

This subroutine is called once for every cooling pond in the series. It is not called if the system under consideration is a natural lake or reservoir. The flow chart for GEOM1 is shown in Figure 2-4.

2.2.3 Subroutine GEOM2

Subroutine GEOM2 contains the data input statements that establish the geometry and initial temperature distribution of the vertically stratified portion of a cooling pond or of a natural lake or reservoir. It also contains the data input statements for river inflow rates and temperatures and for
outflow rates.

This subroutine is called if the system being considered is a stratified cooling pond or an unloaded lake or reservoir. The flow chart for GEOM2 is shown in Figure 2-5.

2.3 Subroutine WEATHR

In subroutine WEATHR, the meteorological conditions for each time step are determined from the read in data, which do not necessarily have an input frequency equal to the time step. The equilibrium temperature associated with the meteorological conditions is also computed. The flow chart for subroutine WEATHR is shown in Figure 2-6.

2.4 Subroutine HEAT

In subroutine HEAT, surface heat losses are computed using the equations in Appendix A of Part A of this report. The flow chart for this subroutine is shown in Figure 2-7.

2.5 Subroutine DISPER

In subroutine DISPER, the dispersive flow equation with cross-sectionally averaged variables

\[
\frac{\partial T}{\partial t} + U \frac{\partial T}{\partial x} = E_L \frac{\partial^2 T}{\partial x^2} - \frac{\phi_n}{\rho c H}
\]

(2.1)

where \( T \) = cross-sectional mean temperature, \( U \) = cross-sectional mean velocity, \( x \) = longitudinal distance, \( t \) = time, \( E_L \) = longitudinal dispersion coefficient, \( H \) = mean depth, \( \phi_n \) = net heat flux across the surface, \( \rho c \) = specific heat per unit volume, is written in finite difference form using the Crank-Nicholson method and incorporating the boundary conditions discussed in Chapter V of
Part A of this report. This results in a set of simultaneous linear equations relating the temperature distribution in the vertically well mixed region at time step n to the temperature distribution at time step n-1.

2.5.1 Subroutine TRIDAG

The set of simultaneous equations developed in subroutine DISPER form a tridiagonal matrix. Subroutine TRIDAG is a standard subroutine for finding the eigenvectors of a tridiagonal matrix. Subroutine TRIDAG returns the temperature distribution in the vertically well mixed region at time step n to subroutine DISPER. The flow chart for subroutine DISPER is shown in Figure 2-8.

2.6 Subroutine SUREL

Subroutine SUREL computes the variation in elevation of the surface of a natural lake or reservoir based on mass conservation for cases in which the inflows are not equal to the outflows. It also computes the associated changes in the surface area. The flow chart for subroutine SUREL is shown in Figure 2-9.

2.7 Subroutine SPEED

In subroutine SPEED, the horizontal velocity distributions induced by inflows to and outflows from the vertically stratified portion of a cooling pond or a natural lake or reservoir are computed. The velocities are assumed to have Gaussian distributions with respect to the vertical coordinate. The width of the Gaussian outflow profile is a function of the vertical stratification and is computed with a modified Kao equation (1965). Vertical advective velocities are computed from continuity requirements (see Chapter IV of Part A
of this report). The flow chart for subroutine SPEED is shown in Figure 2-10.

2.8 **Subroutine TOUTQ**

In subroutine TOUTQ, the average temperature of water released from an outlet located in the vertically stratified portion of a cooling pond or a natural lake or reservoir is computed from the outflow velocity distribution and the temperature profile.

2.9 **Subroutine SUBLAY**

The basic heat transport equation governing the temperature distribution in the vertically stratified region is

\[
\frac{\partial T}{\partial t} + \frac{1}{A} \frac{\partial}{\partial z} \left( Q_v T \right) = \frac{E}{A} \frac{\partial}{\partial z} \left[ A \frac{\partial T}{\partial z} \right] + \frac{B_u T_i}{A} - \frac{B_o T_o}{A} - \frac{1}{\rho c A} \frac{\partial (A \phi_z)}{\partial z} \tag{2.2}
\]

where \( T \) is the temperature at depth \( z \), \( A \) = area of the element, \( B \) = width of the element, \( u_i \) = horizontal inflow velocity, \( T_i \) = temperature of the inflow, \( u_o \) = horizontal outflow velocity, \( Q_v \) = vertical flow rate, \( \phi_z \) = internal short wave solar radiation flux per unit horizontal area, \( E \) = vertical diffusion coefficient, assumed constant with depth, \( c \) = heat capacity of water and \( \rho \) = density of water. This equation is written in finite difference form (Ryan and Harleman, 1971). One can identify incremental changes in the temperature of an element due to:

1. the differential absorption of short wave solar radiation
2. vertical advection
3. outflows
4. inflows
5. diffusion

In the case of a natural lake or reservoir, the temperature of the surface
element is also incremented by the contribution from the surface heat fluxes. The flow chart for subroutine SUBLAY is shown in Figure 2-11.

2.10 Wind Mixing Subroutines

The influence of wind mixing on the temperature profile in a natural lake or reservoir is represented by an iterative algorithm that treats heating and wind mixing separately. This algorithm is discussed in Bloss and Harleman (1979).

2.10.1 Subroutine HTMX

Subroutine HTMX directs the iterative procedure and contains the heating calculations. Its flow chart is shown in Figure 2-12.

2.10.2 Subroutine WDMIX

A fraction of the kinetic energy of the wind is transformed into potential energy of the water column. For an arbitrary temperature profile and wind speed, subroutine WDMIX computes the mixed layer depth and temperature associated with the given change in potential energy. The derivation of this subroutine is given in Bloss and Harleman (1979). The flow chart for subroutine WDMIX is shown in Figure 2-13.

2.11 Density Instability Mixing Subroutines

2.11.1 Subroutine AVER

Subroutine AVER eliminates density instabilities in vertically stratified systems by mixing adjacent elements until the instability is eliminated when necessary. In vertically stratified cooling ponds, this includes elements at the cooler end of the horizontally stratified heated surface region as well as elements in the vertically stratified region. The flow chart for
subroutine AVER is shown in Figure 2-14.

2.11.2 Subroutine COLDCK

Subroutine COLDCK initiates mixing of unstable adjacent layers when water temperatures are below 40°F. Note, however, that the program does not consider freezing.

2.12 Subroutine ENERGY

Subroutine ENERGY provides a check on whether the model is working in a manner that conserves thermal energy. It computes the value of a ratio formed by rewriting the thermal energy conservation equation,

\[
\frac{\text{Heat content (t=n)} + \sum_{t=0}^{n-1} \text{Heat out}}{\text{Heat content (t=0)} + \sum_{t=0}^{n-1} \text{Heat in}}
\]

This ratio should equal 1. The heat content is computed from the temperature distribution and the geometry. Heat out is comprised of surface heat losses and heat advected out by outflows while heat in is comprised of surface heat inputs and heat advected in by inflows. The flow chart for subroutine ENERGY is shown in Figure 2-15.

2.12.1 Subroutine SUMFLX

Subroutine SUMFLX keeps running sums of the surface heat inputs and of the surface heat losses. For cooling ponds the sums are over space as well as time. It also keeps a cumulative sum of the evaporative mass loss.

2.13 Output Subroutines

The output statements have been divided into three groups, each of which is contained in a separate subroutine. Each subroutine contains conversion
equations for use when the output is desired in English units.

2.13.1 Subroutine PRINT

Subroutine PRINT determines which data output subroutines will be called. Depending on the case being modeled, one, two or all of the output subroutines will be called.

2.13.2 Subroutine PRINT1

Subroutine PRINT1 contains the output statements for information associated with the vertically well mixed portion of a cooling pond.

2.13.3 Subroutine PRINT2

Subroutine PRINT2 contains the output statements for information associated with the vertically stratified portion of a cooling pond or a natural lake or reservoir.

2.13.4 Subroutine PRINTA

Subroutine PRINTA contains output statements for a summary of meteorological information.

2.14 Date Subroutines

The date subroutines are used in order to facilitate output retrieval for specific days.

2.14.1 Subroutine DAXIME

Subroutine DAXIME converts an output date into number of days since 1/1/1800.
2.14.2 **Subroutine TIMDAX**

Subroutine TIMDAX converts the number of days since 1/1/1800 into the date in the form MONTH/DAY/YEAR.

2.14.3 **Function LEAP**

Function LEAP computes leap year corrections.
Figure 2-1: General Model Structure
Figure 2-2: MAIN Program Flow Chart

START

CALL MET

KSTRAT

1

CALL GEOM2

KHEAT

2

CALL GEOM1

CALL WEATHR

CONTINUE
Figure 2-2 Cont'd

1. KMODE
   2. Stratified Cooling Pond
      - Set Geometry Temperature Distribution
      - Call DEPTH
      - Call HEAT
      - Call DISPER
      - Call SPEED
      - Continue
   3. Natural Lake or Reservoir
      - Set Geometry Temperature Distribution
      - KSUR
      - Call SUREL
      - Call HEAT
      - Call SPEED
      - Continue
   4. Shallow Cooling Pond
      - Set Geometry Temperature Distribution
      - Call HEAT
      - Call DISPER
      - Continue
Figure 2-3: Subroutine MET Flow Chart

START

READ LABEL

READ NUMBER OF PONDS

READ POND STRUCTURE SWITCHES

\[ i = i + 1 \]

INITIALIZE SOME ENERGY CHECK VARIABLES

READ METEOROLOGICAL DATA SWITCHES

READ AIR TEMPERATURES

READ RELATIVE HUMIDITY VALUES

READ WIND SPEEDS

READ SHORT WAVE SOLAR RADIATION

CONTINUE
Figure 2-3 cont'd

CONTINUE

1,1

KFIN KATRAD

READ CLOUD COVER

2,1
2,2
1,2

KATRAD

READ MEASURED ATMOSPHERIC RADIATION

2

READ EXTINCTION COEFFICIENT \( \eta \) and \( \beta \)

1

READ TIME STEP, STOP TIME, PRINT INTERVALS

1

KUNITS

2

CONVERT UNITS

RETURN
Figure 2-4: Subroutine GEOM1 Flow Chart

START

READ IN NUMBER OF SEGMENTS

READ DEPTH, WIDTH AND LENGTH

COMPUTE VOLUME

COMPUTE VERTICAL CROSS SECTIONAL AREA

READ IN INITIAL TEMPERATURE DISTRIBUTION

READ FULLY MIXED FRACTION, DILUTION

KCIRC

1

COMPUTE LENGTH OF SEGMENTS

COMPUTE VOLUME IN MIXING REGION

2

COMPUTE LENGTH OF SEGMENTS IN JET SIDE

COMPUTE LENGTH OF SEGMENTS IN RETURN FLOW SIDE

COMPUTE VOLUME IN MIXING REGION

CONTINUE
Figure 2-4 Cont'd

CONTINUE

1 = 1 (First Pond?)

NO

READ FLOW RATES

1

KOPERA

READ TEMPERATURE RISE

2

READ TEMPERATURES

1

KUNITS

2

CONVERT UNITS

INITIALIZE SOME ENERGY CHECK VARIABLES

COMPUTE INITIAL HEAT CONTENT

RETURN
Figure 2-5: Subroutine GEOM2 Flow Chart

START

READ NUMBER OF ELEMENTS

READ ELEMENT THICKNESS, TOP ELEMENT ELEVATION

READ HORIZONTAL CROSS SECTIONAL AREAS

READ LENGTHS

READ INITIAL VERTICAL TEMPERATURE DISTRIBUTION

READ DIFFUSIVITY COEFFICIENT

READ CHARACTERISTICS OF INFLOW DISTRIBUTION

READ NUMBER OF INFLOWS

READ ENTRANCE MIXING PARAMETERS

READ INFLOW RATES

READ INFLOW TEMPERATURES

CONTINUE
Figure 2-5 Cont'd

CONTINUE

READ NUMBER OF OUTLETS

READ OUTLET GRID NUMBER, ELEVATION

K = K + 1

READ OUTFLOW RATES

1

KUNITS

2

CONVERT UNITS

ESTABLISH GEOMETRY OF EACH ELEMENT

INITIALIZE SOME ENERGY CHECK VARIABLES

COMPUTE INITIAL HEAT CONTENT

RETURN
Figure 2-6: Subroutine WEATHR Flow Chart

START

INTERPOLATE TO FIND AIR TEMPERATURE

INTERPOLATE TO FIND RELATIVE HUMIDITY

COMPUTE VAPOR PRESSURE

INTERPOLATE TO FIND WIND SPEED

INTERPOLATE TO FIND SHORT WAVE SOLAR RADIATION

KFIN

1

MULTIPLY CLEAR SKY SHORT WAVE SOLAR BY CLOUD COVER CORRECTION

2

KATRAD

1

COMPUTE ATMOSPHERIC RADIATION

2

INTERPOLATE TO FIND ATMOSPHERIC RADIATION

COMPUTE EQUILIBRIUM TEMPERATURE

RETURN

38
Figure 2-7: Subroutine HEAT Flow Chart

START

K = K + 1

> 1

NAR no. of elements = 1

TS = TEMP(K)

SURAR = DXX*WSTR

TS = T(JM,1)

SURAR = AYSUR

K = 1, NAR

SURAR = SURAR/2

COMPUTE SATURATED VAPOR PRESSURE

KHEAT

1

COMPUTE EVAPORATION AND CONDUCTION FLUX - RYAN FORMULA

2

COMPUTE EVAPORATION AND CONDUCTION FLUX - ROHWER FORMULA

COMPUTE BACK RADIATION FLUX

CALL SUMFLX (I)

CONTINUE
Figure 2-7 Cont'd

CONTINUE

1

KSTRAT

2

1

KHEAT

2

ALL SHORT WAVE SOLAR RADIATION ABSORBED IN HEATED LAYER

COMPUTE PORTION OF SHORT WAVE SOLAR RADIATION ABSORBED IN HEATED LAYER

COMPUTE PORTION OF SHORT WAVE SOLAR RADIATION ABSORBED IN TOP ELEMENT

COMPUTE TEMPERATURE CHANGE

RETURN
Figure 2-8 Subroutine DISPER Flow Chart

START

1. ESTABLISH FRICTION FACTOR

2. ESTABLISH FRICTION FACTOR

3. THERM

4. OHTA

5. OHTL

6. L.A.M. MATRIX COEFFICIENTS

7. T.R.H.S. MATRIX COEFFICIENTS

8. CALL TRIDAC (GAUSS EQUATIONS)

9. RETURN

41
Figure 2-9: Subroutine SUREL Flow Chart

Start

Sum inflows

Sum outflows

Compute cumulative net inflow, O1O

\( O1O \leq 0 \)

Compute number of elements lost

Compute new surface elevation

Establish number of vertical elements JNEW

Compute thickness of top element DYSUR

Compute surface area

\( O1O > 0 \)

Compute number of elements added

Compute new surface elevation

Continue
Figure 2-3 Cont'd

Continue

< \( \text{IMNEW:} \)
\( \text{NEL}(I) \) >

Combine Previous Top Two Elements

Combine New Element with Element Below

Update \( \text{NEL}(I) \)

Return
Figure 2-10: Subroutine SPEED Flow Chart

START

INTERPOLATE TO FIND INFLOW TEMPERATURE

K = K + 1

INTERPOLATE TO FIND INFLOW RATE

NIN = NIN + 1

INTERPOLATE TO FIND OUTFLOW RATE

KHEAT

NIN1 = NIN + 1

TIN(NIN1) = TEMP(MP1)

QIN(NIN1) = QHINI

Kmix

K = K + 1

COMPUTE MIXED INFLOW TEMPERATURE

LOCATE LEVEL OF INFLOW

CONTINUE

44
Figure 2-10 Cont'd

CONTINUE

COMPUTE NORMALIZED INFLOW VELOCITY PROFILE

COMPUTE MAXIMUM INFLOW VELOCITY $u_{i\text{max}}$, HENCE $u_{i,j}$

CALCULATE TEMPERATURE GRADIENT AT OUTLET (L) (DERIV)

FOR VERY SMALL GRADIENTS, PUT WITHDRAWAL LAYER THICKNESS = TO TWICE THE DISTANCE BETWEEN THE OUTLET AND A SPECIFIED TEMP. GRADIENT. CALCULATE $\sigma_0\cdot$ IF SPECIFIED TEMP. GRADIENT DOES NOT EXIST, PUT $\sigma_0$ = 100 $\Delta y$.

CALCULATE DENSITY GRADIENT

DERIV: 0.01

CALCULATE WITHDRAWAL LAYER THICKNESS, $\delta$, USING KOH'S FORMULA

KOH

1

CALCULATE WITHDRAWAL LAYER THICKNESS, $\delta$, USING KAO'S MODIFIED FORMULA

2

CALCULATE $\sigma_0$

CONTINUE

45
Figure 2-10 Cont'd

1. COMPUTE NORMALIZED VELOCITY PROFILE FOR OUTLET (L)
2. CALCULATE MAX. OUTFLOW VELOCITY $u_{omax}^{(L)}$ HENCE $u_{o}^{(L)}$
3. SUM OUTFLOW VELOCITIES AT EACH LEVEL, INCLUDING THOSE DUE TO ENTRANCE MIXING, THUS OBTAINING $u_{oj}$
4. CALCULATE VERTICAL VELOCITIES FROM CONTINUITY
5. CONTINUE
6. RETURN

Repeat for all (L)
Figure 2-11: Subroutine SUBLAY Flow Chart

Start

Initialize Variables

Determine Maximum Vertical Velocity, VVV

< VVV: DY

VVV: DTAU

> Decrease the Time Increment

Maintain the Same Time Increment

IDT = 1

Initialize Variables

Determine Intermediate Thickness and Area of the Top Element

Heat Transport Calculation

Bottom Element

Compute ΔT due to

Direct absorption DELTA

Vertical advection DELTB

Horizontal advection DELTC

Diffusion DELTD

Continue
Heat transport calculation

Internal elements
Compute $\Delta T$ due to
- direct absorption $\Delta T_A$
- vertical advection $\Delta T_B$
- horizontal advection $\Delta T_C$
- diffusion $\Delta T_D$

Repeat for $J=2$, $J=M-1$

Heat transport calculation
Top element in vertically stratified region

$\Delta T$ due to
- direct absorption $\Delta T_A$
- no surface flux $\Delta T_{S0}=0.0$
- surface fluxes $\Delta T_S$

$\Delta T$ due to
- vertical advection $\Delta T_B$
- horizontal advection $\Delta T_C$
- diffusion $\Delta T_D$

Continue
Figure 2-11 Cont'd

Continue

Call TOUTQ

sum the ΔTs for
new temperature distribution

1

KHEAT

2

Call SUMFLX

IDT > 50

END

79

Repeat M=1, IDT < 50

compute outflow temperature

END
Figure 2-12: Subroutine HTMIX Flow Chart

START

COMPUTE SURFACE HEATING

CALL WDMIX
(COMPUTES WIND MIXING)

CALL HEAT

RECOMPUTE SURFACE HEATING

ESTABLISH NEW TEMPERATURE PROFILE

CALL WDMIX

> 0.004

CHANGE IN SURFACE HEATING

< 0.004

RETURN
Figure 2-13: Subroutine WDMIX Flow Chart

START

1. Convert temperature profile to density profile
2. Compute shear stress
3. Compute energy input of the wind, ENGY
4. Add an element to the wind mixed layer
5. Compute induced change in potential energy, PE
6. Compute temperature and density of wind mixed layer
7. If PE < ENGY, go to step 8; otherwise, go to step 9
8. Compute fractional part of element to be added to wind mixed layer
9. Compute temperature of wind mixed layer
10. Compute temperature of element below wind mixed layer
11. Assign temperature to elements in the wind mixed layer
12. Return
Figure 2-14: Subroutine AVER Flow Chart

Start

Initialize Variables

100

Compute Average Temperature of Surface Heated Layer

\[ J = J_{M} \]

\[ T_{j} \geq T_{j-1} \]

\[ J \geq 2 \]

\[ ELBSE:EL \]

Avera\[ \text{Average Temperatures of Bottom Two Elements} \]

Allow Convective Mixing of the Surface Heated Layer and Horizontal Elements to Occur Until Instability Disappears

Allow Convective Mixing of the Horizontal Elements to Occur Until Instability Disappears

Refine Temperature Distribution

\[ J = J - 1 \]

Continued
Figure 2-14 Cont'd

Continued

Check Revise Temperature Distribution for Stability

100

No

Stable?

Yes

Return
Figure 2-15: Subroutine ENERGY Flow Chart

Start

1. KSTRAT

1. Compute Heat Content of Horizontally Stratified Region

2. Compute Heat Content of Vertically Stratified Region

3. Compute Energy Advedted Out by Heated Throughflow

4. Compute Energy Advedted In by Heated Throughflow

5. Compute Energy Advedted Out by Outflows

6. Compute Energy Advedted In by River Inflows

7. KHFAT

8. Compute Energy Ratio

9. Return
III. Preparation of Input Data

In this chapter, the order and format of the input data are described. Each card with its associated input information is listed. When a card or group of cards must be repeated a number of times this is indicated in the explanation of the card(s). (This can also be seen by consulting the flow charts in Chapter II.)

The input data requirements of the model have been divided into three blocks, each of which is handled in a separate subroutine. The first block is treated in subroutine MET. It includes information that establishes the structure of the system under consideration and the meteorological data. The second block is treated in subroutine GEOM2. It includes the geometric information and initial temperature distribution in the vertically stratified portion of a given cooling pond or lake. It also contains river inflow rates and temperatures and outflow rates. The third block is treated in subroutine GEOM1. It includes the geometric information and initial temperature distribution in the horizontally stratified portion of a given cooling pond. It also contains heated through-flow rates and temperatures.
Number of Runs

(1st card read in. Read in from main program—not a subroutine)

<table>
<thead>
<tr>
<th>NNNRUN</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NNNUN = Number of runs
Table 3.1 Preparation of Input Data for Subroutine MET

System Structure and Meteorological Data

<table>
<thead>
<tr>
<th>CARD</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET 1</td>
<td>Title Card</td>
</tr>
<tr>
<td>MET 2</td>
<td>System Size Parameter</td>
</tr>
<tr>
<td>MET 3</td>
<td>Pond Structure Parameters</td>
</tr>
<tr>
<td>MET 4</td>
<td>Data Input Parameters</td>
</tr>
<tr>
<td>MET 5</td>
<td>Air Temperature Input Parameters</td>
</tr>
<tr>
<td>MET 6</td>
<td>Air Temperature with Time</td>
</tr>
<tr>
<td>MET 7</td>
<td>Relative Humidity Input Parameters</td>
</tr>
<tr>
<td>MET 8</td>
<td>Relative Humidity with Time</td>
</tr>
<tr>
<td>MET 9</td>
<td>Wind Speed Input Parameters</td>
</tr>
<tr>
<td>MET 10</td>
<td>Wind Speed with Time</td>
</tr>
<tr>
<td>MET 11</td>
<td>Wind Height</td>
</tr>
<tr>
<td>MET 12</td>
<td>Short Wave Solar Radiation Input Parameters</td>
</tr>
<tr>
<td>MET 13</td>
<td>Short Wave Solar Radiation with Time</td>
</tr>
<tr>
<td>MET 14</td>
<td>Cloud Cover Input Parameters</td>
</tr>
<tr>
<td>MET 15</td>
<td>Cloud Cover with Time</td>
</tr>
<tr>
<td>MET 16</td>
<td>Long Wave Atmospheric Radiation Input Parameters</td>
</tr>
<tr>
<td>MET 17</td>
<td>Long Wave Atmospheric Radiation with Time</td>
</tr>
<tr>
<td>MET 18</td>
<td>Short Wave Solar Radiation Absorption Coefficients</td>
</tr>
<tr>
<td>MET 19</td>
<td>Time Parameters</td>
</tr>
<tr>
<td>MET 20</td>
<td>Number of Dates on which Output is Required</td>
</tr>
<tr>
<td>MET 21</td>
<td>Starting Date</td>
</tr>
<tr>
<td>MET 22</td>
<td>Output Dates</td>
</tr>
</tbody>
</table>
### SYSTEM SIZE PARAMETER

<table>
<thead>
<tr>
<th>NPOND</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NPOND = number of ponds in series
POND STRUCTURE PARAMETERS
(Repeat the pond structure card for all ponds)

<table>
<thead>
<tr>
<th>KSTRT(I)</th>
<th>KCIRC(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>5x,15</td>
</tr>
</tbody>
</table>

KSTRT(I) = 1 Pond I is vertically fully mixed
= 2 Pond I is vertically stratified

KCIRC(I) = 1 Pond I has no recirculation
= 2 Pond I has recirculation (2 sides)
## DATA INPUT PARAMETERS

<table>
<thead>
<tr>
<th>KFIN</th>
<th>KATRAD</th>
<th>KUNITS</th>
<th>KSUR</th>
<th>KHEAT</th>
<th>KOPERA</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>5x,15</td>
<td>5x,15</td>
<td>5x,15</td>
<td>5x,15</td>
<td>5x,15</td>
</tr>
</tbody>
</table>

- **KFIN** = 1 Measured Solar Radiation  
  = 2 Computed Solar Radiation
- **KATRAD** = 1 Measured Atmospheric Radiation  
  = 2 Compute Atmospheric Radiation
- **KUNITS** = 1 Units for input and output are KCAL, METERS, °C, M/S, DAY  
  = 2 Units for input and output are BTU, FEET, °F, MPH, DAY
- **KSUR** = 1 Constant Surface Elevation (ΣQin = ΣQout)  
  = 2 Variable Surface Elevation (ΣQin ≠ ΣQout)
- **KHEAT** = 1 Heat Loading  
  = 2 No Heat Loading
- **KOPERA** = 1 Closed Cycle Operation  
  = 2 Open Cycle Operation
<table>
<thead>
<tr>
<th>NTA</th>
<th>DTTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

**NTA** = Number of Air Temperature Values

**DTTA** = Time Interval Between Values of TA
AIR TEMPERATURE WITH TIME

<table>
<thead>
<tr>
<th>°C or °F</th>
<th>TA(M)</th>
<th>TA(M+1)</th>
<th>TA(M+2)</th>
<th>TA(M+3)</th>
<th>TA(M+4)</th>
<th>TA(M+5)</th>
<th>TA(M+6)</th>
<th>TA(M+7)</th>
<th>TA(M+8)</th>
<th>TA(M+9)</th>
<th>TA(M+10)</th>
<th>TA(M+11)</th>
<th>TA(M+12)</th>
<th>TA(M+13)</th>
<th>TA(M+14)</th>
<th>TA(M+15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TA(M), TA(M+1), etc = Air Temperature Values
<table>
<thead>
<tr>
<th>NSIGH</th>
<th>DTSIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
<tr>
<td>days</td>
<td></td>
</tr>
</tbody>
</table>

NSIGH = Number of Relative Humidity Values
DTSIGH = Time Intervals Between Values of SIGH
## RELATIVE HUMIDITY WITH TIME

<table>
<thead>
<tr>
<th>SIGH(M)</th>
<th>SIGH(M+1)</th>
<th>SIGH(M+2)</th>
<th>SIGH(M+3)</th>
<th>SIGH(M+4)</th>
<th>SIGH(M+5)</th>
<th>SIGH(M+6)</th>
<th>SIGH(M+7)</th>
<th>SIGH(M+8)</th>
<th>SIGH(M+9)</th>
<th>SIGH(M+10)</th>
<th>SIGH(M+11)</th>
<th>SIGH(M+12)</th>
<th>SIGH(M+13)</th>
<th>SIGH(M+14)</th>
<th>SIGH(M+15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
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<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

SIGH(M), SIGH(M+1), etc. = Relative Humidity Values (0.0 to 1.0)
<table>
<thead>
<tr>
<th>NWIND</th>
<th>DTWIND</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

NWIND = Number of Wind Speed Values

DTWIND = Time Interval Between Values of WIND
<table>
<thead>
<tr>
<th>WIND(M)</th>
<th>WIND(M+2)</th>
<th>WIND(M+3)</th>
<th>WIND(M+4)</th>
<th>WIND(M+5)</th>
<th>WIND(M+6)</th>
<th>WIND(M+7)</th>
<th>WIND(M+8)</th>
<th>WIND(M+9)</th>
<th>WIND(M+10)</th>
<th>WIND(M+11)</th>
<th>WIND(M+12)</th>
<th>WIND(M+13)</th>
<th>WIND(M+14)</th>
<th>WIND(M+15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

**WIND(M), WIND(M+1), etc. = Wind Speed Values**
<table>
<thead>
<tr>
<th>WIND HEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHGT</td>
</tr>
<tr>
<td>5x, F5.1</td>
</tr>
</tbody>
</table>

| meters or feet | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |

WHGT = Measurement Height for Wind Speed
<table>
<thead>
<tr>
<th>NFIN</th>
<th>DTFIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

NFIN = Number of Short Wave Solar Radiation Values

DTFIN = Time Interval Between Values of FIN
## SHORT WAVE SOLAR RADIATION WITH TIME

<table>
<thead>
<tr>
<th>FIN(M)</th>
<th>FIN(M+1)</th>
<th>FIN(M+2)</th>
<th>FIN(M+3)</th>
<th>FIN(M+4)</th>
<th>FIN(M+5)</th>
<th>FIN(M+6)</th>
<th>FIN(M+7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
</tr>
</tbody>
</table>

Kcal/m²/day or BTU/ft²/day

<table>
<thead>
<tr>
<th>FIN(M)</th>
<th>FIN(M+1), etc. = Short Wave Solar Radiation Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>
CLOUD COVER INPUT PARAMETERS

(Use this card only if KFIN = 2 or KATRAD = 2)

<table>
<thead>
<tr>
<th>N_CLOUD</th>
<th>D_CLOUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

**N_CLOUD** = Number of Cloud Cover Values

**D_CLOUD** = Time Interval Between Values of CLOUD
## CLOUD COVER WITH TIME

(Use this card only if KFIN = 2 or KATRAD = 2)

<table>
<thead>
<tr>
<th>CLOUD(M)</th>
<th>CLOUD(M+1)</th>
<th>CLOUD(M+2)</th>
<th>CLOUD(M+3)</th>
<th>CLOUD(M+4)</th>
<th>CLOUD(M+5)</th>
<th>CLOUD(M+6)</th>
<th>CLOUD(M+7)</th>
<th>CLOUD(M+8)</th>
<th>CLOUD(M+9)</th>
<th>CLOUD(M+10)</th>
<th>CLOUD(M+11)</th>
<th>CLOUD(M+12)</th>
<th>CLOUD(M+13)</th>
<th>CLOUD(M+14)</th>
<th>CLOUD(M+15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td>F5.2</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- CLOUD(M), CLOUD(M+1), etc. = Cloud Cover Values (0.0 to 1.0)
LONG WAVE ATMOSPHERIC RADIATION INPUT PARAMETERS

(use this card only if KATRAD = 1)

<table>
<thead>
<tr>
<th>NATRAD</th>
<th>DATRAD</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NATRAD = Number of Atmospheric Radiation Values

DATRAD = Time Interval Between Values of ATRAD
LONG WAVE ATMOSPHERIC RADIATION WITH TIME

(Use this card group only if KATRAD = 1)

<table>
<thead>
<tr>
<th>ATGAD(M)</th>
<th>ATGAD(M+1)</th>
<th>ATGAD(M+2)</th>
<th>ATGAD(M+3)</th>
<th>ATGAD(M+4)</th>
<th>ATGAD(M+5)</th>
<th>ATGAD(M+6)</th>
<th>ATGAD(M+7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
<td>F10.1</td>
</tr>
</tbody>
</table>

Kcal/m²/day or BTU/ft²/day

| 10        | 20        | 30        | 40        | 50        | 60        | 70        | 80        |

ATRAD(M), ATRAD(M+1), etc. = Long Wave Atmospheric Radiation Values
### SHORT WAVE SOLAR RADIATION ABSORPTION COEFFICIENTS

<table>
<thead>
<tr>
<th>ETA</th>
<th>BETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.1</td>
<td>F10.1</td>
</tr>
</tbody>
</table>

| meters$^{-1}$ or feet$^{-1}$ |
| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |

ETA = Extinction Coefficient of Light in Water

BETA = Fraction of Solar Radiation Absorbed at the Surface
## TIME PARAMETERS

<table>
<thead>
<tr>
<th>DTAU</th>
<th>TAUMAX</th>
<th>IFREQ1</th>
<th>IFREQ2</th>
<th>IFREQA</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>I10</td>
<td>I10</td>
<td>I10</td>
</tr>
<tr>
<td>days</td>
<td>days</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|     | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   |

DTAU = Time Step in Computations  
TAUMAX = Time at which Program Stops  
IFREQ1 = Frequency of Printed Output of PRINT1, in Time Steps  
IFREQ2 = Frequency of Printed Output of PRINT2, in Time Steps  
IFREQA = Frequency of Printed Output of Met Data in Time Steps
NUMBER OF DATES ON WHICH OUTPUT IS REQUIRED

<table>
<thead>
<tr>
<th>NDD</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NDD = Number of Dates on which Output is Required
DATES OUTPUT IS REQUIRED FOR
(Repeat Card NPD Times)

<table>
<thead>
<tr>
<th>IPDAT(1,I)</th>
<th>IPDAT(2,I)</th>
<th>IPDAT(3,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2</td>
<td>1x, I2</td>
<td>1x, I2</td>
</tr>
</tbody>
</table>

IPDAT(1,I) = Month
IPDAT(2,I) = Day
IPDAT(3,I) = Year
Table 3.2 Preparation of Input Data for Subroutine
GEOM2 Vertically Stratified Region Data

<table>
<thead>
<tr>
<th>CARD</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOM2 1</td>
<td>Vertical Grid Parameters</td>
</tr>
<tr>
<td>GEOM2 2</td>
<td>Vertical Grid Parameters</td>
</tr>
<tr>
<td>GEOM2 3</td>
<td>Cross Sectional Area Input Parameters</td>
</tr>
<tr>
<td>GEOM2 4</td>
<td>Cross Sectional Areas with Depth</td>
</tr>
<tr>
<td>GEOM2 5</td>
<td>Length Input Parameters</td>
</tr>
<tr>
<td>GEOM2 6</td>
<td>Lengths with Depth</td>
</tr>
<tr>
<td>GEOM2 7</td>
<td>Initial Vertical Temperature Distribution</td>
</tr>
<tr>
<td>GEOM2 8</td>
<td>Vertical Diffusivity</td>
</tr>
<tr>
<td>GEOM2 9</td>
<td>Inflow Distribution Parameters</td>
</tr>
<tr>
<td>GEOM2 10</td>
<td>Number of River Inflows</td>
</tr>
<tr>
<td>GEOM2 11</td>
<td>Inflow Mixing Parameters</td>
</tr>
<tr>
<td>GEOM2 12</td>
<td>Inflow Input Parameters</td>
</tr>
<tr>
<td>GEOM2 13</td>
<td>Inflow Rate with Time</td>
</tr>
<tr>
<td>GEOM2 14</td>
<td>Inflow Temperature with Time</td>
</tr>
<tr>
<td>GEOM2 15</td>
<td>Number of Outlets</td>
</tr>
<tr>
<td>GEOM2 16</td>
<td>Outlet Parameters</td>
</tr>
<tr>
<td>GEOM2 17</td>
<td>Outflow Input Parameters</td>
</tr>
<tr>
<td>GEOM2 18</td>
<td>Outflow Rates with Time</td>
</tr>
<tr>
<td>NELSV(I)</td>
<td>NELMAX(I)</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>5x,15</td>
<td>5x,15</td>
</tr>
</tbody>
</table>

NELSV(I) = Initial Number of Vertical Grid Points in Pond I
NELMAX(I) = Maximum Number of Vertical Grid Points in Pond I
VERTICAL GRID PARAMETERS

<table>
<thead>
<tr>
<th>DYY(I)</th>
<th>YSURI(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.5</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

(meters or feet) (meters or feet)

DYY(I) = Vertical Grid Increment in Pond I

YSURI(I) = Initial Surface Elevation of Pond I

(If Pond I is a deep stratified cooling pond
YSURI(I) = Elevation of top of vertically stratified portion)
## CROSSSECTIONAL AREA INPUT PARAMETERS

<table>
<thead>
<tr>
<th>NAA(I)</th>
<th>DAA(I)</th>
<th>AAB(I)</th>
<th>meters or feet</th>
<th>meters or feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
<td>F10.5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>140</td>
<td>150</td>
</tr>
</tbody>
</table>

NAA(I) = Number of Horizontal Cross Sectional Areas to be Read in for Pond I

DAA(I) = Vertical Distance Interval Between Values of AA(I)

AAB(I) = Elevation of First (Lowest) Value of AA(I)
### CROSS SECTIONAL AREAS WITH DEPTH

<table>
<thead>
<tr>
<th>AA(J,I)</th>
<th>AA(J+1,I)</th>
<th>AA(J+2,I)</th>
<th>AA(J+3,I)</th>
<th>AA(J+4,I)</th>
<th>AA(J+5,I)</th>
<th>AA(J+6,I)</th>
<th>AA(J+7,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
</tr>
<tr>
<td>meters or feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>60</td>
<td>80</td>
</tr>
</tbody>
</table>

AA(J,I), AA(J+1,I), etc. = Values of Horizontal Cross-Sectional Areas for Pond I
## LENGTH INPUT PARAMETERS

<table>
<thead>
<tr>
<th>NXXL(I)</th>
<th>DXXL(I)</th>
<th>XXLB(I)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
<td>F10.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>meters or feet</td>
<td>meters or feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **NXXL(I)** = Number of Horizontal Lengths to be Read in for Pond I
- **DXXL(I)** = Vertical Distance Interval Between Values of XXL(I)
- **XXLB(I)** = Elevation of First (Lowest) Value of XXL(I)
<table>
<thead>
<tr>
<th>XXL(J,I)</th>
<th>XXL(J+1,I)</th>
<th>XXL(J+2,I)</th>
<th>XXL(J+3,I)</th>
<th>XXL(J+4,I)</th>
<th>XXL(J+5,I)</th>
<th>XXL(J+6,I)</th>
<th>XXL(J+7,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
<td>F10.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>meters or feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

XXL(J,I), XXL(J+1,I), etc. = Values of Horizontal Lengths for Pond I
### INITIAL VERTICAL TEMPERATURE DISTRIBUTION

<table>
<thead>
<tr>
<th>TLOW(J, I)</th>
<th>TLOW(J+2, I)</th>
<th>TLOW(J+4, I)</th>
<th>TLOW(J+6, I)</th>
<th>TLOW(J+8, I)</th>
<th>TLOW(J+10, I)</th>
<th>TLOW(J+12, I)</th>
<th>TLOW(J+14, I)</th>
<th>TLOW(J+16, I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

°C or °F

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |

TLOW(J, I), TLOW(J+1, I), etc. = Initial Temperature Distribution in Vertically Stratified Region of Pond I
## VERTICAL DIFFUSIVITY

<table>
<thead>
<tr>
<th>DD(1,1)</th>
<th>F10.5</th>
<th>m²/day or ft²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DD(1,1) = Value of Vertical Diffusion Coefficient in Pond I
### INFLOW DISTRIBUTION PARAMETERS

<table>
<thead>
<tr>
<th>SPREAD</th>
<th>SIGMAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.5</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

SPREAD = Number of Outflow Standard Deviations Equal to Half the Withdrawal Thickness = 1.96

SIGMAI = Inflow Standard Deviation
<table>
<thead>
<tr>
<th>NIN(I)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NIN(I) = Number of River Inflows into Pond I
### INFLOW MIXING PARAMETERS
(cards GEOM2-11, GEOM2-12, GEOM2-13, and GEOM2-14 form a package and must be repeated NIN times.)

<table>
<thead>
<tr>
<th>KOH</th>
<th>KMIX</th>
<th>MIXED(K,I)</th>
<th>RMIX(K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>5x,15</td>
<td>5x,15</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

KOH = 1  KOH's Equation  
= 2  KA0's Equation  * Preferred

KMX = 1  No Entrance Mixing  
= 2  Entrance Mixing

MIXED(K,I) = Number of Grid Elements in Layer Influenced by Entrance Mixing by Inflow K in Pond I

RMIX(K,I) = Mixing Ratio for Inflow K in Pond I
<table>
<thead>
<tr>
<th>NQIN(K,I)</th>
<th>DTQIN(K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
<tr>
<td>days</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>80</td>
</tr>
</tbody>
</table>

NQIN(K,I) = Number of Inflow Rate Values for River Inflow K in Pond I

DTQIN(K,I) = Time Interval Between Values of QQIN(J,K,I)
<table>
<thead>
<tr>
<th>QQIN(M,K,I)</th>
<th>QQIN(M+1,K,I)</th>
<th>QQIN(M+2,K,I)</th>
<th>QQIN(M+3,K,I)</th>
<th>QQIN(M+4,K,I)</th>
<th>QQIN(M+5,K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
</tr>
</tbody>
</table>

**m³/day or ft³/day**

| 0          | 20           | 30           | 40           | 50           | 60           |

QQIN(M,K,I), QQIN(M+1,K,I), etc. = Inflow Rates for River Inflow K in Pond I
### INFLOW TEMPERATURE WITH TIME

<table>
<thead>
<tr>
<th>TTIN(M,K,I)</th>
<th>TTIN(M+2,K,I)</th>
<th>TTIN(M+4,K,I)</th>
<th>TTIN(M+6,K,I)</th>
<th>TTIN(M+8,K,I)</th>
<th>TTIN(M+10,K,I)</th>
<th>TTIN(M+12,K,I)</th>
<th>TTIN(M+14,K,I)</th>
<th>TTIN(M+16,K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>°C or °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
</tbody>
</table>

TTIN(M,K,I), TTIN(M+1,K,I), etc. = Value of the Temperature of Inflowing River K Water in Pond I
### NUMBER OF OUTLETS

<table>
<thead>
<tr>
<th>NOUT(I)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOUT(I) = Number of Outlets in Pond I
OUTLET PARAMETERS
(cards GEOM2-16, GEOM2-17 and GEOM2-18 form a package and must be repeated NOUT times)

<table>
<thead>
<tr>
<th>LOUT(K,I)</th>
<th>ELOUT(K,T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

LOUT(K,I) = Number of Grid Point Corresponding to Outlet K Elevation in Pond I
ELOUT(K,I) = Outlet K Elevation in Pond I
<table>
<thead>
<tr>
<th>NQO(K,I)</th>
<th>DTQO(K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
</tr>
<tr>
<td>days</td>
<td></td>
</tr>
</tbody>
</table>

NQO(K,I) = Number of Outflow Rate Values for Outlet K in Pond I

DTQO(K,I) = Time Intervals Between Values of QO(J,K,I)
<table>
<thead>
<tr>
<th>QO(M,K,I)</th>
<th>QO(M+1,K,I)</th>
<th>QO(M+2,K,I)</th>
<th>QO(M+3,K,I)</th>
<th>QO(M+4,K,I)</th>
<th>QO(M+5,K,I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
<td>F12.1</td>
</tr>
</tbody>
</table>

\[ \text{m}^3 / \text{day or ft}^3 / \text{day} \]

10 20 30 40 50 60 70 80

QO(M,K,I), QO(M+1,K,I), etc. = Values of Outflow Rates from Outlet K in Pond I
Table 3.3 Preparation of Input Data for Subroutine

GEOM1 Horizontally Stratified Region Data

<table>
<thead>
<tr>
<th>CARD</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOM1 1</td>
<td>Horizontal Grid Parameter</td>
</tr>
<tr>
<td>GEOM1 2</td>
<td>Heated Layer Geometry Parameters</td>
</tr>
<tr>
<td>GEOM1 3</td>
<td>Horizontal Temperature Distribution Parameter</td>
</tr>
<tr>
<td>GEOM1 4</td>
<td>Initial Horizontal Temperature Distribution</td>
</tr>
<tr>
<td>GEOM1 5</td>
<td>Entrance Mixing Parameters</td>
</tr>
<tr>
<td>GEOM1 6</td>
<td>Heated Inflow Input Parameters</td>
</tr>
<tr>
<td>GEOM1 7</td>
<td>Heated Inflow Rate with Time</td>
</tr>
<tr>
<td>GEOM1 8</td>
<td>Heated Inflow Temperature with Time</td>
</tr>
<tr>
<td>GEOM1</td>
<td>1</td>
</tr>
<tr>
<td>-------</td>
<td>---</td>
</tr>
<tr>
<td>HORIZONTAL GRID PARAMETER (cards GEOM1-1, GEOM1-2, GEOM1-3 and GEOM1-4 form a package and must be repeated KCIRC(T) times)</td>
<td></td>
</tr>
<tr>
<td>NSEG(1,III)</td>
<td>5x15</td>
</tr>
<tr>
<td></td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

NSEG(1,III) = Number of Segments in Dispersive Flow Region of Pond I, Side III
<table>
<thead>
<tr>
<th>DZ(I,III)</th>
<th>WDTH(I,III)</th>
<th>LENGTH(I,III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F15.3</td>
<td>F15.3</td>
<td>F15.3</td>
</tr>
</tbody>
</table>

**DZ(I,III)** = Depth of Vertically Mixed Layer of Pond I, Side III

**WDTH(I,III)** = Width of Vertically Mixed Layer of Pond I, Side III

**LENGTH(I,III)** = Length of Vertically Mixed Layer of Pond I, Side III
HORIZONTAL TEMPERATURE DISTRIBUTION PARAMETER

<table>
<thead>
<tr>
<th>NTO(I,III)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5x.I5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NTO(I,III) = Number of Initial Temperatures to be Read in for Pond I, Side III
<table>
<thead>
<tr>
<th>THLM(J, I, III)</th>
<th>THLM(J+1, I, III)</th>
<th>THLM(J+3, I, III)</th>
<th>THLM(J+5, I, III)</th>
<th>THLM(J+7, I, III)</th>
<th>THLM(J+9, I, III)</th>
<th>THLM(J+11, I, III)</th>
<th>THLM(J+13, I, III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
<tr>
<td>°C or °F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

THLM(J, I, III) = Initial Temperature Distribution in the Heated Layer of Pond I, Site III
<table>
<thead>
<tr>
<th>THETA(I)</th>
<th>DSS(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.5</td>
<td>F10.5</td>
</tr>
</tbody>
</table>

THETA(I) = Fraction of Pond I that is a Fully Mixed Entrance Region

DSS(I) = Entrainment Coefficient for Pond I
HEATED INFLOW INPUT PARAMETERS
(use this card only for Pond 1)

<table>
<thead>
<tr>
<th>NQHIN</th>
<th>DTQHIN</th>
<th>days</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x,15</td>
<td>F10.5</td>
<td></td>
</tr>
</tbody>
</table>

NQHIN = Number of Heated Inflow Rate Values
DTQHIN = Time Interval Between Values of QHIN
<table>
<thead>
<tr>
<th>DTMP</th>
<th>F5.1</th>
<th>°C or °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DTMP = Temp rise across condenser

TEMPERATURE RISE ACROSS CONDENSER
(use this card only for Pond 1 and only when KOPERA = 1)

107
HEATED INFLOW TEMPERATURE WITH TIME
(use this card only for Pond 1 and only when KOPERA = 2)

<table>
<thead>
<tr>
<th>TTHIN(M)</th>
<th>TTHIN(M+2)</th>
<th>TTHIN(M+4)</th>
<th>TTHIN(M+6)</th>
<th>TTHIN(M+8)</th>
<th>TTHIN(M+10)</th>
<th>TTHIN(M+12)</th>
<th>TTHIN(M+14)</th>
<th>TTHIN(M+15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
<td>F5.1</td>
</tr>
</tbody>
</table>

°C or °F

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |

TTHIN(M), TTHIN(M+1), etc. = Value of the Temperature of Heated Inflow Water
IV. APPLICATION OF MITEMP

This chapter is intended to demonstrate the use and versatility of MITEMP as a planning tool for the design and analysis of cooling impoundments and natural reservoirs. In Section 4.1 the application of MITEMP to seven existing or proposed impoundments with strongly differing geometries and heat loadings is shown. In particular, geometric schematization, the use of classification criteria and the application of the mathematical predictive model are presented. Furthermore, it is frequently necessary to introduce ad hoc modifications or additions to the general model structure because of site-specific peculiarities. By virtue of its molecular structure, such changes are easily incorporated into MITEMP. The seven impoundments are:

North Anna Cooling System, Virginia*
Dresden Cooling Pond, Illinois*
Powertown Cooling Pond, Illinois*
Collins Cooling Pond, Illinois
LaSalle Cooling Pond, Illinois
Braidwood Cooling Pond, Illinois
Merom Cooling Lake, Indiana

Background data on these systems was summarized as part of Table 1.1 of Part A and is included here as Table 4.1. The discussion of these cases is focused on the essentials and reference is made to other technical reports for more detailed information. The case studies present examples of MITEMP application in both the verification mode and the simulation mode.

* Additional discussion on these cases is found in Sections 4.4, 5.1.4 and 5.2.4 of Part A, respectively.
<table>
<thead>
<tr>
<th>Lake or Pond</th>
<th>Surface Area (acres)</th>
<th>Station Capacity (MWe)</th>
<th>Thermal Loading (MWt/acre)</th>
<th>No. of Major Compartments</th>
<th>L/W (each compartment)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Anna 1</td>
<td>4300</td>
<td>3784 (nuclear)</td>
<td>0.5</td>
<td>1</td>
<td>0.3</td>
<td>~3 deep stratified</td>
</tr>
<tr>
<td>Dresden</td>
<td>1275</td>
<td>1600 (nuclear)</td>
<td>2.1</td>
<td>3</td>
<td>0.9</td>
<td>5-20 vert. mixed dispersive</td>
</tr>
<tr>
<td>Powerton</td>
<td>1442</td>
<td>1670 (fossil)</td>
<td>1.7</td>
<td>3</td>
<td>0.5</td>
<td>~2 vert. mixed recirculating</td>
</tr>
<tr>
<td>Collins</td>
<td>2009</td>
<td>2520 (fossil)</td>
<td>1.5</td>
<td>2</td>
<td>0.7</td>
<td>6-10 vert. mixed dispersive</td>
</tr>
<tr>
<td>La Salle</td>
<td>2058</td>
<td>2156 (nuclear)</td>
<td>2.1</td>
<td>3</td>
<td>0.4</td>
<td>3 bracket between vert.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mixed recirculating and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>deep stratified</td>
</tr>
<tr>
<td>Braidwood</td>
<td>2539</td>
<td>2200 (nuclear)</td>
<td>1.8</td>
<td>2</td>
<td>0.6</td>
<td>1.3 (1st) vert. mixed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>recirculating (1st)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 (2nd) vert. mixed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dispersive (2nd)</td>
</tr>
<tr>
<td>Merom Lake</td>
<td>1550</td>
<td>980 (fossil)</td>
<td>0.9</td>
<td>1</td>
<td>0.3</td>
<td>3 deep stratified</td>
</tr>
</tbody>
</table>

1Main Lake as modeled; WHTF treated separately
The Section 4.2 contains comments about the use of MITEMP for long-term simulations of cooling systems, the establishment of the necessary meteorological and hydrological data base and the statistical analysis of the predicted impoundment temperature series. The reader should also look to Part C for comments on long term simulation.

4.1 Case Studies

4.1.1 North Anna Cooling System, Virginia

(a) Background Information

Lake Anna was formed by impounding the North Anna River through construction of a dam (see Figure 4.1). Additional construction of three dikes and the dredging of channels formed a separate series of ponds, called the Waste Heat Treatment Facility (WHTF). The entire system is referred to as the North Anna Cooling System.

At a design elevation of 250 ft above sea level, Lake Anna has a surface area of 9,600 acres, a volume of $10.6 \times 10^9 \text{ ft}^3$, and an average depth of 25 ft. The maximum depth at the dam is 70 ft. The lake receives an average annual inflow of about 270 cfs. The lake elevation is maintained by radial gates at the dam. The outflow rate equals the inflow minus the rate of evaporation from the lake surface (estimated at about 60 cfs, natural conditions).

The WHTF has a surface area of 3400 acres, a volume of $2.66 \times 10^9 \text{ ft}^3$ and an average depth of 18 ft. The maximum depth is 50 ft in the vicinity of the dikes. After passing through Ponds 1, 2 and 3, the cooling water is discharged into the main lake through a submerged discharge structure in Dike III. After residence in the main lake, cooling water is withdrawn through near-surface intakes in the vicinity of the station. In essence, a closed-cycle cooling system is formed, consisting of a series of ponds, which form the WHTF,
1, 3, 4 indicate continuous temperature monitoring stations.

Figure 4-1: Map of the North Anna Cooling System
and of Lake Anna.

At its ultimate capacity, the North Anna Nuclear Power Station is expected to have four nuclear units with a combined capacity of 3784 MWₑ, a cooling water flow of 8400 cfs and a temperature rise of 14°F.

(b) Schematization and Classification

The North Anna cooling system, consisting of a series of ponds in the WHTF with attached side arms and connecting channels, and of the main lake, is expected to have a particularly complex thermal structure. For example, while the individual ponds of the WHTF will be distinctly stratified, there is a tendency for destratification in the connecting channels of the WHTF. Also, the role of buoyant convective circulations into the dead-end side arms of the WHTF is of a complicated nature. A "segmented model" was developed which links different mathematical models applicable for each of the components of the WHTF and the main lake. A schematic of the segmented model is shown in Figure 4-2.

For the WHTF, a site-specific analysis was adopted: a two-layer model was developed in which each of the layers is assumed to be vertically uniform and which includes the inflow into and outflows from the convective side arm circulation (see Jirka et al., 1977 and Brocard et al., 1977).

In the "main lake", the is excluding the WHTF and the area upstream of the Section A-A in Figure 4-1, the following pond characteristics are taken for full operating conditions (Qₒ = 8,400 cfs):

\[
\begin{align*}
L &= 25,000 \text{ ft} \\
W &= 7,500 \text{ ft} \\
H_{\text{ave}} &= 40 \text{ ft}
\end{align*}
\]
Figure 4-2: Schematization of the North Anna cooling system used in the Segmented Model
\[ D_v = 1.5^* \]

\[ \Delta T_o = 5^\circ F \text{ (estimated in main lake)} \]

\[ (\beta \Delta T o = 0.0005) \]

This leads to a pond number, \( P = 0.34 \) and determines the applicability of the deep, stratified cooling pond model as a first approximation. The heated surface layer depth is computed as \( h_s = P H_{ave} = 14 \text{ ft} \), which is small compared to the total average depth.

(c) Model Predictions

The predictive model was applied to natural conditions (\( \Phi = 0 \text{ MW}_t/\text{acre} \)) and to plant operating conditions (\( \Phi = 0.58 \text{ MW}_t/\text{acre, 4 units} \)). The model verification for natural conditions was shown in Chapter IV of Part A. For operating conditions the model gave the following information: (i) transient response of temperature at the end of ponds 1, 2 and 3, (ii) transient horizontal temperature distribution in the lake surface layer, (iii) transient vertical temperature distribution in the lake subsurface layer, and (iv) transient power plant intake temperature.

When the model for natural conditions is run with the same meteorological data as the model for operating conditions, the temperature increase above "natural" can be determined. Figure 4-3 shows the result of simulations for both natural and operating conditions (4 units) with 1962 meteorological data.

---

*A special stratified flow analysis was developed to describe the entrance mixing due to the submerged jet discharge from Dike III into the main lake. The mixing is restricted due to local topography effects leading to the establishment of a stratified control section. For lower flowrates, \( Q_o \), proportionally higher values of \( D_v \) are found.*
Figure 4-3: Load and Unload Temperature Variations at North Anna in 1962 with 4 Units Operational (After Jirka et al., 1977)
4.1.2 Dresden Cooling Pond, Illinois

a) Background Information

The Dresden Cooling pond, (see Figure 4-4), is a man-made cooling facility with internal baffles and dikes which serves as the heat dissipation system for the Dresden Nuclear Power Station Units 2 and 3. The surface area of the pond is 1275 acres and the average depth is 10 ft (with several locations that exceed 20 ft depth). For two units operation, the power production is approximately 1700 MW, and the condenser flow rate is 2102 cfs and the temperature rise is approximately 23°F. The water circulates through the lake in a clockwise direction. An important aspect of the pond is a laterally crossing causeway with two restricted bridge openings of 60 ft width and 10 ft depth. This feature essentially forms three separate pond compartments.

b) Schematization and Classification

The schematic data for the three pond compartments has been summarized in Table 5-3 of Part A. For the second compartment, which comprises about 50% of the total pond area, a pond number $P = 0.9$ can be predicted. The length/width ratio is $L/W \approx 20$. Thus, a vertically mixed dispersive cooling pond model is applicable for the second compartment. Similar criteria prevail in the other compartments.

Available field data (see Figure 4-5) verifies the lack of vertical stratification. The values of dispersion coefficients are included in Table 5-3 of Part A.

*In Section 5.1.4 of Part A the observed temperature drop in the second compartment $\Delta T = 12^\circ F$ has been used to evaluate $P$. In a predictive mode, $\Delta T$ has to be estimated (for example, by using a steady-state approximation; see Appendix B of Part A).
Figure 4-5: Longitudinal Temperature Profiles Indicating the Absence of Vertical Stratification in Dresden Cooling Pond
c) Model Predictions

The application of the fully mixed dispersive model portion of MITEMP to two periods (September 12, 1975 to October 31, 1975, July 12, 1976 to August 15, 1976) is shown in Figures 4-6 and 4-7, respectively. The following input data was used:

- monitored discharge temperature $T_0$ (showing strong variability due to meteorological changes and intermittent plant operation)
- on-site meteorological data for air temperature, relative humidity, cloud cover and wind velocity (meteorological tower is 2 miles away from the pond)
- solar radiation data from Argonne National Laboratory weather station (approximately 30 miles away)
- measured horizontal temperature distribution for the initial condition

The comparison between measured ($T_{i}^*$) and predicted ($T_i$) intake temperatures is shown in Figures 4-6 and 4-7 and relevant statistics are given.

Further long-term simulations of Dresden Cooling Pond have been conducted by NUS Corporation (NUS, 1977) assuming plant operation at full capacity.

4.1.3 Powerton Cooling Pond, Illinois

a) Background Information

The Powerton Cooling Pond is a man-made cooling pond with internal dikes as shown in Figure 4-8. The lake can be divided into four compartments following the internal diking arrangement. The geometric characteristics of each compartment have been summarized in Table 5-4 of Part A. For two units operation of 1670 MW$e$ power production, the circulating flow rate is 1537 ft$^3$/sec with a temperature increase of approximately 23°F through the condensers.
Figure 4-6: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from September 12 to October 31, 1975

\[(T_4 - T_1) = -0.81 \degree F\]

Standard Deviation = 0.99 \degree F
Figure 4-7: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from July 12 to August 15, 1976

\[ (T_1 - T_2) = -0.28 \, ^\circ F \]

Standard Deviation = 1.15 \, ^\circ F
b) Schematization and Classification

A pond number $P = 0.5$ has been computed for the Powerton Cooling Pond (see Section 5.2.4 of Part A). This criterion together with the length/width ratio $L/W \geq 2$ for each compartment calls for the use of a shallow vertically mixed recirculating cooling pond model.

The character of the recirculating flow can be seen from available field data on surface temperature distributions (see Figure 2-12 of Part A). The Powerton Pond is schematized as three compartments in which internal recirculation exists. An entrance compartment which is assumed to have a completely mixed temperature structure precedes the three compartments. A schematic diagram has been given in Figure 5-7 of Part A.

The parameter values for the jet area fractions $q = 1/3$ and the lateral entrance dilutions $D_s = 1.8, 1.5$ and $1.5$, respectively, have been estimated based on a combination of theoretical considerations, schematic laboratory experiments and available field data (for a discussion and sensitivity studies, see Section 5.2.4 of Part A).

c) Model Predictions

The comparison of the model predictions with available field data for a one-month period from August 1 to August 31, 1976 has been discussed in Part A. In addition, the model was run in a simulation mode for several years of plant performance using historic meteorological data and full plant load. As an example, the prediction for the entire 1964 data series is shown in Figure 4-9.

4.1.4 Collins Cooling Pond, Illinois

a) Background Information

A plan view of the Collins Cooling Lake is shown in Figure 4-10.
Figure 4-9: Simulated Intake Temperatures for 1 Unit Operation at Powerton Station, Illinois using 1964 Meteorological Data
Because of the internal diking, the lake is divided into four sections, namely the discharge channel, the entrance mixing zone, pond 1 and pond 2. The cooling water circulates through the lake in a clockwise direction. The geometric characteristics of each section are as follows:

<table>
<thead>
<tr>
<th>Surface Area (Acres)</th>
<th>Average width (ft)</th>
<th>Average Depth (ft)</th>
<th>Average Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge Channel</td>
<td>109.4</td>
<td>250.</td>
<td>10.</td>
</tr>
<tr>
<td>Entrance Mixing Zone</td>
<td>231.4</td>
<td>1750.</td>
<td>12.</td>
</tr>
<tr>
<td>Pond 1</td>
<td>749.0</td>
<td>1862.</td>
<td>12.</td>
</tr>
<tr>
<td>Pond 2</td>
<td>919.5</td>
<td>3333.</td>
<td>10.</td>
</tr>
<tr>
<td>Total: 2009.3 acres</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For full load operation, the fossil-fired station produces 2520 MWₑ and the circulating flow rate is 2250 ft³/sec with a temperature increase of approximately 22°F through the condensers.

b) Schematization and Classification

Based on full load operation, a temperature drop of 10°F (ΔTₐ = 0.001) and some minimal entrance dilution Dᵥ = 1.25, a pond number IP = 0.66 has been computed for Pond 1 of the system. An even higher value applies for Pond 2. This, together with the condition L/W > 5, determines the applicability of the shallow, vertically mixed dispersive cooling pond model.

In the discharge channel, a plug flow model with heat loss is applied as dispersion will be insignificant due to the high throughflow velocity. In the entrance mixing region, vertical and lateral temperature gradients are assumed to be minimal due to the strong jet mixing and thus a simple
completely mixed model has been applied:

\[
\frac{dT_{\text{out}}}{dt} = \frac{Q_{\text{in}}}{\psi} (T_{\text{in}} - T_{\text{out}}) - \frac{\phi_{\text{n}}}{\rho c_p} A
\]

where

- \( T_{\text{out}} \): outflow temperature from entrance mixing zone
- \( T_{\text{in}} \): inflow temperature
- \( c_p \): specific heat
- \( \rho \): density of water
- \( Q_{\text{in}} \): inflow
- \( \phi_{\text{n}} \): net heat flux at surface
- \( \psi \): volume of entrance mixing region
- \( A \): surface area of entrance mixing region

c) Model Predictions

The Collins Power Station is in its initial stage of operation. No temperature monitoring results are available. The model was applied in the simulation mode to determine the response of the cooling system under historical meteorological conditions. A sample result for 1969 and full load operation is given in Figure 4-11 depicting the fluctuations of intake temperature.

4.1.5 LaSalle Cooling Pond, Illinois

a) Background Information

A plan view of the LaSalle Cooling Pond is shown in Figure 4-12. The surface area of the pond is 1786 acres and the average depth is 15 ft. The
Figure 4-11: Simulated Intake Temperatures for Full Load Plant Operation at Collins Station, Illinois using 1969 Meteorological Data.
lake is connected to the condenser discharge flume by a discharge channel which has a surface area of 135 acres. The total volume of the lake is approximately $1.25 \times 10^9$ ft$^3$. For two units operation, the power production is approximately 2150 MWe. The condenser flow rate is 2673 cfs with a temperature rise of approximately 24°F. At the middle of the discharge channel, the discharge water is mixed with makeup water (78 cfs). The blowdown flow rate is approximately 45 cfs.

b) Schematization and Classification

The LaSalle pond resembles the three compartment structure also found at the Powerton Pond. The pond number criterion was applied with the following characteristic values: total length $L = 28,000$ ft, average width $W = 2800$ ft, average depth $H = 15$ ft, flow rate $Q_o = 2673$ ft$^3$/sec, temperature rise $\Delta T_o = 24^\circ F$ ($\beta \Delta T_o \approx 0.0024$) and dilution $D_v = 1.25$ (this is a reduced value - using the procedure of Appendix C, Part A - as much higher vertical dilution ratios would be expected under deep lake conditions). The typical pond number is $IP = 0.42$, lower than for Powerton, due to the larger average depth. Thus the LaSalle lake will operate in the transition range between significantly deep lake and significantly shallow lake behavior. A shallow vertically mixed recirculating pond model consisting of three compartments with the same model parameters as Powerton is proposed as a first approximation for simulation purposes. As mentioned in Section 3.5 (Part A), the simulation results may be bracketed by alternatively applying the deep stratified cooling pond model.
Figure 4-12: Plan View of LaSalle Cooling Pond
c) **Model Predictions**

The LaSalle Station is in its initial stage of operation and no temperature monitoring data are available. The predictive model was run purely in the simulation mode and no specific examples are shown herein.

4.1.6 **Braidwood Cooling Pond, Illinois**

a) **Background Information**

The Braidwood Cooling Pond has an overall area of about 3540 acres with a water surface area of about 2539 acres. Thus approximately 25% of the total lake area is occupied by islands. It serves as the waste heat dissipator for the Braidwood Nuclear Power Station which has a \(2200 \text{ MW}_e\) generating capacity. For two unit operation, the circulating flow is 3252 ft\(^3\)/sec with a temperature increase of approximately 20°F through the condenser. The heated water is discharged into the lake through a channel which has a depth of 5 ft, a width of 375 ft and a length of 2815 ft.

The cooling pond has interior dikes to prevent the possibility of channeling or short-circuiting. Figure 4-13 indicates the general layout of the pond. The lake can be divided into two parts following the internal diking arrangement. Pond 1 has a rectangular shape, without islands, and a surface area of 1025.5 acres, an average depth of 7.7 ft, a length of 8200 ft, and an average width of 5448 ft. Pond 2 has many islands and therefore a complex geometry. The actual water surface area is 1513.7 acres, the average depth 7.2 ft, the length 16082 ft and the average width 4100 ft.

b) **Schematization and Classification**

The pond can be schematized as a two compartment sequence. The pond number criterion is applied to the first pond to check for any stratification. For this purpose a vertical dilution \(D_v = 1.25\) and a temperature drop
Figure 4-13: Plan View of Braidwood Cooling Pond
\( \Delta T = 10^\circ F (\beta \Delta T_o \approx 0.001) \) are used. The resulting pond number \( IP = 0.60 \) indicates a predominantly vertically mixed flow structure. Due to the low L/W ratio, \( L/W \approx 1.3 \), it is expected that a significant recirculation pattern will exist in the first pond. The structure of the shallow, vertically mixed recirculating pond model with a symmetric discharge configuration (Figure 3-5 of Part A) is shown in Figure 4-14. By using Eq. (5.8) of Part A for the lateral jet mixing \( L_{jet} = 8400 \text{ ft}, 2b_o = 375 \text{ ft} \) a dilution factor \( D_s = 3 \) is computed, and a value of \( q = 1/3 \) is assumed.

In the second pond, the flow field is expected to be more one-dimensional with a highly non-uniform velocity distribution due to the islands. In a macroscopic sense, the heat transport will experience dispersion because of the extreme velocity non-uniformities.

A shallow, vertically mixed dispersive cooling pond model is used. The dispersion coefficient is computed according to Eq. (5.5) of Part A as a lower bound on the pond dispersivity.

c) Model Predictions

The model was run in a simulation mode as the cooling system is currently under construction. No specific sample results are given here.

4.1.7 Merom Lake, Indiana

a) Background Information

The impoundment of Merom Lake has been proposed to serve as the heat dissipation system of the Merom Station, a fossil-fueled generating station with a two unit capacity of 1000 MW. With a design elevation of 470 ft above

*Application reported by R.W. Beck and Associates (1976).
Figure 4-14: Schematic View of Pond 1 at Braidwood Cooling Pond
MSL the lake (see Figure 4-15) has a surface area of 1,550 acres, a volume of 13,400 acre-ft. and an average depth of 8.65 ft. The station cooling water flow is 910 cfs with a temperature rise of 27.5°F at maximum waste heat loading.

b) **Schematization and Classification**

The lake is schematized to have a mean flow length $L = 14,000$ ft with an average width $W = 4820$ ft. Using a value $D_v = 1.5$ for the vertical entrance mixing (which will be inhibited due to the shallow depth of the discharge arm) and $\beta AT_o = 0.0027$ a pond number $IP = 0.32$ is computed indicating the predominantly stratified nature of the cooling lake. Thus, the deep stratified cooling pond model has been used for calculations of the thermal performance of Merom Lake with a surface layer depth $h_s = IP H_s 3.0$ ft.

c) **Model Predictions**

Examples of the model predictions in the simulation mode can be seen in R.W. Beck (1976) including comparisons with the predicted natural reservoir conditions using the natural deep lake and reservoir model.

4.2 **Comment on Long-Term Simulations**

The meteorological and hydrological parameters at a cooling pond site can have significant variations from year to year. In order to provide a valid representation of the operating characteristics and environmental impacts of a cooling facility, it therefore seems necessary to carry out simulations over a number of years approaching a good portion of the life time of the installation. Because of its computational efficiency MITEMP is well suited to carry out these multi-year computations. The following questions arise, however: 1) How to generate a correct input data series since on-site observations for meteorology are typically of short duration
or not available at all? (This is related to the planning lead time of power plant projects.) 2) What is a meaningful presentation of the large amount of output data which is generated in the course of a multi-year simulation?

4.2.1 The Establishment of an Input Data Series

If limited on-site data for meteorology (or hydrology) is available, the following steps can be taken:

a) In the most trivial case, one can directly use historical data from other sites in the region (mostly airport data). The utility and accuracy of this approach will depend on the climatological (related to geographic) differences between the two localities. Some statistical check is usually in order if some on-site data is available.

b) If the regional information is limited, one can formulate a probabilistic model based on the analysis of the given on-site data. The long-term data can then be generated (synthetic data generation) from the probabilistic model.*

c) When the historical on-site record is short, but extensive regional records are available, then it is possible to establish multiple regressions between coincident on-site and regional time series. Upon selection of appropriate regression equations (using statistical criteria and physical judgement), the equations can then be used with regional time series to generate synthetic on-site data. This process, called regionalization ** was used in the analysis of the North Anna cooling system (Jirka et al. 1977).

* For comparison in hydrologic data generation, see Fiering and Jackson (1971).

** Regionalization methods are in frequent usage in hydrology to extend or establish hydrologic data records, such as rainfall, runoff etc. See Vicens et al. (1974).
4.2.2 Presentation of Results

The temperature information is of interest for three purposes: (i) technical evaluation of plant performance, (ii) biological evaluation of environmental impacts and (iii) conformance with regulatory (numerical) standards. In general, this requires three temperature indicators: a) Natural temperature, (b) Induced temperature and (c) Induced excess (above natural) temperature. Of course, each temperature indicator has its temporal and spatial variability.

The following appears to be a minimum presentation of these temperature indicators:

1. Establish the long-term average yearly temperature cycle for a point of interest, such as mean surface temperature, plant intake temperature or river discharge temperature. This can be obtained by averaging corresponding days of the year over the entire simulation period. (Note that because of model nonlinearities this is generally different than a one-year simulation using long-term averaged input data!) An example of this procedure is shown in Figure 4-16 for the North Anna cooling system. In addition, such information can be monthly-averaged and tabulated, as shown in Table 4-1.

2. Establish measures for temporal temperature variability and extremes.
   a) Variability: A simple measure is the computation of standard deviations from the long-term simulation
record. This procedure is included in Figure 4-16.

b) **Extremes:** It is possible to single out that year (or season) from the simulation period which has extreme temperature conditions (related to induced temperatures and/or induced excess temperatures). Furthermore, incidences of extreme conditions can be summarized in tabular form (see Table 4-1) including cumulative times and/or frequencies of exceedance of temperature standards.

3. Establish measures for spatial temperature distributions. Cumulative distribution curves (either surface area - temperature, or volume - temperature) can be drawn for selected dates or seasons of the year (including natural and operational conditions (see Jirka et al. (1977)). Other forms of data presentations may be appropriate on an ad hoc basis, e.g. the detailed temperature response of short-term events (hot spells) to assess the survival of specific fish populations, etc.
Figure 4-16: Average Yearly Temperature Cycle for Natural and Operational Conditions (Obtained from 10-year Simulation of the North Anna Cooling System) (After Jirka et al. 1977)
Table 4-1: Selected characteristics of the long term temperature simulations. (Surface temperatures at the North Anna Dam, in °F). (From Jirka et al. 1977)

<table>
<thead>
<tr>
<th></th>
<th>Natural</th>
<th>1 unit</th>
<th>2 units</th>
<th>3 units</th>
<th>4 units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10 year averaged data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Monthly means</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July mean temperature</td>
<td>82.4</td>
<td>83.2</td>
<td>85.3</td>
<td>87.5</td>
<td>89.4</td>
</tr>
<tr>
<td>January mean temperature</td>
<td>39.2</td>
<td>40.8</td>
<td>45.3</td>
<td>49.2</td>
<td>52.7</td>
</tr>
<tr>
<td>July mean temp. rise above natural</td>
<td>0.0</td>
<td>0.8</td>
<td>2.9</td>
<td>5.1</td>
<td>7.0</td>
</tr>
<tr>
<td>January mean temp. rise above natural</td>
<td>0.0</td>
<td>1.6</td>
<td>6.1</td>
<td>10.0</td>
<td>13.5</td>
</tr>
<tr>
<td>b) Single day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>83.4</td>
<td>84.0</td>
<td>86.1</td>
<td>88.3</td>
<td>90.2</td>
</tr>
<tr>
<td>Corresponding standard deviation*</td>
<td>2.1</td>
<td>1.9</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Non-averaged data</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>92.2</td>
<td>90.2</td>
<td>92.0</td>
<td>93.7</td>
<td>95.8</td>
</tr>
<tr>
<td>(in 10 years studied, occurred June 30, 1959)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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*For a process with Gaussian probability distribution, the region within the standard deviations represents 68% probability of occurrence.
REFERENCES FOR PART B


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APPENDIX A

THE COMPUTER PROGRAM
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /SWITCHM/ KFIN,KATRAD
COMMON /CUM/ CUMQIN,CUMQOT,SAREA(5),DYSUR(5),JM1,NELSV(5)
COMMON /MIX/ KMIX,MIXED(3,5),RMIX(3,5),KOH
COMMON /METEOA/ TA(3000),SIGH(3000),WIND(3000),CLOUD(3000)
COMMON /METEOB/ FIN(3000),ATRAD(3000)
COMMON /METIME/ DTTA,DTSIGH,DTWIND,DCL CLOUD,DTFIN,DATRAD
COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
COMMON /HFLWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,CHINI,NQHIN,
,DTQHIN
COMMON /FLOWS/ QQIN(366,3,5),TIN(366,3,5),TIN(3),QIN(3),
,QOUT(5),NQIN(3,5),DTQIN(3,5),NQO(3,5),DTQO(3,5),NOUT(5),NOUTI,
,LQO(5,5),ETQOUT(5,5),QIN(5),QO(366,3,5),QIN,THI N
COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /TEMPB/ T(100,2),TLM(100,5),NEL(5),NELMAX(5)
COMMON /GEOMA/ VTOTAL(5),VF M(5),VDF(5),LENGTH(5,2),DXD(5,2),
,DZ(5,2),WIDTH(5,2),AREA(5,2),DH,THETA(5),NSR(5,2),NAR,MP1
COMMON /GEOMB/ A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
COMMON /GEOMC/ YBots(5),DYY(5),AI(100,5),XLI(100,5),BI(100,5),
,DYSUR(5),YSURI(5),ELL(100,5),SAREA(5),AYSURI(5)
COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),FF
COMMON /METWD/ WHGT,TAU
COMMON /ELB/ ELBLSL
COMMON /CONST/ RHO,HCA P,GRA V
COMMON /VELS/ V(102,1),UI(102,5),UO(102,5),UOT(102,5)
COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
COMMON /FLVL/ JIN(3)
COMMON /CONMIX/ DMIX,DXH
COMMON /FLXES/ SR, EVAP, RAD, CONDUC, AR, TAIR, TAIRF, PSI, EA, W, WINDY, CC
COMMON /GAUS/ SIGMAI,SPREAD,SIGMIN(3)
COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
COMMON /EQUIL/ TE,IDT
COMMON /ENTRN/ DSS(5),DS
COMMON /ETIME/ ET,NPOND
COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
COMMON /ENGYA/ EIN(5),EPRES1(5),EQIN(5),EOUT1(5),ESTRT1(5)
COMMON /ENGYC/ EQIN3(5),EOUT3(5)
COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),E0(5),ENOW(5)
COMMON /GFW/ H,EMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
COMMON /TENGY/ TENRAD(5)
COMMON /TENTR/ TEDDY(5),THINI,TN P
COMMON /DELTTS/ DELSAV,DELTS,DELT(10),TSAVE
COMMON /SURFLR/ KSUR
COMMON /DPTH/THIN1,CHIN1
COMMON /PRNTKT/ KT1,KT2,KTA
COMMON /DISCH/ DTEMP
COMMON /ISTART/ ATIME1,MMO,MDY,MYR,NDD
COMMON /NDY/ NDAYS(13)
COMMON /IPR/ KMODE,IPRINT(20),IFREQT
READ (5,1234) NNNRUN
1234 FORMAT (I5)
DO 700 NNN=1,NNNRUN
ICOUNT=0
ET=0.0
IDT=1
KT2=1
CALL MET
C INITIALIZE CONFIGURATION
DO 80 I=1,NPOND
KSTRAT=KSTRT(I)
GO TO (50,40), KSTRAT
40 CALL GEOM2(I)
50 GO TO (60,70), KHEAT
60 CALL GEOM1(I)
70 CONTINUE
80 CONTINUE
IFREQT= IFREQA
IF(IFREQT.GE.IFREQ1)IFREQT=IFREQ1
IF (IFREQT.GE.IFREQ2)IFREQT=IFREQ2
C PERFORM CALCULATIONS OVER SUCCESSIVE TIME STEPS
20 ICOUNT=ICOUNT+1
IF (ET.GE.TAUMAX) GO TO 600
CALL WEATHR (ICOUNT)
ET=ET+DTAU
86 QSAVE=QHIN
88 CONTINUE
DO 500 I=1,NPOND
KSTRAT=KSTRT(I)
KMODE=KSTRAT+KHEAT-1
GO TO (100,200,300), KODE
C VERTICALLY FULLY MIXED HEATED POND
100 CONTINUE
IF (I.GT.1) GO TO 10
R=(ET-DTAU)/DTQHIN
L=R
RR=R-L
QHIN=QHIN(L+1)+RR*(QHIN(L+2)-QHIN(L+1))
IF(KOPERA.EQ.2) GO TO 9
IF(ICOUNT.GT.1) GO TO 101
NM=NSEG(NPOND, 1)+1
THIN=THLM(NM,NPOND, 1) +DTEMP
GO TO 10
101 THIN=TOUT(ICOUNT-1,NPOND) + DTEMP
GO TO 10
9 THIN=TTHIN(L+1)+RR*(TTHIN(L+2)-TTHIN(L+1))
10 CONTINUE
C LOADING CHECK
108 CONTINUE
DS=DSS(I)
KK=KCIRC(I)
DO 130 III=1,KK
DHL=DZ(I,III)
NAR=NSEG(I,III)+1
MP1=NSEG(I,III)+1
DO 110 J=1,NAR
110 TEMP(J)=THLM(J,I,III)
CALL HEAT (ICOUNT,I,III)
CALL DISPER (ICOUNT, I, III)
DO 120 J=1,NAR
120 THLM(J,I,III)=TEMP(J)
130 CONTINUE
CALL ENERGY (ICOUNT, I)
CALL PRINT (ICOUNT, I)
150 CONTINUE
GO TO 500
C STRATIFIED HEATED POND
200 CONTINUE
IF (I.GT.1) GO TO 201
R=(ET-DTAU)/DTQHIN
L=R
RR=R-L
QHIN=QQHIN(L+1)+RR*(QQHIN(L+2)-QQHIN(L+1))
IF (KOPERA.EQ.2) GO TO 209
NN1=NOUT(NPOND)
LLL=LOUT(NN1,NPOND)
IF (ICOUNT.GT.1) GO TO 206
THIN=TLOW(LLL,NPOND)+DTEMP
GO TO 201
206 THIN=TOUTC(ICOUNT-1,NN1)+DTEMP
GO TO 201
209 THIN=TTHIN(L+1)+RR*(TTHIN(L+2)-TTHIN(L+1))
201 CONTINUE
NINI=NIN(I)
NOUTI=NOUT(I)
III=1
DHL=DZ(I,III)
NAR=NSEG(I,III)+1
MP1=NSEG(I,III)+1
DS=DSS(I)
DO 210 J=1,NAR
210 TEMP(J)=THLM(J,I,III)
JM=NEL(I)
JM1=NELSV(I)
AYSUR=AYSURI(I)
SAREA=SAREAI(I)
SAREAP=SAREA
DYSUR=DYSURI(I)
DYSURP=DYSUR
DY=DYY(I)
YSUR=YSURI(I)
C THIS NEXT STATE HAS BEEN CHANGED, DYSUR INSTEAD OF DHL
ELBSL=YSUR-DYSUR
JMP=NELMAX(I)
DO 181 J=1,JMP
B(J) = BI(J, I)
XL(J) = XLI(J, I)
A(J) = AI(J, I)
EL(J) = ELL(J, I)

181 CONTINUE
YBOT = YYBOT(I)
DO 230 J = 1, JM

230 T(J, 1) = TLOW(J, I)
D1 = DZ(I, III)
CALL HEAT (ICOUNT, I, III)
CALL DISPER (ICOUNT, I, III)
CALL SPEED (ICOUNT, I)
CALL SUBLAY (ICOUNT, I)
CALL AVER (ICOUNT, I)
DO 260 J = 1, NAR

260 THLM(J, I, III) = TEMP(J)
DO 270 J = 1, JM

270 TLOW(J, I) = T(J, 1)
CALL ENERGY (ICOUNT, I)
CALL PRINT (ICOUNT, I)

250 CONTINUE
GO TO 500

C NATURAL RESERVOIR

300 CONTINUE
JM = NEL(I)
JM1 = NELSV(I)
ELBSL = YSURI(I) + DYY(I)
AYSUR = AYSURI(I)
SAREA = SAREAI(I)
SAREAP = SAREA
DYSUR = DYSURI(I)
DYSURP = DYSUR
DY = DYY(I)
YSUR = YSURI(I)
JMP = NELMAX(I)
NINI = NIN(I)
NOUTI = NOUT(I)
NAR = 1
DHL = 0.0
DO 325 J = 1, JMP
B(J) = BI(J, I)
XL(J) = XLI(J, I)
A(J) = AI(J, I)
EL(J) = ELL(J, I)

325 CONTINUE
YBOT = YYBOT(I)
DO 330 J = 1, JM

330 T(J, 1) = TLOW(J, I)
IF (KSUR.EQ.2) CALL SUREL (ICOUNT, I)
CALL HEAT (ICOUNT, I, III)
CALL SPEED (ICOUNT, I)
CALL SUBLAY (ICOUNT, I)
CALL HTMIX (ICOUNT, I)
CALL AVER (ICOUNT, I)
NAR = 2
III=1
DXX(I,III)=0.0
WDTH(I,III)=0.0
NSEG(I,III)=1
TEMP(1)=T(JM,1)
TEMP(2)=T(JM,1)
CALL AVER(ICOUNT,I)
DO 370 J=1,JM
370 TLOW(J,I)=T(J,1)
CALL ENERGY(ICOUNT,I)
CALL PRINT(ICOUNT,I)
350 CONTINUE
500 CONTINUE
501 CONTINUE
GO TO 20
600 CONTINUE
700 CONTINUE
STOP
END

SUBROUTINE MET
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /SWITCHM/ KFIN,KATRAD
COMMON /SURFLR/ KSUR
COMMON /SURFLR/ KSUR
COMMON /CUM/ CUMQIN,CUMQOT,SAREA1(5),DYSUR1(5),JM1,NELSV(5)
COMMON /METEOA/ TA(3000),SIGH(3000),WIND(3000),CLOUD(3000)
COMMON /METEOB/ FIN(3000),ATRAD(3000)
COMMON /METTIME/ DTTA,DTSIGH,DTWIND,DCLOUD,DTFIN,DATRAD
COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
COMMON /ETIME/ ET,NPOND
COMMON /METWD/ WHGT,TAU
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),EO(5),ENOW(5)
COMMON /ISTART/ ATIME1,MMODY,MYR,NDD
COMMON /ETIME/ ET,NPOND
COMMON /IPR/ KMODE,IPRINT(20),IFREQT
COMMON /NDY/ NDAYS(13)
DIMENSION IPDAT(3,10)
DIMENSION WH(20)
C WH= HEADER CARD (A FORMAT)
RHO=997.
HCAP=.998
READ(5,900)(WH(I),I=1,20)
WRITE(6,905) (WH(I),I=1,20)
READ (5,910) NPOND
CUMQIN=0.0
CUMQOT=0.0
DO 5 I=1,NPOND
EO(I)=0.0
EOUT(I)=0.0
EIN(I)=0.0
EFXIN(I)=0.0
EFXOT(I)=0.0
5 READ (5,910) KSTRT(I),KCIRC(I)
READ (5,910) KFIN,KATRAD,KUNITS,KSUR,KHEAT,KOPERA
WRITE (6,800) KFIN,KATRAD,KUNITS,KSUR,KHEAT,KOPERA
800 FORMAT (///10X,'KFIN ',I3,8X,'KATRAD',I3,8X,'KUNITS',I3,8X,
,'KSUR',I3,8X,'KHEAT',I3,8X,'KOPERA',I3)

C KFIN = 1 MEASURED SOLAR RADIATION
C = 2 COMPUTED SOLAR RADIATION
C KATRAD = 1 MEASURED ATMOSPHERIC RADIATION
C = 2 COMPUTED ATMOSPHERIC RADIATION
C KUNITS = 1 UNITS ARE KCAL, METERS, DAY, DEG.C, M/S(WIND SPEED ONLY)
C = 2 UNITS ARE BTU, FEET, DAY, DEG.F, MPH(WIN. SPEED ONLY)
C KHEAT = 1 ARTIFICIAL HEAT LOADING
C = 2 NATURAL RESERVOIR
C KSUR = 1 CONSTANT SURFACE ELEVATION
C = 2 VARIABLE SURFACE ELEVATION
C KCIRC = 1 NO RECIRCULATION
C = 2 RECIRCULATION
C KOPERA = 1 CLOSED CYCLE OPERATION (SPECIFIED FLOW AND TEMP. RISE)
C = 2 OPEN CYCLE OPERATION (SPECIFIED FLOW AND TEMPERATURE)

C READ IN METEOROLOGICAL DATA
C READ IN VALUES OF AIR TEMPERATURE
READ(5,920) NTA,DTTA
READ(5,930) (TA(I),I=1,NTA)
C READ IN VALUES OF RELATIVE HUMIDITY
READ(5,920) NSIGH,DTSIGH
READ(5,930) (SIGH(I),I=1,NSIGH)
C READ IN VALUES OF WIND SPEED
READ(5,920) NWIND,DTWIND
READ(5,930) (WIND(I),I=1,NWIND)
READ(5,935) WHGT
C READ IN VALUES OF SHORT WAVE SOLAR RADIATION
READ(5,920) NFIN,DTFIN
READ(5,940) (FIN(I),I=1,NFIN)
IF((KFIN.EQ.1) AND. (KATRAD.EQ.1)) GO TO 10
C READ IN VALUES OF CLOUD COVER IF EITHER SHORT OR LONG WAVE RADIATION IS TO BE COMPUTED
READ(5,920) NCL CLOUD,DCLOUD
READ (5,980) (CLOUD(I),I=1,NCL CLOUD)
IF(KATRAD.EQ.2) GO TO 20
C MEASURED ATMOSPHERIC RADIATION
10 READ(5,920) NATRAD,DATRAD
READ(5,940) (ATRAD(I),I=1,NATRAD)
C BETA = FRACTION OF SHORT WAVE RADIATION THAT IS ABSORBED AT SURFACE
C ETA = EXTINCTION COEFFICIENT OF LIGHT IN THE POND WATER
20 READ(5,940) ETA,BETA
C DTAU = VALUE OF TIME INCREMENT (F10.2)
C TAUMAX= TOTAL SIMULATION TIME (F10.2)
C IFREQ1 = NUMBER OF TIME INTERVALS BETWEEN CALLING PRINT1
C IFREQ2 = NUMBER OF TIME INTERVALS BETWEEN CALLING PRINT2
READ (5,970) DTAU,TAUMAX,IFREQ1,IFREQ2,IFREQA
C READ STARTING DATE AND TEN OUTPUT DAYS
C READ(5,910)NDD

153
READ(5,972)MMO,MDY,MYR
972 FORMAT(I2,1X,I2,1X,I4)
   DO 112 KK=1,NDD
112 READ(5,972)(IPDAT(K1,KK),K1=1,3)
   CALL DAXIME(MDY,MMO,MYR,ATIME1)
   DO 111 II=1,NDD
         CALL DAXIME(IPDAT(2,II),IPDAT(1,II),IPDAT(3,II),DAZE)
         AN=DAZE-ATIME1
         IPRINT(II)=AN/DTAU
   111 CONTINUE
   WRITE (6,850) DTAU,TAUMAX,IFREQ1,IFREQ2,IFREQA
850 FORMAT (/10X, 'TIME INCREMENT' ,F9.3,4X,'MAXIMUM TIME' ,F10.3,7X,
         ,'IFREQ1',I3,3X,'IFREQ2',I3,3X,'IFREQA',I3)
   IF(KUNITS.EQ.1)WRITE(6,901)
   IF(KUNITS.EQ.2)WRITE(6,902)
901 FORMAT(/10X,'UNITS ARE KCAL, METERS, DAY, DEG.C, ',
         ,'M/S(WIND SPEED ONLY)')
902 FORMAT(/10X,'UNITS ARE BTU, FEET, DAY, DEG.F, ',
         ,'MPH(WIND SPEED ONLY)')
   WRITE(6,903)MMO,MDY,MYR
903 FORMAT(//=5X,'STARTING DATE FOR THE RUN ',I2,'/',I2,'/',I4)
   WRITE(6,904)ETA,BETA
904 FORMAT(//=5X,'ETA= ',F5.3,' BETA= ',F5.3)
C CONVERT UNITS IF NEEDED
   IF(KUNITS.EQ.1) GO TO 100
C CONVERT UNITS FROM BRITISH UNITS TO MKD UNITS
   DO 30 I=1,NTA
         TA(I)=(TA(I)-32.)*5./9.
30 CONTINUE
C WIND SPEEDS CHANGED FROM MPH TO METERS/SEC
   DO 40 I=1,NWIND
         WIND(I)=WIND(I)*.447
   40 CONTINUE
WHGT=WHGT*.3048
C CONVERT INSOLATION FROM BTU/FT**2/DAY TO KCAL/M**2/DAY
   DO 50 I=1,NFIN
         FIN(I) =FIN(I)*2.712
50 CONTINUE
C CONVERT ATRAD FROM BTU/FT**2/DAY TO KCAL/M**2/DAY
   IF(KATRAD.EQ.2) GO TO 85
   DO 60 I=1,NATRAD
         ATRAD(I) =ATRAD(I)*2.712
60 CONTINUE
85 CONTINUE
   ETA=ETA*3.281
100 CONTINUE
C ADJUST WIND SPEED TO 2 METERS
   FACTOR=7.601 ALOG(WHGT/0.001)
   DO 45 I=1,NWIND
         WIND(I)=FACTOR*WIND(I)
45 CONTINUE
980 FORMAT (16F5.2)
RETURN
END
SUBROUTINE GEOM2(I)
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA, KCIRC(5)
COMMON /MIX/ KMIX,MIXED(3,5),RMIX(3,5),KOH
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY, JM, JMP,YSUR,EL(100)
COMMON/GEOMC/ YB(100),XLI(100,5),BI(100,5),
,YSURI(5),YSUR(5),EL(100,5),SAREAI(5),AYSURI(5)
COMMON /ETIME/ ET,NPOND
COMMON /CUM/ CUMQIN,CUMQOT,SAREA1(5),YSURI(5),JM1,NELSV(5)
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /FLOWS/ QQIN(366,3,5),TFIN(366,3,5),TIN(3),QIN(3),
,QOUT(5),NQIN(3,5),DTQIN(3,5),NQO(3,5),DTQO(3,5),NOUT(5),NOUTI,
,NOUT(5,5),ELOUT(5,5),NIN(5),QO(366,3,5),NINI,N1
COMMON /GAUS/ SIGMAI,SPREAD,SIGMIN(3)
COMMON /ENFLW/ TTININ(3),QININ(3),NOUT1
COMMON /ENGYB/ EIN1(5),EPRES2(5),EQIN2(5),EQOUT2(5),ESTRT2(5)
COMMON /ENGYC/ EQIN3(5),EQOUT3(5)
COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),E0(5),ENOW(5)
COMMON /CWU/ H,EMASS(5),EVPAP(5),EBRAD(5),EATRAD(5)
COMMON /METWD/ WHGT,TAU

DIMENSION AA(100,5),XXL(100,5),XXL(100,5),XXL(100,5),AA(5),

C DEFINITION OF VARIABLES IN THE ORDER IN WHICH THEY ARE READ
C NELSV INITIAL NUMBER OF VERTICAL GRID POINTS FOR ENTIRE POND
C NELMAX MAXIMUM NUMBER OF VERTICAL GRID POINTS
C DD VERTICAL DISTANCE INCREMENT
C SYURI ELEVATION OF THE TOP OF THE VERTICALLY STRATIFIED REGION
C NAA NUMBER OF AREAS TO BE READ IN
C DAA VERTICAL DISTANCE INTERVAL BETWEEN READ IN VALUES OF AA
C AAB ELEVATION OF FIRST (LOWEST) VALUE OF AA
C NXXL NUMBER OF LENGTHS TO BE READ IN
C DXL VERTICAL DISTANCE INTERVAL BETWEEN VALUES OF XXL
C XXLB ELEVATION OF FIRST (LOWEST) VALUE OF XXL
C TLOW INITIAL TEMPERATURE DISTRIBUTION
C SPREAD NUMBER OF OUTFLOW STANDARD DEVIATIONS EQUAL TO HALF THE
C Withdrawal Thickness = 1.96
C SIGMAI INFLOW STANDARD DEVIATION
C NIN NUMBER OF INFLOWS (EXCLUDING HEATED DISCHARGE WATER)MIN=1
C KOH = 1 USE KOH'S EQUATION
C = 2 USE KAO'S EQUATION (PREFERRED)
C KMIX = 1 NO ENTRANCE MIXING
C = 2 ENTRANCE MIXING CONSIDERED
C MIXED NUMBER OF GRID ELEMENTS IN LAYER INFLUENCED BY ENTRANCE M
C RMIX MIXING RATIO
C NQIN NUMBER OF INFLOW RATE VALUES TO BE READ IN
C DTQIN TIME INTERVAL BETWEEN VALUES OF QQIN
C QQIN INFLOW RATES
C TTIN TEMPERATURES OF INFLOWING WATER
C NOUT              NUMBER OF RESERVOIR OUTLETS
C LOUT              GRID NUMBER CORRESPONDING TO OUTLET ELEVATION
C ELOUT             OUTLET ELEVATION
C NQO               NUMBER OF OUTFLOW RATES TO BE READ IN FOR OUTLET K
C DTQO              TIME INTERVAL BETWEEN VALUES OF QO
C QO                OUTFLOW RATES
   READ (5,910) NELSV(I),NELMAX(I)
   NEL(I)=NELSV(I)
   READ(5,950) DYY(I),YSURI(I)
   READ(5,925) NAA(I),DAA(I),AAB(I)
   NA=NAA(I)
   READ(5,927) (AA(J,I),J=1,NA)
   READ(5,925) NXXL(I),DXXL(I),XXLB(I)
   NX=NXXL(I)
   READ(5,927) (XXL(J,I),J=1,NX)
C READ INITIAL TEMPERATURE DISTRIBUTION
   JM=NEL(I)
   READ(5,930) (TLOW(J,I),J-1,JM)
   READ (5,950) DD(1,I)
   READ (5,950) SPREAD,SIGMAI
C READ FLOW DATA
   C READ IN VALUES OF THE FLOW RATE OF THE WATER ENTERING THE POND
   READ (5,910) NIN(I)
   NINI=NIN(I)
   DO 20 K=1,NINI
      READ (5,905) KOH,KMIX,MIXED(K,I),RMIX(K,I)
      SIGMIN(K)=SIGMAI
      READ (5,920) NQIN(K,I),DTQIN(K,I)
      NQINN=NQIN(K,I)
      READ (5,951) (QQIN(J,K,I),J=1,NQINN)
   C READ IN VALUES OF THE TEMPERATURE OF THE WATER ENTERING THE POND
   20 READ (5,930) (TTIN(J,K,I),J=1,NQINN)
   WRITE (6,888)DD(1,I)
888 FORMAT(/5X,'VERTICAL DIFFUSION COEFF. = ',F10.5)
   WRITE (6,809)
809 FORMAT (/5X,'STRATIFIED PORTION INFLOW PARAMETERS')
   DO26 K=1,NINI
26 WRITE (6,810) KOH,KMIX,K,MIXED(K,I),K,RMIX(K,I)
810 FORMAT (10X,'KOH',I3,5X,'KMIX',I3,5X,'MIXED(',I2,')',I3,5X,'RMIX('
      ,,I2,')',F5.2)
C READ OUTFLOW DATA
   C READ IN VALUES OF THE FLOW RATE OF THE WATER ENTERING THE POND
   READ (5,910) NOUT(I)
   NOUT1=NOUT(I)
   DO 40 K=1,NOUT1
      READ (5,920) LOUT(K,I),ELOUT(K,I)
      READ (5,920) NQO(K,I),DTQO(K,I)
      NQOONQO(K,I)
40 READ (5,951) (QO(J,K,I),J=1,NQOON)
C CONVERT UNITS IF NECESSARY
   GO TO (200,210), KUNITS
210 CONTINUE
   DYY(I)=DYY(I)*0.3048
   YSURI(I)=YSURI(I)*0.3048
   AAB(I)=AAB(I)*0.3048
DAA(I) = DAA(I) * 0.3048
DD(1,I) = DD(1,I) * 0.3048 * 0.3048
NA = NAA(I)
DO 50 J = 1, NA
AA(J,I) = AA(J,I) * 0.0929
DXXL(I) = DXXL(I) * 0.3048
XXLB(I) = XXLB(I) * 0.3048
NX = NXXL(I)
DO 55 J = 1, NX
XXL(J,I) = XXL(J,I) * 0.3048
JM = NEL(I)
DO 65 J = 1, JM
TLOW(J,I) = (TLOW(J,I) - 32.) * 5./9.
160 CONTINUE
DO 70 K = 1, NINI
NQINN = NQIN(K,I)
DO 70 II = 1, NQINN
C CONVERT FLOW RATE FROM FT³/DAY TO M³/DAY
QQIN(II,K,I) = QQIN(II,K,I) * 0.02832
C CONVERT TEMPERATURE FROM F TO C
DO 80 K = 1, NOUT1
ELOUT(K,I) = ELOUT(K,I) * 0.3048
NQOO = NQO(K,I)
DO 80 J = 1, NQOO
QO(J,K,I) = QO(J,K,I) * 0.02832
200 CONTINUE
C ESTABLISH GEOMETRY
JM = NEL(I)
JMSV = NELSV(I)
JMP = NELMAX(I)
YYBOT(I) = ELOUT(1,I) - DYY(I) * FLOAT(LOUT(1,I) - 1)
DO 30 J = 1, JMP
ELL(J,I) = YYBOT(I) + DYY(I) * FLOAT(J - 1)
RA = (ELL(J,I) - AAB(I)) / DAA(I) + 1.0
IF (J - JMP) 5, 6, 6
5 L = RA
GO TO 7
6 L = RA - 0.001
7 AI(J,I) = AA(L,I) + (RA - FLOAT(L)) * (AA(L+1,I) - AA(L,I))
RA = (ELL(J,I) - XXLB(I)) / DXXL(I) + 1.0
IF (I - JMP) 10, 11, 11
10 L = RA
GO TO 12
11 L = RA - 0.001
12 XLI(J,I) = XXL(L,I) + (RA - FLOAT(L)) * (XXL(L+1,I) - XXL(L,I))
BI(J,I) = AI(J,I) / XLI(J,I)
30 CONTINUE
YSURST = YSURI(I)
DYSURI(I) = YSURST - ELL(JM,I) + DYY(I) / 2.0
IF (YSURST - ELL(JM,I)) 15, 15, 16
15 AYSURI(I) = AI(JM,I) - (DYY(I) / 2.0 - DYSURI(I)) * (AI(JM,I) - AI(JM-1,I)) / $DYY(I)
GO TO 17
AYSURI(I)=AI(JM,I)+(DYSURI(I)-DYY(I)/2.0)*(AI(JM+1,I)-AI(JM,I))/DYY(I)

SAREAI(I)=(AYSURI(I)+(AI(JM,I)+AI(JM-1,I))/2.0)/2.0

DYSURI(I)=YSURI(I)-ELL(JMSV,I)+DYY(I)/2.0
IF (YSURI(I)-ELL(JMSV,I)) 35,35,36

AYSUR=AI(JMSV,I)-(DYY(I)/2.0-DYSURI(I))*f(AI(JMSV,I)-AI(JMSV-1,I))/DYY(I)
GO TO 37

AYSURT=AI(JMSV,I)+(DYSURI(I)-DYY(I)/2.0)*
*(AI(JMSV+1,I)-AI(JMSV,I))/DYY(I)

SAREA1(I)=(AYSURT+(AI(JMSV,I)+AI(JMSV-1,I))/2.0)/2.0

WRITE (6,839)
839 FORMAT (///5X,'STRATIFIED PORTION GEOMETRY')

WRITE (6,840)
DO 280 J=1,JM
IF (KUNITS.EQ.2) GO TO 275
WRITE(6,850) J,AI(J,I),XLI(J,I),BI(J,I),TLOW(J,I)
GO TO 280
275 AIF=AI(J,I)/0.0929
XLIF=XLI(J,I)/0.3048
BIF=BI(J,I)/0.3048
TTFF=TLOW(J,I)*9./5.+32.
WRITE (6,850) J,AIF,XLIF,BIF,TTFF
280 CONTINUE

840 FORMAT (/14X,'ELEMENT',14X,'AREA',12X,'LENGTH',13X,
,'WIDTH',12X,'TEMPERATURE')

285 CONTINUE

FORMAT (15X,I4,8X,E12.5,8X,F10.0,8X,F10.0,13X,F6.2)
C INITIALIZE ENERGY CHECK

EQIN2(I)=0.0
EQOUT2(I)=0.0
EQIN3(I)=0.0
EQOUT3(I)=0.0
EEMASS(I)=0.0
EEVAP(I)=0.0
EBRAD(I)=0.0
EATRAD(I)=0.0
ESTRT2(I)=AI(1,I)*DYY(I)/2.0*TLOW(1,I)*RHO*HCAP
ESTRT2(I)=ESTRT2(I)+SAREAI(I)*DYSURI(I)*TLOW(JM,I)*RHO*HCAP
JMM=JM-1
DO 285 J=2,JMM
285 ESTRT2(I)=ESTRT2(I)+AI(J,I)*DYY(I)*TLOW(J,I)*RHO*HCAP
GO TO (301,302), KHEAT
301 KSTRAT=KSTRT(I)
GO TO (303,302), KSTRAT
302 EO(I)=EO(I)+ESTRT2(I)
303 CONTINUE

FORMAT(3(5X,I5),F5.2)
1 FORMAT (5(5X,I5))
2 FORMAT (5X,I5,F10.5)
5 FORMAT (5X,I5,F10.5,F10.5)
7 FORMAT(8F10.2)
9 FORMAT (16F5.1)
10 FORMAT (8F10.5)
11 FORMAT (6F12.1)
SUBROUTINE GEOM1(I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /TEMP/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),DF
COMMON /FLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,THINI,QNQHIN,
,,DTQHIN
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
,,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSSEG(5,2),NAR,MP1
COMMON /ENTRN/ DSS(5),DS
COMMON /TENTR/ TEDDY(5),THINI,TNP
COMMON /ETIME/ ET,NPOND
COMMON /ENGYA/ EIN1(5),EPRES1(5),EQIN1(5),EQOUT1(5),ESTRT1(5)
COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),EO(5),ENOW(5)
COMMON /CWU/ H,EEMASS(5),EEM(5),EBRAD(5)
COMMON /CIRCL/ REDDY(5)
COMMON /DISCH/ DTEMP
DIMENSION NTO(5,2)

C DEFINITION
C NSEG NUMBER OF SEGMENTS IN DISPERSIVE FLOW REGION
C DZ DEPTH OF POND
C WDTH WIDTH OF POND
C LENGTH LENGTH OF DISPERSIVE FLOW REGION
C NTO NUMBER OF VALUES TO BE READ IN FOR THLM (NSSEG+1)
C THLM TEMPERATURE DISTRIBUTION IN DISPERSIVE FLOW REGION
C THETA FRACTION OF POND WHICH IS FULLY MIXED
C DSS DILUTION BY ENTRAINMENT
C NQHIN NUMBER OF FLOW RATES OF HEATED WATER TO BE READ IN
C DTQHIN TIME INTERVAL BETWEEN READ-IN VALUES OF HEATED WATER
C QQHIN FLOW RATE OF HEATED WATER
C TTHIN INFLOW TEMPERATURE OF HEATED WATER
C DEFINITION OF OTHER VARIABLES
C VTOTAL VOLUME OF ENTIRE POND
C VFM VOLUME OF FULLY MIXED REGION
C VDF VOLUME OF DISPERSIVE FLOW REGION
C AREA AREA OF EACH SECTION IN THE DISPERSIVE FLOW REGION
C DXX LENGTH OF EACH SECTION IN THE DISPERSIVE FLOW REGION

VTOTAL(I) = 0.0
KK = KCIRC(I)
DO 100 III=1,KK
READ (5,910) NSSEG(I,III)
READ (5,960) DZ(I,III),WDTH(I,III),LENGTH(I,III)
VTOTAL(I)=VTOTAL(I)+DZ(III)*WDTH(I,III)*LENGTH(I,III)
AREA(I,III)=DZ(III)*WDTH(I,III)

C READ IN INITIAL TEMP DISTRIBUTION
READ (5,910) NTO(I,III)
NM=NTO(I,III)
READ (5,930) (THLM(J,I,III),J=1,NM)
100 CONTINUE
READ (5,950) THETA(I),DSS(I)
IF (KCIRC(I).EQ.2) GO TO 110
\[ DXX(I,1) = (1.0 - \Theta(I)) \times \text{LENGTH}(I,1) / \text{FLOAT}(\text{NSEG}(I,1)) \]

\[ VFM(I) = \Theta(I) \times V_{\text{TOTAL}}(I) \]

\[ VDF(I) = (1.0 - \Theta(I)) \times V_{\text{TOTAL}}(I) \]

GO TO 115

110 \[ DXX(I,1) = \text{LENGTH}(I,1) / \text{FLOAT}(\text{NSEG}(I,1)) \]

\[ DXX(I,2) = (1.0 - \Theta(I)) \times \text{LENGTH}(I,1) / \text{FLOAT}(\text{NSEG}(I,2)) \]

\[ VFM(I) = \Theta(I) \times \text{LENGTH}(I,2) \times \text{WDTH}(I,2) \times DZ(I,2) \]

\[ VDF(I) = V_{\text{TOTAL}}(I) - VFM(I) \]

CONTINUE

CALL PRHDG(I)

IF (I.GT.1) GO TO 162

C READ IN VALUES OF THE FLOW RATE OF HEATED WATER ENTERING POND
READ (5,920) NQHIN, DTQHIN
READ (5,951) (QQHIN(J), J=1,NQHIN)

C READ IN TEMP. RISE (KOPERA=1) OR TEMPERATURE (KOPERA=2)
IF (KOPERA.EQ.2) GO TO 118
READ (5,930) DTEMP
GO TO 162

118 READ (5,930) (TTHIN(J), J=1,NQHIN)
162 CONTINUE

WRITE (6,860) I

860 FORMAT (///10X,'INITIAL TEMPERATURE DISTRIBUTION IN POND',I4)

KK=KCIRC(I)

DO 2 II=1,KK

NM=NTO(I,II)

WRITE (6,865) (THLM(J,I,II), J=1,NM)

865 FORMAT (10(/10X,10(F6.2,5X)))

C CONVERT UNITS IF NECESSARY
GO TO (160,150), KUNITS

150 \[ V_{\text{TOTAL}}(I) = V_{\text{TOTAL}}(I) \times 0.02832 \]

KK=KCIRC(I)

DO 90 II=1,KK

AREA(I,II)=AREA(I,II) \times 0.0929

DZ(I,II)=DZ(I,II) \times 0.3048

WDTH(I,II)=WDTH(I,II) \times 0.3048

LENGTH(I,II)=LENGTH(I,II) \times 0.3048

DXX(I,II)=DXX(I,II) \times 0.3048

NM=NTO(I,II)

DO 80 J=1,NM

THLM(J,I,II)=(THLM(J,I,II)-32.) \times 5./9.

80 CONTINUE

90 \[ VFM(I) = VFM(I) \times 0.02832 \]

VDF(I)=VDF(I) \times 0.02832

IF (I.GT.1) GO TO 160

DO 60 J=1,NQHIN

60 QQHIN(J)=QQHIN(J) \times 0.02832

IF (KOPERA.NE.1) GO TO 61

DTEMP=DTEMP \times 5./9.

61 IF (KOPERA.EQ.1) GO TO 75

DO 70 J=1,NQHIN

70 TTHIN(J)=(TTHIN(J)-32.) \times 5./9.

75 CONTINUE

160 CONTINUE

IF (KK.EQ.2) TEDDY(I)=THLM(NM,I,2)
C INITIALIZE ENERGY CHECK
EQIN1(I)=0.0
EQOUT1(I)=0.0
EEMASS(I)=0.0
EEVAP(I)=0.0
EBRAD(I)=0.0
EATRAD(I)=0.0
KK=KCIRC(I)
ESTRT1(I)=0.0
DO 210 III=1,KK
NM=NTO(I,III)
ESTRT1(I)=ESTRT1(I)+THLM(1,I,III)*DZ(I,III)*WDTH(I,III)*
*DX(I,III)/2.*RHO*HCAP
ESTRT1(I)=THLM(NM,I,III)*DZ(I,III)*WDTH(I,III)*DX(I,III)/2.0*
*RHO*HCAP+ESTRT1(I)
NMM=NTO(I,III)-1
DO 200 J=2,NM
200 ESTRT1(I)=THLM(J,I,III)*DZ(I,III)*WDTH(I,III)*DX(I,III)*RHO*HCAP+
JESTRT1(I)
210 CONTINUE
EO(I)=EO(I)+ESTRT1(I)
910 FORMAT (5(5X,I5))
920 FORMAT (5X,I5,F10.5)
930 FORMAT (16F5.1)
950 FORMAT (8F10.5)
951 FORMAT (6F12.1)
960 FORMAT (5F15.3)
RETURN
END
SUBROUTINE WEATHR(ICOUNT)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /SWITCHM/KFIN,KATRAD
COMMON /METEOA/ TA(3000),SIGH(3000),WIND(3000),CLOUD(3000)
COMMON /METEOB/ FIN(3000),ATRAD(3000)
COMMON /METE/ DTTA,DTSIGH,DTWIND,DCLOUD,DTFIN,DATRAD
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
COMMON /EQUIL/ TE,IDT
COMMON /ETIME/ ET,NPOND
C DETERMINE METEOROLOGICAL DATA FROM READ IN VALUES
C AIR TEMPERATURE
R=ET/DTTA
L=R
RR=R-L
TAIR =TA(L+1)+RR*(TA(L+2)-TA(L+1))
TAIRF=TAIR*9./5.+32.
C RELATIVE HUMIDITY
R=ET/DTSIGH
L=R
RR=R-L
PSI=(SIGH(L+1)+RR*(SIGH(L+2)-SIGH(L+1)))
C EXPONENTIAL APPROXIMATION FOR VAPOR PRESSURE OF THE AIR IN MM HG
EA=PSI*(25.4*EXP(17.62-9500./(TAIRF+460.)))
C WIND SPEED
R = ET/DTWIND
L = R
RR = R - L
W = WIND(L+1) + RR*(WIND(L+2) - WIND(L+1))
WINDY = W

C SOLAR RADIATION, MEASURED
R = ET/DTFIN
L = R
RR = R - L
SR = FIN(L+1) + RR*(FIN(L+2) - FIN(L+1))
GO TO (20,10), KFIN

C SOLAR RADIATION, COMPUTED
79
10 R = ET/DCCLOUD
L = R
RR = R - L
CC = CLOUD(L+1) + RR*(CLOUD(L+2) - CLOUD(L+1))
SR = SR*(1.0 - 0.65*CC**2)
SR = SR*.94
20 GO TO (40,30), KATRAD

C ATMOSPHERIC RADIATION COMPUTED FROM CLOUD COVER AND AIR TEMP
30 R = ET/DCCLOUD
L = R
RR = R - L
CC = CLOUD(L+1) + RR*(CLOUD(L+2) - CLOUD(L+1))
AR = 1.13587E-6*0.937E-5*(TAIR+273.16)**6*(1.0 + 0.17*CC**2)
GO TO 50

C ATMOSPHERIC RADIATION, MEASURED
40 R = ET/DATRAD
L = R
RR = R - L
AR = ATRAD(L+1) + RR*(ATRAD(L+2) - ATRAD(L+1))
50 CONTINUE

C COMPUTE EQUILIBRIUM TEMPERATURE
TAIRV = (TAIRF + 460.)/(1. - 0.378*EA/760.) - 460.
EA = PSI*(25.4*EXP(17.62 - 9500./(TAIRF + 460.)))
KT = 0
RHS = AR + SR
T1 = TAIR
345 CONTINUE
KT = KT + 1
TSF = T1*9./5.+32
ES = 25.4*EXP(17.62 - 9500./(TSF + 460.))
DE = ES - EA
IF(ABS(DE).LT.0.00001) DE = 0.00001
RADE = 1.13587E-6*(T1+273.16)**4
GO TO (230,235), KHEAT

C EVAPORATION RYAN EQN FOR HEATED LAKES (ORIGINAL WINDSPEED FNT
C MULTIPLIED BY 0.85 FOLLOWING HICKS' MEASUREMENTS AT DRESDEN COOLING
C POND)
230 CONTINUE
TSV = (TSF + 460.)/(1. - .378*ES/760.) - 460.
DTV = TSV - TAIRV
IF(DTV.LE.0.0) DTV = 0.0

162
FR = 22.4 * DTV ** 0.333 + 14. * W / 0.447
FR = 0.85 * FW
EVAPE = FW * DE * 2.712
CONDCE = EVAPE * (T1 - TAIR) / DE * 0.46
IF (EVAPE.LE.0.0) EVAPE = 0.0
GO TO 270

C EVAPORATION ROHWER EQN FOR UNHEATED LAKE
235 FR = 0.0308 + 0.0185 * W
CHI = RHO * ((597.3 - 0.56 * T1) * DE + T1 * HCAP * DE)
EVAPE = CHI * FW * 0.01
IF (EVAPE) 250,250,260
EVAPE = 0.0
260 CONDCE = RHO * 0.01 * 269.1 * (T1 - TAIR) * FR
270 CONTINUE
SHS = EVAPE + CONDCE + RAD
X = RHS - SHS
IF ((X.LT.30.).AND.(X.GT.-30.)) GO TO 300
IF (KT.GT.20) GO TO 300
T1 = T1 + X / 2000.
GO TO 345
300 TE = T1
350 RETURN

END

SUBROUTINE HEAT (ICOUNT, I, III)
REAL LENGTH
COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON /SWTCHM/KFIN, KATRAD
COMMON /METEOA/ TA(3000), SIGH(3000), WIND(3000), CLOUD(3000)
COMMON /METEOB/ FIN(3000), ATRAD(3000)
COMMON /METETIME/ DTTA, DTSIGH, DTWIND, DCLOUND, DTFIN, DATRAD
COMMON /EXTIN/ DAU, DTAU, ETA, BETA, TAUMAX, IFREQ1, IFREQ2, IFREQA
COMMON /GEOMA/ VTOTAL(5), VFM(5), VDF(5), LENGTH(5, 2), DXX(5, 2),
, DZ(5, 2), WDTH(5, 2), AREA(5, 2), DHL, THETA(5), NSEG(5, 2), NAR, MF1
COMMON /GEOMB/ A(100), B(100), XL(100), DD(1, 5), DY, JM, JMP, YSUR, EL(100)
COMMON /TEMPA/ TEMP(100), THLM(100, 5, 2), TLOSS(100), TOUT(3000, 5)
COMMON /TEMPB/ T(100, 2), TLOW(100, 5), NEL(5), NELMAX(5)
COMMON /CONST/ RHO, HCAP, GRAV
COMMON /FLXES/ SR, EVAP, RAD, CONDUC, AR, TAIR, TAIRF, PSI, EA, W, WINDY, CC
COMMON /CWU/ H, EEMASS(5), EEVAP(5), EBRAD(5), EATRAD(5)
COMMON /SURF/ SAREAP, DYSURP, DYSUR, AYSUR, SAREA, SURAR
COMMON /EQUIL/ TE, IDT
COMMON /ETIME/ ET, NPOND

C HEAT LOSS COMPUTATIONS
DO 200 K = 1, NAR
IF (NAR.GT.1) GO TO 60
TS = T(JM, 1)
DY1 = DYSUR
SURAR = AYSUR
GO TO 70

60 TS = TEMP(K)
DT = DTAU
DY1 = DHL
SURAR = W DXX(I, III) * DXX(I, III)
IF ((K.EQ.1).OR.(K.EQ.NAR)) SURAR = SURAR/2.0
C LATENT HEAT
70 H=597.3-0.56*TS
C EXPONENTIAL APPROXIMATION FOR SATURATED VAPOR PRESSURE AT TS IN MM
TSF=TS*9./5.+32.
ES=25.4*EXP(17.62-9500./(TSF+460.))
DE=ES-EA
IF(ABS(DE).LT.0.00001) DE=0.00001
GO TO (90,80),KHEAT
C EVAPORATION ROHWER EQUATION FOR UNHEATED LAKE
80 CHI=RHO*(H*DE+TS*HCP*DE)
C WIND SPEED REDUCED FROM 2 METERS TO 6 IN USING LOGARITHMIC PROFILE
C ADJUSTMENT TO REDUCE DATA HEIGHT FROM 2M TO 6 IN
IF (W-1.76) 61,61,62
61 W=W*.66
GO TO 65
62 W=W*.57
65 CONTINUE
FW=0.0308+0.0185*W
EVAP=CHI*FW*.01
IF(EVAP)85,85,86
85 EVAP=0.0
C CONDUCTION
86 CONDUC=RHO*0.01*269.1*(TS-TAIR)*FW
GO TO 100
C EVAPORATION RYAN EQUATION FOR HEATED LAKE
90 TAIRF=TAIR*.9./5.+32.
TAIRV=(TAIRF+460.)/(1.-0.378*EA/760.)-460.
TSV=(TSF+460.)/(1.-0.378*ES/760.)-460.
DTV=TSV-TAIRV
IF(DTV.LE.0.) DTV=0.
C IN BRITISH UNITS THIS EQN IS FW=22.4*DTV**.33+14.*W
FW=22.4*DTV**.333+14.*W/.447
C IN BRITISH UNITS THIS EQN IS FW=17.*W
FW2=17.*W/.447
IF(FW2.GT.FW) FW=FW2
FW=0.85*FW
EVAP=FW*DE*2.712
C CONDUCTION
CONDUC=EVAP*(TS-TAIR)/DE*.46
IF (EVAP.LE.0.0) EVAP=0.0
C BACK RADIATION
100 RAD=1.13587E-6*(TS+273.16)**4
C ENERGY CHECK CALCULATIONS FOR HEAT LOADED CONDITIONS
IF (KHEAT.EQ.1) CALL SUMFLX(I)
GO TO (110,120),KSTRAT
C VERTICALLY FULLY MIXED
110 R=1.0
ARATIO=1.0
GO TO 150
C VERTICAL STRATIFICATION
120 GO TO (130,140),KHEAT
C VERTICALLY STRATIFIED COOLING POND
130 AREADX=WDTH(I,III)*DXX(I,III)
ABOT=AYSUR/NSEG(I,III)
AAV = (ABOT + AREADX) / 2.0
ARATIO = AREADX / AAV
R = 1.0 - EXP(-ETA * DHL) * ABOT / AREADX
GO TO 150

C NATURAL RESERVOIR

ARATIO = AYSUR / SAREA
R = 1.0 - EXP(-ETA * DYSUR) * (A(JM) + A(JM-1)) / 2.0 / AYSUR

TLOSS(K) = (EVAP + CONDUC + RAD - AR - BETA * SR - (1.0 - BETA) * SR * R)

## Subroutine: Energy (Icount, I)

REAL LENGTH

COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON /EXTIN/ DTAU, ETA, BETA, TAUMAX, IFREQ1, IFREQ2, IFREQA
COMMON /HFLOWS/ QQHIN(3000), TTHIN(3000), THIN, CHIN, QHIN, QHINI, DTQHIN
COMMON /FLOWS/ QQIN(366, 3, 5), TTIN(366, 3, 5), TIN, QIN(3), QOUT(5), NQIN(3, 5), DTQIN(3, 5), NQO(3, 5), NOUT, NOUTI, NOUTL(5, 5), QO(366, 3, 5), NINI, NIN1
COMMON /TEMPA/ TEMP(100), THLM(100, 5), TLOSS(100), TOUT(3000, 5)
COMMON /TEMPB/ T(100, 2), TLOW(100, 5), NEL(5), NELMAX(5)
COMMON /GEOMA/ VTOTAL(5), vM(5), VDF(5), LENGTH(5, 2), DXX(5, 2), DZ(5, 2), WIDTH(5, 2), AREA(5, 2), DHL, THETA(5), NSEG(5, 2), NAR, MP1
COMMON /GEOMB/ AI(100), B(100), XL(100), DD(1, 5), DY, JM, YSUR, EL(100)
COMMON /GEOMC/ YYBOT(5), DYY(5), AI(100, 5), XLI(100, 5), BI(100, 5), DYSURI(5), YSUR(5), EL(100, 5), SAREA(5), AYSURI(5)
COMMON /CONST/ RHO, HCAP, GRAV
COMMON /TENTR/ TEDDY(5), THINI, TINP
COMMON /TOUT/ TOUTC(3000, 5), HEATOT(5), FLOWOT(5)
COMMON /ENFLW/ TININ(3), QININ(3), NOUT1
COMMON /ENGYA/ EIN(5), EFRS1(5), EQIN1(5), EQOUT1(5), ESTRT1(5)
COMMON /ENGYB/ EIN(5), EFRS2(5), EQIN2(5), EQOUT2(5), ESTRT2(5)
COMMON /ENGYC/ EQIN3(5), EQB1JT3(5)
COMMON /ENGY/ EFXIN(5), EFXOT(5), EOUT(5), EIN(5), E0(5), ENOW(5)
COMMON /TENGY/ TENRAT(5)
ENOW(I)=0.0
EOUT(I)=EFXOT(I)
EIN(I)=EFXIN(I)
GO TO (100,500),KSTRAT
500 GO TO (400,200),KHEAT
200 JM=NEL(I)
C NATURAL LAKE ENERGY
JMM=JM-1
EPRES2(I)=TLOW(1,I)*DYY(I)/2.0*AI(1,I)*RHO*HCAP
DO 210 J=2,JMM
210 EPRES2(I)=EPRES2(I)+TLOW(J,I)*DYY(I)*AI(J,I)*RHO*HCAP
EPRES2(I)=EPRES2(I)+TLOW(JM,I)*DYSURI(I)*SAREAI(I)*RHO*HCAP
DO 220 LT=1,NOUT1
220 EQOUT2(I)=EQOUT2(I)+QOUT(LT)*DTAU*TOUTC(ICOUNT,LT)*RHO*HCAP
DO 230 K=1,NIN1
230 EQIN2(I)=EQIN2(I)+QININ(K)*DTAU*TININ(K)*RHO*HCAP
20 EOUT(I)=EOUT(I)+EQWUT2(I)
EIN(I)=EIN(I)+EQIN2(I)
ENOW(I)=EPRES2(I)
GO TO 300
C COMPUTE ENERGY IN A STRATIFIED POND
C
C COMPUTE ENERGY IN THE STRATIFIED PORTION
400 JM=NEL(I)
JMM=JM-1
EPRES2(I)=TLOW(1,I)*DYY(I)/2.0*AI(1,I)*RHO*HCAP
DO 410 J=2,JMM
410 EPRES2(I)=EPRES2(I)+TLOW(J,I)*DYY(I)*AI(J,I)*RHO*HCAP
EPRES2(I)=EPRES2(I)+TLOW(JM,I)*DYSURI(I)*SAREAI(I)*RHO*HCAP
C COMPUTE ENERGY IN THE VERTICALLY MIXED REGION
III=1
MP1=NSSEG(I,III)+1
NMP=MP1-1
EPRES1(I)=THLM(1,I,III)*DZ(I,III)*DXX(I,III)*WDTH(I,III)/2.
*RHO*HCAP
DO 420 J=2,NMP
420 EPRES1(I)=EPRES1(I)+THLM(J,I,III)*DZ(I,III)*WDTH(I,III)*
*DXX(I,III)*RHO*HCAP
EPRES1(I)=EPRES1(I)+THLM(MP1,I,III)*DZ(I,III)*DXX(I,III)*
WDTH(I,III)/2.*RHO*HCAP
C COMPUTE INFLOW ENERGY
EQIN3(I)=EQIN3(I)+QHIN*DTAU*THIN*RHO*HCAP
KKK=NIN(I)
IF(KKK.EQ.0)GO TO 440
DO 430 K=1,KKK
430 EQIN3(I)=EQIN3(I)+QININ(K)*DTAU*TININ(K)*RHO*HCAP
440 CONTINUE
C COMPUTE OUTFLOW ENERGY
LLT=NOUT(I)
DO 450 LT=1,LLT
450 EQOUT3(I)=EQOUT3(I)+QOUT(LT)*DTAU*TOUTC(ICOUNT,LT)*
*RHO*HCAP
EOUT(I)=EOUT(I)+EQOUT3(I)
EIN(I)=EIN(I)+EQIN3(I)
ENOW(I) = EPRES2(I) + EPRES1(I)
GO TO 300
C VERTICALLY FULLY MIXED POND
100  EPRES1(I) = 0.0
    KK = KCIRC(I)
    DO 150 III = 1, KK
        MP1 = NSEG(I, III) + 1
        NMP = MP1 - 1
        EPRES1(I) = EPRES1(I) + THLM(1, I, III) * DZ(I, III) * DXX(I, III) * WDTH(I, III) / 2.0 * RHO * HCAP
    DO 110 J = 2, NMP
        EPRES1(I) = EPRES1(I) + THLM(J, I, III) * DZ(I, III) * WDTH(I, III) * DXX(I, III) * RHO * HCAP
    EPRES1(I) = EPRES1(I) + THLM(MP1, I, III) * DZ(I, III) * WDTH(I, III) * DXX(I, III) / 2.0 * RHO * HCAP
150  CONTINUE
    EQIN1(I) = EQIN1(I) + QHIN * DTAU * TINP * RHO * HCAP
    MP1 = NSEG(I, 1) + 1
    EQOUT1(I) = EQXJT1(I) + QHIN * DTAU * THLM(MP1, I, 1) * RHO * HCAP
30  EOUT(I) = EOUT(I) + EQJT1(I)
    EIN(I) = EIN(I) + EQIN1(I)
    ENOW(I) = ENOW(I) + EPRES1(I)
300  TENRAT(I) = (ENOW(I) + EOUT(I)) / (EIN(I) + EO(I))
RETURN
END
SUBROUTINE DISPER(ICOUNT, I, III)
REAL LENGTH, LAMBDA
COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON / MIX/ KMIX, MIXED(3, 5), RMIX(3, 5), KOH
COMMON /DISP/ DCOEF(5), DBETA(5), TEND(5), FF
COMMON /GEOMA/ VTOTAL(5), VFM(5), VDF(5), LENGTH(5, 2), DXX(5, 2),
    DZ(5, 2), WDTH(5, 2), AREA(5, 2), DHL, THETA(5), NSEG(5, 2), NAR, MP1
COMMON /GBOMB/A(100), B(100), XL(100), DD(1, 5), DY, JM, JMP, YSUR, EL(100)
COMMON /TEMPA/ TEMP(100), THLM(100, 5, 2), TLOSS(100), TOUT(3000, 5)
COMMON /HFLows/ QQHIN(3000), TTHIN(3000), THIN, QHIN, QINI, QHIN, QHIN, QHIN,
    DTQHIN
COMMON /FLOWS/ QQIN(366, 3, 5), TTIN(366, 3, 5), TIN(3), QIN(3),
    QOUT(5), QNIN(3, 5), QTQIN(3, 5), NQO(3, 5), DTQO(3, 5), NOUT(5), NOUTI,
    LOUT(5, 5), ELOUT(5, 5), NIN(5), QO(366, 3, 5), NNI, NIN1
COMMON /EXTIN/ DTAU, DT, ETA, BETA, TAUMAX, IFREQ1, IFREQ2, IFREQA
COMMON /ENFLW/ TININ(3), QININ(3), NOUT1
COMMON /ENTHR/ TEDDY(5), THINI, TINP
COMMON /EOUT/ TOUTC(3000, 5), HEATOT(5), FLOWOT(5)
COMMON /ETIME/ ET, NPOND
COMMON /TEMPB/ T(100, 2), TLOW(100, 5), NEL(5), NELMAX(5)
COMMON /ENTRN/ DSS(5), DS
COMMON /DPTH/ THIN, QHIN1
DIMENSION X(101), Y(101), Z(101), D(101)
DIMENSION VEL(5)
C FF = FRICTION FACTOR
C VKRMN = VON KARMAN CONSTANT
VKRMN = 0.4
GO TO (50, 60), KSTRAT
60  F = 0.01
GO TO (61,62), KMIX
62  NIN1=NIN(I)+1
NIN1=NIN(I)+1
MIXED(NIN1,I)=MIXED(1,I)
MIXED(NIN1,I)=MIXED(1,I)
MXX=MIXED(NIN1,I)+1
MXX=MIXED(NIN1,I)+1
JMIXB=JM-MIXED(NIN1,I)
JMIXB=JM-MIXED(NIN1,I)
IF (JMIXB.GT.0) GO TO 88
IF (JMIXB.GT.0) GO TO 88
JMIXB=1
JMIXB=1
MXX=JM
MXX=JM
88  CONTINUE
88  CONTINUE
NOUT1=NOUT(I)+1
NOUT1=NOUT(I)+1
QOUT(NOUT1)=DS*QHIN
QOUT(NOUT1)=DS*QHIN
TOUTC(ICOUNT,NOUT1)=0.0
TOUTC(ICOUNT,NOUT1)=0.0
DO70  J=JMIXB,JM
DO70  J=JMIXB,JM
70  TOUTC(ICOUNT,NOUT1)=TOUTC(ICOUNT,NOUT1)+T(J,1)/FLOAT(MXX)
70  TOUTC(ICOUNT,NOUT1)=TOUTC(ICOUNT,NOUT1)+T(J,1)/FLOAT(MXX)
IF (I.GT.1) GO TO 75
IF (I.GT.1) GO TO 75
THINI=(THIN+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
THINI=(THIN+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
GO TO 78
GO TO 78
75  THINI=(TEND(I-1)+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
75  THINI=(TEND(I-1)+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
78  QHINI=(1.+DS)*QHIN
78  QHINI=(1.+DS)*QHIN
GOTO 22
GOTO 22
61  CONTINUE
61  CONTINUE
QHINI=QHIN
QHINI=QHIN
IF (I.GT.1) GO TO 20
IF (I.GT.1) GO TO 20
THINI=THIN
THINI=THIN
GO TO 22
GO TO 22
20  THINI=TEND(I-1)
20  THINI=TEND(I-1)
22  CONTINUE
22  CONTINUE
TINP=THINI
TINP=THINI
GO TO 65
GO TO 65
50  FF=0.02
50  FF=0.02
IF (III.GT.1) GO TO 10
IF (III.GT.1) GO TO 10
QHINI=(1.+DS)*QHIN
QHINI=(1.+DS)*QHIN
IF (I.GT.1) GO TO 30
IF (I.GT.1) GO TO 30
THINI=THIN
THINI=THIN
GO TO 32
GO TO 32
30  THINI=TEND(I-1)
30  THINI=TEND(I-1)
32  CONTINUE
32  CONTINUE
TINP=THINI
TINP=THINI
GO TO 65
GO TO 65
C RECIRCULATION
C RECIRCULATION
10  QHINI=DS*QHIN
QHINI=DS*QHIN
THINI=TEND(I)
THINI=TEND(I)
65  DCOEF(I)=0.3*(SQR(F/8.)*QHINI/AREA(I,III))*(WDTH(I,III)**2.)/4.
65  DCOEF(I)=0.3*(SQR(F/8.)*QHINI/AREA(I,III))*(WDTH(I,III)**2.)/4.
./DZ(I,III)/VXRMN**2
./DZ(I,III)/VXRMN**2
C MINIMUM VALUE IN CASE OF NO THROUGHFLOW
C MINIMUM VALUE IN CASE OF NO THROUGHFLOW
IF (QHINI .EQ. 0.) DCOEF(I) =100000000000.
IF (QHINI .EQ. 0.) DCOEF(I) =100000000000.
VEL(I)=QHINI/AREA(I,III)
VEL(I)=QHINI/AREA(I,III)
SIGMA=D/TAU*VEL(I)/DXX(I,III)
SIGMA=D/TAU*VEL(I)/DXX(I,III)
LAMBDAD=DTAU*DCOEF(I)/(DXX(I,III)**2*DXX(I,III))
LAMBDAD=DTAU*DCOEF(I)/(DXX(I,III)**2*DXX(I,III))
C CHECK INPUT PARAMETERS AND SET ARRAYS A, B, C
C CHECK INPUT PARAMETERS AND SET ARRAYS A, B, C
DO 2 J=2,MP1
DO 2 J=2,MP1
4&  X(J)=-(LAMBDAD+SIGMA)
4&  X(J)=-(LAMBDAD+SIGMA)
Y(J)=2.0+2.0*LAMBDAD+SIGMA
Y(J)=2.0+2.0*LAMBDAD+SIGMA
2  Z(J)=-LAMBDAD
2  Z(J)=-LAMBDAD
IF (QHINI .NE. 0.) GO TO 11
C SPECIAL BOUNDARY CONDITION FOR ZERO THROUGHFLOW (SIGMA=0)
C SPECIAL BOUNDARY CONDITION FOR ZERO THROUGHFLOW (SIGMA=0)
X(1)=0.
Y(1)=2.0+LAMBDA
Z(1)=LAMBDA
GO TO 12
11 CONTINUE
X(2)=-SIGMA
Y(2)=2.0+LAMBDA+SIGMA
12 CONTINUE
Y(MP1)=2.0+LAMBDA+SIGMA
Z(MP1)=0.0
25 CONTINUE
C COMPUTE RIGHT-HAND SIDE VECTOR D
IF (KCIRC(I).EQ.2) GO TO 27
C NO RECIRCULATION
IF (THETA(I).EQ.0.) GO TO 33
TN1=TEMP(1)* EXP(-QHINI/VFM(I)*DTAU)+THINI*(1.0-
-EXP(-QHINI/VFM(I)*DTAU))-TLOSS(1)
GO TO 34
33 TN1=THINI
GO TO 40
34 CONTINUE
C RECIRCULATION
27 CONTINUE
IF (III.EQ.2) GO TO 90
TINP1=(THINI+TEDDY(I)*DS)/(1.+DS)
82 TN1=TINP1
GO TO 40
90 TN1=TEND(I)
40 CONTINUE
MM=NSEG(I,III)
DO 5 J=2,MM
5 D(J)=(LAMBDA+SIGMA)*TEMP(J-1)+(2.0-2.0*LAMBDA-SIGMA)*TEMP(J)
LAMBDA*TEMP(J+1)-2.0*TLOSS(J)
D(MP1)=(LAMBDA+SIGMA)*TEMP(MP1-1)+(2.0-LAMBDA-SIGMA)*TEMP(MP1)
-2.0*TLOSS(MP1)
IF (QHINI .NE. 0.) GO TO 15
C SPECIAL BOUNDARY CONDITION FOR ZERO THROUGHFLOW (SIGMA=0)
D(1)=(2.0-LAMBDA)*TEMP(1)+LAMBDA*TEMP(2)-2.0*TLOSS(1)
CALL TRIDAG(1,MP1,X,Y,Z,D,TEMP)
GO TO 16
15 CONTINUE
D(2)=SIGMA*TEMP(1)+(2.0-LAMBDA-SIGMA)*TEMP(2)+LAMBDA*TEMP(3)+
SIGMA*(TN1)-2.0*TLOSS(2)
C COMPUTE NEW CONCENTRATIONS
CALL TRIDAG(2,MP1,X,Y,Z,D,TEMP)
TEMP(1)=TN1
16 CONTINUE
IF (III.EQ.2) GO TO 100
TEND(I)=TEMP(MP1)
TOUT(ICOUNT,I)=TEND(I)
RETURN
100 TEDDY(I) = TEMP(MP1)
RETURN
END
SUBROUTINE TRIDAG (IF, L, A, B, C, D, V)
DIMENSION A(1), B(1), C(1), D(1), V(1), BETA(101), GAMMA(101)
C TRIDAG SOLVES THE SYSTEM OF LINEAR SIMULTANEOUS EQUATIONS
C GENERATED BY THE IMPLICIT SCHEME
C COMPUTE INTERMEDIATE ARRAYS BETA AND GAMMA
BETA(IF) = B(IF)
GAMMA(IF) = D(IF)/BETA(IF)
IFP1 = IF + 1
DO 1 I = IFP1, L
BETA(I) = B(I) - A(I)*C(I-1)/BETA(I-1)
1 GAMMA(I) = (D(I) - A(I)*GAMMA(I-1))/BETA(I)
C COMPUTE FINAL SOLUTION VECTOR V
V(L) = GAMMA(L)
LAST = L - IF
DO 2 K = 1, LAST
I = L - K
2 V(I) = GAMMA(I) - C(I)*V(I+1)/BETA(I)
RETURN
END
SUBROUTINE SPEED(N, I)
REAL LENGTH
COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON /HFLows/ QQHIN(3000), TTHIN(3000), THIN, QHIN, QHINI, NQHIN,
, DTQHIN
COMMON /MIX/ KMIX, MIXED(3,5), RMIX(3,5), KOH
COMMON /FLOWS/ QQIN(366,3,5), TTIN(366,3,5), TIN(3), QIN(3),
, NQIN(3,5), DTQIN(3,5), NQO(3,5), DTQO(3,5), NOUT(5), NOUTI,
, LOUT(5,5), ELOUT(5,5), NIN(5), QO(366,3,5), NINI, NINI1
COMMON /GEOMB/A(100), B(100), XL(100), DD(1,5), DY, JM, JMP, YSUR, EL(100)
COMMON /GAUS/ SIGMAI, SPREAD, SIGMIN(3)
COMMON /TEMPB/ T(100,2), TLOW(100,5), NEL(5), NELMAX(5)
COMMON /VELS/ V(102,1), UI(102,5), UO(102,5), UOT(102,5)
COMMON /SURF/ SARAF, DYSUR, DYSUR, AYSUR, SAREA, SURAR
COMMON /GEOMA/ VTOTAL(5), VFM(5), VDF(5), LENGTH(5,2), DXX(5,2),
, DZ(5,2), WDTH(5,2), AREA(5,2), DHL, THETA(5), NSEG(5,2), NAR, MP1
COMMON /TEMPA/ Temp(100), THLM(100,5,2), TLOSS(100), TOUT(3000,5)
COMMON /ENFLW/ TININ(3), QININ(3), NOUT1
COMMON /ETIME/ ET, NPOND
COMMON /FLVL/ JIN(3)
COMMON /ENTRN/ DSS(5), DS
COMMON /TOTUT/ TOUTC(3000,5), HEATOT(5), FLOWOT(5)
DIMENSION EX(102), EXI(102), UIMAX(102), QQMIX(102)
DIMENSION S(102), OX(102), EXO(102), UOMAX(5)
C COMPUTATION OF VERTICAL AND SOURCE AND SINK VELOCITIES.
C ALSO, COMPUTATION OF WITHDRAWAL THICKNESS.
C SOURCE AND SINK VELOCITIES ARE ASSUMED TO HAVE GAUSSIAN DISTRIBUTION.
DELCON = .00461
DO 60 K = 1, NINI
R = ET/DTQIN(K,I)
L = R
RR = R - L
60
QIN(K) = QIN(L+1, K, I) + RR*(QIN(L+2, K, I) - QIN(L+1, K, I))
QININ(K) = QIN(K)
TIN(K) = TIN(L+1, K, I) + RR*(TIN(L+2, K, I) - TIN(L+1, K, I))
TININ(K) = TIN(K)

60 CONTINUE
DO 77 NN = 1, NOUTI
R = ET/DTQO(NN, I)
L = R
RR = R - L
77 QOUT(NN) = QO(L+1, NN, I) + RR*(QO(L+2, NN, I) - QO(L+1, NN, I))
GO TO (66, 67), KHEAT
66 NIN1 = NIN(I) + 1
TIN(NIN1) = TEMP(MP1)
TININ(NIN1) = TIN(NIN1)
QIN(NIN1) = QHINI
QININ(NIN1) = QIN(NIN1)
SIGMIN(NIN1) = DHL/SPREAD
RMIX(NIN1, I) = 0.0
MIXED(NIN1, I) = MIXED(1, I)
JIN(NIN1) = JM
GO TO 68
67 NIN1 = NIN(I)
68 CONTINUE
C MIX INFLOW WATER IF INDICATED
GO TO (85, 80), KMIX
80 DO 65 K = 1, NINI
JMIXB = JM - MIXED(K, I)
MXX = MIXED(K, I) + 1
IF (JMIXB .GT. 0) GO TO 73
JMIXB = 1
MXX = JM
73 CONTINUE
TP = 0.0
DO 83 J = JMIXB, JM
TP = TP + T(J, 1)/FLOAT(MXX)
TIN(K) = (TIN(K) + TP*RMIX(K, I))/(1.0 + RMIX(K, I))
65 CONTINUE
85 CONTINUE
C LOCATE ACTUAL LEVEL OF DAYS INPUT
DO 88 K = 1, NINI
DO 87 JJ = 1, JM
J = JM + 1 - JJ
IF (TIN(K) - T(J, 1)) 87, 90, 90
87 CONTINUE
90 JIN(K) = J + 1
IF (JIN(K) .GT. JM) JIN(K) = JM
88 CONTINUE
C COMPUTE INFLOW VELOCITY
C COMPUTE EXPONENTIAL FACTOR
DO 9 K = 1, NIN1
DO 1 J = 1, JM
S(J) = (DY*FLOAT(J-1))**2
ARGI = S(J)/2.0/SIGMIN(K)/SIGMIN(K)
IF (ARGI - 20.0) 4, 4, 5
4 \( \text{EX}(J) = \exp(-\text{ARGI}) \)
5 \( \text{GO TO 1} \)
1 \( \text{CONTINUE} \)
2 \( \text{DO 2 J=1,JM} \)
3 \( \text{II}=\text{IABS(J-JIN(K))}+1 \)
2 \( \text{EXI}(J)=\text{EX}(\text{II}) \)

C COMPUTE MAX INFLOW VEL.
3 \( \text{VOLIN} = \text{EXI}(1)*B(1)*\text{DY}/2.0+\text{EXI(JM)}*B(JM)*\text{DYSUR} \)
4 \( \text{JMM}=\text{JM}-1 \)
5 \( \text{DO 3 J=2,JMM} \)
6 \( \text{UIMAX(1)}=\text{QIN(K)}/\text{VOLIN} \)
7 \( \text{GO TO (8,7),KMINX} \)
8 \( \text{UIMAX(1)}=\text{UIMAX(1)}*(1.0+\text{RMINX(K,I)}) \)
9 \( \text{DO 6 J=1,JM} \)
10 \( \text{UI(J,K)}=-\text{UIMAX(1)}*\text{EXI(J)} \)
11 \( \text{CONTINUE} \)
12 \( \text{CONTINUE} \)

C COMPUTE OUTFLOW VELOCITIES
13 \( \text{DO 10 LT=1,NOUT} \)
14 \( \text{JOUT=LOUT(LT, I)} \)
15 \( \text{C COMPUTE WITHDRAWAL THICKNESS.} \)
16 \( \text{C NOTE THAT ONLY HALF THE WITHDRAWAL THICKNESS IS COMPUTED.} \)
17 \( \text{IF (JOUT.EQ.1) GO TO 40} \)
18 \( \text{IF (JOUT.EQ.JM) GO TO 45} \)
19 \( \text{DERIV}=(\text{T(JOUT+1,1)}-\text{T(JOUT-1,1)})/2.0/\text{DY} \)
20 \( \text{GO TO 49} \)
21 \( \text{DERIV}=(\text{T(JOUT+1,1)}-\text{T(JOUT,1)})/\text{DY} \)
22 \( \text{GO TO 49} \)
23 \( \text{DERIV}=(\text{T(JOUT,1)}-\text{T(JOUT-1,1)})/\text{DY} \)
24 \( \text{IF (DERIV-.010)} 11,11,15 \)
25 \( \text{JOUT=JOUT+2} \)
26 \( \text{C CUTOFF DUE TO SHARP CHANGE IN DENSITY GRADIENT} \)
27 \( \text{IF (JOUT-JMM)} 50,51,51 \)
28 \( \text{DO 12 J=JOUT1,JMM} \)
29 \( \text{IF(}((\text{T(J+1,1)}-\text{T(J,1)})/\text{DY}-.05)12,13,13 \)
30 \( \text{CONTINUE} \)
31 \( \text{SIGMAO=100.0*DY} \)
32 \( \text{GO TO 19} \)
33 \( \text{HAFDEL}=\text{FLOAT(J-JOUT)}*\text{DY} \)
34 \( \text{SIGMAO}=\text{HAFDEL}/\text{SPREAD} \)
35 \( \text{19 JOUT2=JOUT-2} \)
36 \( \text{IF (JOUT2)} 14,14,53 \)
37 \( \text{DO 21 JJ=1,JOUT2} \)
38 \( \text{J=JOUT2+2-JJ} \)
39 \( \text{IF(}((\text{T(J,1)}-\text{T(J-1,1)})/\text{DY}-.05)21,21,22 \)
40 \( \text{CONTINUE} \)
41 \( \text{GO TO 14} \)
42 \( \text{HAFD1}=\text{FLOAT(JOUT-J)}*\text{DY} \)
43 \( \text{SIGM1}=\text{HAFD1}/\text{SPREAD} \)
44 \( \text{IF(SIGM1.LT.SIGMAO)} \text{SIGMAO}=\text{SIGM1} \)
45 \( \text{GO TO 14} \)

C APPROXIMATING FORMULA USED DENSITY IS \( RHO=1.0-0.00000663*(T-4.0)^2 \)
15  EPSIL=2.0* ABS(T(JOUT,1)-4.0)/(151000.0-(T(JOUT,1)-4.0)**2)*DERIV
   GO TO (17,16),KOH
C CALCULATION OF WITHDRAWAL THICKNESS USING KAO FORMULA.
16  QPUW=QOUT(LT)/B(JOUT)
   HAFDEL=DELCON* SQRT(QPUW)/EPSIL**0.25
   GO TO 18
C CALCULATION OF WITHDRAWAL THICKNESS USING KOH FORMULA.
17  HAFDEL = DELCON/EPSIL**0.1666667
18  SIGMAO = HAFDEL/SPREAD
   IF(SIGMAO) 20,20,14
20  SIGMAO=1.0
14  CONTINUE
C COMPUTE EXP. FACTOR
   DO 100 J=1,JM
   S(J)=(DY*FLOAT(J-1))**2
   ARGO=S(J)/2.0/SIGMAO/SIGMAO
   IF(ARGO-20.0) 104,105,105
104  OX(J)= EXP(-ARGO)
   GO TO 100
105  OX(J)=0.0
100  CONTINUE
  DO 110 J=1,JM
  IO=IABS(J-JOUT)+1
110  EXO(J)=OX(IO)
C FIRST COMPUTE MAXIMUM VELOCITIES, THEN OTHERS.
   VOUT=EXO(1)*B(1)*DY/2.0+EXO(JM)*B(JM)*DYSUR
   JMM=JM-1
   DO 120 J=2,JMM
120  VOUT=VOUT+EXO(J)*B(J)*DY
   UOMAX(LT)=QOUT(LT)/VOUT
   DO 130 J=1,JM
130  UOT(J,LT)=UOMAX(LT)*EXO(J)
10  CONTINUE
   IF (NOUT1.EQ.NOUTI) GO TO 59
   JMIXB=JM-MIXED(NIN1,I)
   MXX=MIXED(NIN1,I)+1
   IF (JMIXB.GT.0) GO TO 75
   JMIXB= 1
   MXX=JM
75  CONTINUE
   DO55 J=JMIXB,JM
55  UOT(J,NOUT1)=QW1JT(NOUT1)/FLOAT(MXX)/B(J)/DY
   UOT(JM,NOUT1)=UOT(JM,NOUT1)*DY/DYSUR
   JMM1 =JMIXB-1
   IF (JMM1.LE.1) JMM1=1
   DO 56 J=1,JMM1
56  UOT(J,NOUT1)=-0.0
59  CONTINUE
C COMPUTE VELOCITIES CAUSED BY ENTRAINMENT
   DO 36 J=1,JM
   GO TO (31,32),KMIX
32  QQMIX(J)=0.0
   DO 34 K=1,NINI
34  JMIXB=JM-MIXED(K,I)
MXX=MIXED(K, I)+1
IF (JMIXB.GT.0) GO TO 79
JMIXB=1
MXX=JM

79 CONTINUE
IF (J-JMIXB) 34, 33, 33
33 QQQMIX=QIN(K)*RMIX(K, I)/FLOAT(MXX)
QQMIX(J)=QQMIX(J)+QQQMIX

34 CONTINUE
UO(J, 1)=QQMIX(J)/B(J)/DY
IF(J.EQ.JM) UO(JM, 1)=UO(J, 1)*DY/DYSUR
GO TO 37
31 UO(J, 1)=0.0
37 DO 35 LT=1, NOUT1
35 UO(J, 1)=UO(J, 1)+UOT(J, LT)
36 CONTINUE
C COMPUTE VERTICAL ADVECTIVE VELOCITY
V(1, 1)=0.0
UIN=0.0
DO 47 K=1, NIN1
UIN=UIN+UI(1, K)
V(2, 1)=(UIN-UO(1, 1))*B(1)*DY/(A(1)+A(2))
JMIX=JM+1
DO 500 J=3, JMX
UIN=0.0
DO 38 K=1, NIN1
UIN=UIN+UI(J-1, K)
V(J, 1)=(V(J-1, 1)*(A(J-2)+A(J-1))/2.0+(UIN-UO(J-1, 1))*B(J-1)*DY)
/(A(J)+A(J-1))*2.0
500 CONTINUE
RETURN
END

SUBROUTINE SUBLAY(N, I)
REAL LENGTH
COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON /SWITCHM/ KFIN, KATRAD
COMMON /METEOM/ DTTA, DTSIGH, DTWIND, DCLOUND, DFIN, DATRAD
COMMON /METEOA/ TA(3000), SIGH(3000), WIND(3000), CLOUD(3000)
COMMON /METEOB/ FIN(3000), ATRAD(3000)
COMMON /FLXES/ SR, EVAP, RAD, CONDUC, AR, TAIR, TAIRF, PSI, EA, W, WINDY, CC
COMMON /VELS/ V(102, 1), UI(102, 5), UO(102, 5), UOT(102, 5)
COMMON /GEOMA/ VTOTAL(5), VFM(5), VDF(5), LENGTH(5, 2), DXX(5, 2),
,DZ(5, 2), WDTH(5, 2), AREA(5, 2), DHL, THETA(5), NSEG(5, 2), NAR, MP1
COMMON /GEOMB/A(100), B(100), XL(100), DD(1, 5), DY, JM, JMP, YSUR, EL(100)
COMMON /TEMPB/ T(100, 2), TLOW(100, 5), NEL(5), WELMAX(5)
COMMON /FLOWS/ QQIN(366, 3, 5), TTIN(366, 3, 5), TIN(3), QIN(3),
,QOUT(5), NQIN(3, 5), DTQIN(3, 5), NQO(3, 5), DTQO(3, 5), NOUT(5), NOUTI,
,LOUT(5, 5), ELOUT(5, 5), NIN(5), QO(366, 3, 5), NINI, NIN1
COMMON /EXTIN/ DTAU, DT, ETA, BETA, TAUMAX, IFREQ1, IFREQ2, IFREQ3
COMMON /CONST/ HCAP, RHO, GRAV
COMMON /SURF/ SAREAP, DYSURP, DYSUR, AYSUR, SAREA, SURAR
COMMON /TEMPA/ TEMP(100), THLM(100, 5, 2), TLOSS(100), TOUT(3000, 5)
COMMON /DISP/ DCOEF(5), DBETA(5), TEND(5), FF
COMMON /DELTTS/ DELSAV, DELTSAV, DELT(10), TSAVE
COMMON /EQUIL/ TE, IDT
COMMON /ELB/ ELBSL
COMMON /ETIME/ ET, NPOND
COMMON /TOUTT/ TOUTC(3000, 5), HEATOT(5), FLOWOT(5)
TSAVE = T(JM, 1) * SAREAP * DYSURP / (SAREA * DYSUR)
DT = DTAU
DO 70 LT = 1, NOUTI
    HEATOT(LT) = 0.0
70   FLOWOT(LT) = 0.0
JMM = JM - 1
C STABILITY CHECK V*DT IS LESS THAN DY
VVV = ABS(V(2, 1))
DO 501 J = 3, JM
    IF (VVV - ABS(V(J, 1))) 502, 501, 501
502  VVV = ABS(V(J, 1))
501  CONTINUE
VM = DY / DTAU
IF (VVV - VM) 503, 504, 504
504  DT = DY / VVV
   IDT = DTAU / DT + 1
   DT = DTAU / IDT
GO TO 506
503  IDT = 1
506  CONTINUE
C WRITE IF TIME STEP HAS BEEN SUBDIVIDED
IF (IDT .GT. 1) WRITE(6, 507) IDT
507  FORMAT(//, 5X, 'TIME STEP IN SUBLAY DIVIDED BY', 2X, I3)
DYSINC = (DYSUR - DYSURP) / FLOAT(IDT)
SARINC = (SAREA - SAREAP) / FLOAT(IDT)
SAROLD = SAREAP
DYSOLD = DYSURP
DELSAV = 0
505  DO 79 M = 1, IDT
C HEAT TRANSPORT CALCULATIONS
   SARNEW = SAROLD + SARINC
   DYNEW = DYSOLD + DYSINC
   YSRNEW = EL(JMM) + DY/2. + DYNEW + DHL
C CALCULATIONS FOR BOTTOM HALF LAYER
   DELTA = (1.0 - BETA) * SR * EXP(-ETA * (YSRNEW - EL(1) - DY/2.0)) *(A(2) + A(1)) /
   /2.0 / RHO / HCAP / A(1) / (DY/2.)
   IF (V(2, 2)) 1166, 1167, 1167
1167  DELTB = -V(2, 2) * T(1, 1) * (A(1) + A(2)) / 2. * A(1) / (DY/2.)
   GO TO 1168
1166  DELTB = -V(2, 2) * T(2, 1) * (A(1) + A(2)) / 2. * A(1) / (DY/2.)
1168  DELTC = -UO(1, 1) * T(1, 1) * B(1) / A(1)
   DO 1187 K = 1, NIN1
1187  DELTC = DELTC + UI(1, K) * B(1) * DY/2. * TIN(K) / A(1) / (DY/2.)
   DELTB = DD(1, I) * ((T(2, 1) - T(1, 1)) * (A(2) + A(1)) / 2.0 / DY) / A(1) / (DY*2.0)
   T(1, 2) = T(1, 1) + DT * (DELTA + DELTB + DELTC + DELTD)
C CALCULATIONS FOR INTERMEDIATE LAYERS
DO 1115 J = 2, JMM
1115   ARJ1 = (A(J) + A(J + 1)) / 2.
1116   ARJ2 = (A(J) + A(J - 1)) / 2.
C DIRECT ABSORPTION TERM
DELTA=(1.0-BETA)*SR*( EXP(-ETA*(YSRNEW-EL(J)-DY/2.0))*ARJ1-
   1 EXP(-ETA*(YSRNEW-EL(J)+DY/2.0))*ARJ2)/A(J)/DY/HCAP/RHO

C VERTICAL ADVECTION TERM
IF(V(J,1)) 1160,1160,1161
1160 IF(V(J+1,1))1170,1170,1171
1170 DELTB=(V(J,1)*T(J,1)*(A(J)+A(J-1))/2.0-V(J+1,1)*T(J+1,1)*(A(J+1)+
   1A(J))/2.0)/A(J)/DY
   GO TO 1162
1171 DELTB=(V(J,1)*T(J,1)*(A(J)+A(J-1))/2.0-V(J+1,1)*T(J+1,1)*(A(J+1)+
   1A(J))/2.0)/A(J)/DY
   GO TO 1162
1172 DELTB=(V(J,1)*T(J,1)*(A(J)+A(J-1))/2.0-V(J+1,1)*T(J+1,1)*(A(J+1)/
   1+A(J))/2.0)/A(J)/DY

C HORIZONTAL ADVECTION TERM
1162 DELTC=-UO(J,1)*T(J,1)*B(J)*DY/A(J)/DY
   DO 1188 K=1,NIN1
1188 DELTC=DELTC+UI(J,K)*TIN(K)*B(J)*DY/A(J)/DY

C DIFFUSION TERM
DELTD=DD(1,I)*((T(J+1,1)-T(J,1))/DY*ARJ1-(T(J,1)-T(J-1,1))/DY*ARJ2
   1)/A(J)/DY
   DELT=(DELTA+DELTB+DELTC+DELTD)*DT
1114 T(J,2)=T(J,1)+DELT
1115 CONTINUE

C CALCULATIONS FOR THE TOP LAYER IN THE VERTICALLY STRATIFIED REGION
   GO TO (2100,2200),KHEAT

C NATURAL RESERVOIR

C DIRECT ABSORPTION TERM
2200 DELTA=(1.0-BETA)*SR*(AYSUR- EXP(-ETA*DYNEW)*(A(JM)+A(JM-1))/2.0)/
   $SARNEW/DYNEW/HCAP/RHO

C SURFACE FLUXES
   DELTS=(BETA*SR-EVAP-CONDUC-RAD+AR
   )*AYSUR/RHO/HCAP/DYNEW/SARNEW
   GO TO 2101

C HEATED POND
2100 CONTINUE
   DELTS=0.0
   DELTA:(1.0-BETA)*SR*( EXP(-ETA*DHL)*A(JM)- EXP(-ETA*(DHL+DYNEW)))*
   .(A(JM)+A(JM-1))/2.0)/A(JM)/DYNEW/HCAP/RHO
   2101 CONTINUE

C ADVECTION TERMS
   IF (V(JM,1))1163,1164,1164
1164 DELTB=(V(JM,1)*T(JM-1,1)*(A(JM)+A(JM-1))/2.0/SARNEW/DYNEW
   DELTC=-UO(JM,1)*T(JM,1)*B(JM)*DYSUR/SARNEW/DYNEW
   DO 1189 K=1,NIN1
1189 DELTC=DELTC+UI(JM,K)*TIN(K)*B(JM)*DYSUR/(DYNEW*SARNEW)
   GO TO 1165
1163 DELTB=(V(JM,1)*T(JM,1)*(A(JM)+A(JM-1))/2.0/SARNEW/DYNEW
   DELTC=-UO(JM,1)*T(JM,1)*(A(JM)+A(JM-1))/2.0/SARNEW/DYNEW
   DO 1190 K=1,NIN1
1190 DELTC=DELTC+UI(JM,K)*TIN(K)*B(JM)*DYSUR/(DYNEW*SARNEW)

C DIFFUSION TERM
DELTD = DD(1,I)*(T(JM,1)-T(JM-1,1))/DY*(A(JM)+A(JM-1))/2.0/SARNEW/
/DYNEW
TSAVI = T(JM,1)*SARCLD*DYSCLD/(SARNEW*DYNEW)
T(JM,2) = TSAVI + DT*(DELTA + DELTB + DELTC + DELTD + DELTS)
DELSAV = DELSAV + (DELTA + DELTB + DELTC + DELTD) * DT
SAROLD = SARNEW
DYSOLD = DYNEW
DO 75 LT = 1,NOUTI
75 CALL TOUTQ(N,LT)
DO 1118 J = 1,JM
1118 T(J,1) = T(J,2)
IF (KHEAT.EQ.2) CALL SUMFLX(I)
IF (IDT.GE.50) GO TO 80
79 CONTINUE
IDT = 1
DO 85 LT = 1,NOUTI
85 TOUTC(N,LT) = HEATOT(LT)/FLOWOT(LT)
IF (KHEAT.EQ.2) GO TO 87
IF (NEL(I).EQ.JM) GO TO 87
NM = NEL(I)
DO 88 J = JM, NM
88 T(J,1) = T(JM,1)
JM = NEL(I)
87 CONTINUE
ET = TAUMAX
RETURN
80 ET = TAUMAX
RETURN
END
SUBROUTINE HTMIX(N,I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
, DZ(5,2), WDTH(5,2), AREA(5,2), DHL, THETA(5), NSSEG(5,2), NAR, MP1
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DXY(1,5),DD(1,5),JMO,JSUR,EL(100)
COMMON /EXTIN/ DTAU,DT,TETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
COMMON /SURF/ SAREP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
COMMON /METWD/ WHGT,TAU
COMMON /DELTTS/ DELSAV,DELT,DELT(10),TSAVE
DIMENSION FLX(10)
FLX(1) = EVAP + CONDUC + RAD - AR - BETA*SR
DELT(1) = FLX(1)*AYSUR/RHO/HCAP/DYSUR/SAREA
JM = JM - 1
MM = 1
CALL WDMIX(N,I)
DO 2000 MM = 2,10
CALL HEAT(N,I,III)
FLX(MM) = EVAP + CONDUC + RAD - AR - BETA*SR
DELT(1) = FLX(1)*AYSUR/RHO/HCAP/DYSUR/SAREA
DELT(1) = (DELT(1) + DELT(MM))/2.
T(JM,1) = TSAVE + DELSAV + DELTS*DTAU
DO 2001 J=1,JMM
   T(J,1)=T(J,2)
   CALL WDMIX(N,I)
   IF (ABS(DELT(MM)-DELT(MM-1)).LE.0.004) GO TO 2002
2000 CONTINUE
2002 CONTINUE
   IF (NEL(I).EQ.JM) GO TO 87
   NM=NEL(I)
   DO 88 J=JM,NM
      T(J,1)=T(JM,1)
      JM=NEL(I)
88 CONTINUE
   RETURN
END

SUBROUTINE WDMIX(N,I)
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMF,YSUR,EL(100)
COMMON /SURF/ SARSEP,DYSURP,DYSUR,AYSUR,SAREA,SGRAR
COMMON /CONST/ RHO,HCAV,GRAV
COMMON /METWD/ WHGT,TAU
COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
DIMENSION D(100)
GRAV=73150000000.
DO 100 J=1,JM
   D(J)=1000.-0.00663*(T(J,1)-4.)*(T(J,1)-4.)
   PAIR=1.18
   VKARMN=0.41
   W=WINDY
   KT=0
   C WHGT HAS BEEN SET EQUAL TO 2.0 METERS IN THE NEXT
   C STATEMENT. WIND SPEED WAS ADJUSTED TO 2.0M IN SUB MET.
   RHS=(ALOG(GRAV**2.0/86400./86400./0.011/W/W))/VKARMN
   IF (W.LE.1.) GO TO 170
   IF (W.LT.3.) GO TO 125
   IF (W.GT.12.) GO TO 130
   C1=0.0016
   GO TO 140
125 C1=0.00125
   GO TO 140
130 C1=0.0026
140 OS=1./(C1**.5)+ALOG(C1)/VKARMN
   IF (ABS(OS-RHS).LE.0.5) GO TO 180
   C1=1.+(OS-RHS)/20000.
   KT=KT+1
   IF (KT.GT.10) GO TO 180
   GO TO 140
170 C1=0.0005
180 CO=C1
   TAU=CO*W**W*PAIR
   VSTR=(TAU/1000.)**.5
   C ENTRAINMENT VELOCITY APPROACH
   TMIX=T(JM,1)
RHOMIX = D(JM)
VMIX = DYSUR * A(JM)

PE = 0.0

ENGY = TAU * VSTR * DT * 86400.

JMM = JM - 1
DO 200 K1 = 1, JMM
J = JM - K1

H2 = DYSUR / 2. + (K1 - 1) * DY / 2.
PE1 = (D(J) - RHOMIX) * DY * 9.8 * H2

IF (VSTR) 210, 210, 220

220 RICH = ((D(J) - RHOMIX) * 9.8 * H2 * 2.) / (1000. * VSTR * VSTR)
IF (RICH .LT. 0.) RICH = 0.
IF (RICH .GT. 860.) GO TO 210
CWIND = 0.057 * RICH * (29.46 - SQRT(RICH)) / (14.2 + RICH)
GO TO 230

210 CWIND = 0.
C FOR K. HURLEY'S VERSION OF WDMIX CWIND = 1.0

230 IF (PE1 .LE. CWIND * ENGY) 250, 250, 300
C MIX ENTIRE LAYER WITH MIXED LAYER

250 TMIX = (TMIX * VMIX + T(J, 1) * A(J) * DY) / (VMIX + A(J) * DY)
VMIX = VMIX + A(J) * DY
RHOMIX = 1000. - 0.00663 * (TMIX - 4) * (TMIX - 4.)

K2 = K1 + 1
DO 260 JJ = 1, K2
IJ = JM + 1 - JJ
T(IJ, 1) = TMIX

260 D(IJ) = RHOMIX

IF (PE1 .LE. 0.0) GO TO 200
ENGY = ENGY - PE1 / CWIND

200 CONTINUE
GO TO 350

C MIX FRACTION OF A LAYER

300 X = ENGY * CWIND
DELTAY = X / ((D(J) - RHOMIX) * 9.8 * H2)
DELY = DELTAY / DY
TMIX = (TMIX * VMIX + T(J, 1) * A(J) * DELTAY) / (VMIX + A(J) * DELTAY)
T(J, 1) = T(J, 1) * (1. - DELY) + TMIX * DELY
DO 330 JJ = 1, K1
IJ = JM + 1 - JJ

330 T(IJ, 1) = TMIX

350 CONTINUE
RETURN
END
COMMON /HFLOWS/ QHHIN(3000), TTHIN(3000), TIN, QHIN, QHINI, NQHIN, DTQHIN
COMMON /EXTIN/ DTAU, DT, ETA, BETA, TAUMAX, IFREQ1, IFREQ2, IFREQA
COMMON /SURF/ SAREAP, DYSURP, DYSUR, AYSUR, SAREA, SURAR
COMMON /TEMPB/ T(100,2), TLOW(100,5), NEL(5), NELMAX(5)

C COMPUTATIONS WHEN SURFACE ELEVATION VARIES WITH TIME.
DT=DTAU
DO 60 K=1,NINI
R=ET/DTQIN(K,I)
R=R-0.99
L=R
RR=R-L
QIN(K)=QQIN(L+1,K,I)+RR*(QQIN(L+2,K,I)-QQIN(L+1,K,I))
60 CONTINUE
GO TO (65, 62), KHEAT
65 NIN1=NIN(I)+1
R=ET/DTQHIN
R=R-0.99
L=R
RR=R-L
QHIN=QHHIN(L+1)+RR*(QHHIN(L+2)-QHHIN(L+1))
QIN(NIN1)=QHIN
GO TO 63
62 NIN1=NIN(I)
63 CONTINUE
31 JJM=JM
DO 20 K=1,NIN1
20 CUMQIN=CUMQIN+QIN(K)*DT
DO 332 NN=1,NOUTI
R=ET/DTQO(NN,I)
R=R-0.99
L=R
RR=R-L
QOUT(NN)=QO(L+1,NN,I)+RR*(QO(L+2,NN,I)-QO(L+1,NN,I))
332 CUMQOT=CUMQOT+QOUT(NN)*DT
QIO=CUMQIN-CUMQOT
IF (ABS(QIO).LE. 1.0E-08) QIO=0.0
IF(QIO) 34,34,35
C NET ADDITION OF MASS
35 SUM=SAREA(I)*DYSUR1(I)
DO 36 M=1,JM
SUM=SUM+A(JM1+M-1)*DY
IF(QIO-SUM) 37,37,36
36 CONTINUE
C NET LOSS OF MASS
34 SUM=DYSUR1(I)*SAREA1(I)
DO 38 M=1,JM
IF(ABS(QIO)-SUM) 39,39,38
38 SUM=SUM+A(JM1-M)*DY
37 YSUR=EL(JM1)+(M-0.5)*DY+(QIO-SUM)/A(JM1+M-1)
GO TO 40

39 CONTINUE
YSUR = EL(JM1) - (M - 0.5) * DY + (QIO + SUM) / A(JM1 - M + 1)

40 DYS = YSUR - EL(JM1) + DY / 2.0
IF (DYS) 41, 42, 42

42 M = IFIX(DYS / DY)
GO TO 43

41 M = IFIX(DYS / DY) - 1

43 JMTP = JM1 + M
JMNEW = JMTP - IFIX(DHL / DY)
ELBSL = YSUR - DHL
DYSUR = ELBSL - EL(JMNEW) + DY / 2.0
IF (DYSUR - 0.25 * DY) 506, 506, 507

506 DYSUR = DYSUR + DY
JMNEW = JMNEW - 1

507 YSURI(I) = YSUR
C CALCULATE SURFACE AREA
IF (ELBSL - EL(JMNEW)) 58, 58, 59

58 AYSUR = A(JMNEW) - (DY / 2.0 - DYSUR) * (A(JMNEW) - A(JMNEW - 1)) / DY
GO TO 61

59 AYSUR = A(JMNEW) + (DYSUR - DY / 2.0) * (A(JMNEW + 1) - A(JMNEW)) / DY

61 SAREA = (AYSUR + (A(JMNEW) + A(JMNEW - 1)) / 2.0) / 2.0
SAREAI(I) = SAREA
AYSURI(I) = AYSUR
DYSURI(I) = DYSUR
IF (JMNEW - NEL(I)) 690, 699, 695
C AN ELEMENT IS LOST IN THE TIME STEP

690 IJL = NEL(I) - JMNEW
VOLM = DYSURP * SAREAP
TVOLM = T(JM, 1) * VOLM
DO 682 KL = 1, IJL
TVOLM = TVOLM + T(JM - KL, 1) * A(JM - KL) * DY

682 T(JMNEW, 1) = TVOLM / VOLM
DYSURP = DYSURP + DY * FLOAT(IJL)
SAREAP = VOLM / DYSURP
JM = JMNEW
GO TO 699
C AN ELEMENT IS GAINED IN THE TIME STEP

695 IJL = JMNEW - NEL(I)
VOLM = SAREA * DYSUR
DO 696 KL = 1, IJL

696 VOLM = VOLM + A(JMNEW - KL) * DY
DYSUR = DYSUR + DY * FLOAT(IJL)
SAREA = VOLM / DYSUR
C THE NUMBER OF ELEMENTS REMAINS THE SAME

699 NEL(I) = JMNEW
RETURN
END

SUBROUTINE AVER(N,I)
C PERFORMS CONVECTIVE MIXING OF SURFACE LAYERS.
REAL LENGTH
COMMON /SURF/ SAREAP, DYSURP, DYSUR, AYSUR, SAREA, SURAR
COMMON /TEMPA/ TEMP(100), THLM(100, 5, 2), TLOSS(100), TOUT(3000, 5)
COMMON /TEMPB/T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /GEOMA/VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
 AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
COMMON /CONMIX/DMIX,MIXH
COMMON /ELB/ELBSL
INTEGER COLD
III=1
Dahl=DXX(I,III)*WDTH(I,III)

NH=NSEG(I,III)
DMIX=DDY
C LOOP COUNTS NO. OF ITERATIONS, ITT=MAX. NO. OF ITERATIONS
LOOP=0
ITT=50
100 AV1=0.
AV2=0.0
K3=NH
LOOP=LOOP+1
IF(LOOP.GE.ITT)GO TO 89
KX2=DHL/DY+1
KX=JM-KX2
TAVX=0.
DO 1 J=1,NAR
IF(TEMP(J).LT.4.44) COLD=2
1 TAVX=TAVX+TEMP(J)
TAVX=TAVX/FLOAT(NAR)
AVX=AYSUR*DHL/DY
AVY=AVX*TAVX
DO 101 J1,JM
101 IF(T(J,1).LT.4.44) COLD=2
C THIS SECTION DETERMINS IF THE HEATED SURFACE SHOULD MIX
C WITH THE LOWER LAYERS
IF(TEMP(NAR).GE.T(JM,1))GO TO 999
AREA1=DAHL*DHL/DY/2.
TAREA1=AREA1*TEMP(NAR)
K33=NH
NAR1=NAR-1
DO 888 K11=1,NAR1
K22=NAR-K11
IF(TEMP(K22)-T(JM,1)) 887,800,800
887 AREA1=AREA1+DAHL*DHL/DY
TAREA1=TAREA1+DAHL/DY*DHL*TEMP(K22)
K33=K22
888 CONTINUE
800 AREA1=AREA1+A(JM)
TAREA1=TAREA1+A(JM)*T(JM,1)
TAV1=TAREA1/AREA1
DO 810 N1=K33,NAR
810 TEMP(N1)=TAV1
T(JM,1)=TAV1
999 CONTINUE
K4=1
JMM=JM-1
DO 5 IJ=1,JMM
5 CONTINUE
J=JM-IJ+1  
JJ=J-1  
GO TO (13,12),COLD  
12 CALL COLDCCK(T(J,1),T(JJ,1),IFLG,LOOP)  
GO TO (7,6),IFLG  
13 IF (T(J,1)-T(JJ,1)+0.001) 6,7,7  
6 CONTINUE  
IF(J-2) 8,8,9  
8 T(2,1)=T(2,1)*A(2)+T(1,1)*A(1)/2.0)/(A(2)+A(1)/2.0)  
T(1,1)=T(2,1)  
GO TO 7  
9 ELY=EL(J)  
DO 10 K=1,JJ  
KJ=J+1-K  
KJJ=KJ-1  
ELX=EL(KJ)  
IF(ELBSL-ELX) 2,2,3  
2 AREA=DAHL*DHL/DY/2.  
TAREA=AREA*TEMP(NAR)  
NAR1=NAR-1  
DO 37 K=1,NAR1  
K2=NAR-K1  
TAR=TEMP(K2)  
GO TO (15,14),COLD  
14 CALL COLDCCK(TAR,T(JJ,1),IFLG,LOOP)  
GO TO (4,35),IFLG  
15 IF(TAR-T(JJ,1))35,4,4  
3 AREAA=AREAA+DAHL*DHL/DY  
TAREA=TAREA+DAHL*DHL /DY*TAR  
37 K3=K2  
GO TO 4  
3 AREAA=A(KJ)  
TAREA=T(KJ,1)*A(KJ)  
4 AV1=AV1+TAREA  
AV2=AV2+AREAA  
TAV=AV1/AV2  
GO TO (17,16),COLD  
16 CALL COLDCCK(TAV,T(KJJ,1),IFLG,LOOP)  
GO TO (20,10),IFLG  
17 IF(TAV-T(KJJ,1)) 10,20,20  
10 CONTINUE  
20 DO 30 L=KJ,J  
30 T(L,1)=TAV  
IF(ELY.GT.ELBSL) GO TO 50  
GO TO 55  
50 DMIX=YSUR-EL(KJ)+DY/2.  
KK=KJ  
TAVX=TAV  
AVX=AV2  
AVY=AV1  
K4=K3  
DO 60 L=J,JM  
60 T(L,1)=TAV  
DO 70 L=K3,NAR
70 TEMP(L)=TAV
55 CONTINUE
7 AV1=0.0
AV2=0.0
5 CONTINUE
DO 90 IJ=1,JMM
J=JM-IJ+1
JJ=J-1
GO TO (19,18),COLD
18 CALL COLDCK(T(J,1),T(JJ,1),IFLG,LOOP)
GO TO (90,100),IFLG
19 IF (T(J,1)-T(JJ,1)+0.001) 100,90,90
90 CONTINUE
GO TO 91
89 WRITE(6,2000)ITT,I
2000 FORMAT(' *** AVER *** ',I5,' ITERATIONS COMPLETED-',
',JUMPING OUT ON STEP ',I5)
91 CONTINUE
RETURN
END
SUBROUTINE COLDCK(T1 ,T2,IFLG, LOOP)
C SUBROUTINE CHECKS FOR INSTABILITIES DUE TO DENSITY DIFFERENCES
C THIS SUBROUTINE IS ONLY CALLED WHEN A LAYER TEMP IS BELOW 40.0F
IF (LOOP.GE.25) GO TO 15
IF((T2.LT.4.0).AND.(T1.GT.T2)) GO TO 10
IF((T2.GE.-18.0).AND.(T1.LT.T2)) GO TO 20
C LAYER IS STABLE
5 IFLG=1
RETURN
10 IF(T1-4.0) 30,30,15
15 D1=1000.0-0.00663*(T1-4.0)*(T1-4.0)
D2=1000.0-0.00663*(T2-4.0)*(T2-4.0)
IF(D1-D2) 5,5,30
20 IF(T1-4.0) 25,25,30
25 IF(T2-4.0) 30,30,15
C LAYER IS UNSTABLE
30 IFLG=2
RETURN
END
SUBROUTINE TOUTQ(N,LT)
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
COMMON /VELS/ V(102,1),UI(102,5),UO(102,5),UOT(102,5)
COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
C COMPUTE OUTLET TEMPERATURE
HEATOT(LT)=HEATOT(LT)+T(JM,1)*B(JM)*UOT(JM,LT)*DYSUR
HEATOT(LT)=HEATOT(LT)+T(1,1)*B(1)*UOT(1,LT)*DY/2.
FLOWOT(LT)=FLOWOT(LT)+B(JM)*UOT(JM,LT)*DYSUR+B(1)*UOT(1,LT)*DY/2.
JMM=JM-1
DO 210 J=2,JMM
HEATOT(LT)=HEATOT(LT)+UOT(J,LT)*B(J)*DY*T(J,1)
210 FLOWOT(LT)=FLOWOT(LT)+UOT(J,LT)*B(J)*DY
RETURN
END

SUBROUTINE PRINT(ICOUNT,I)
C THIS SUBROUTINE DECIDES WHEN TO PRINT OUTPUT DATA
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /HFLWS/ QHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
,DTQHIN
COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2'),DXX(5,2),
,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSBQ(5,2),NAR,MP1
COMMON /EQUIL/ TE,IDT
COMMON /ETIME/ ET,NPOND
COMMON /TENVY/ TENRAT(5)
COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
COMMON /PRNTK/ KT1,KT2,KTA
COMMON /FLEXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,C
COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),FF
COMMON /CONMIX/ DMIX,MIXH
COMMON /FLOWS/ QQIN(366,3,5),TTIN(366,3,5),TIN(3),QIN(3),
,QOUT(5),NQIN(3,5),DTQIN(3,5),NQO(3,5),DTQO(3,5),NOUT(5),NOUTI,
,LOUT(5),ELOUT(5,5),NIN(5),QIN(366,3,5),NINI,NIN1
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
COMMON /FLVL/ JIN(3)
COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
COMMON /SURFLR/ KSUR
COMMON /NDY/ NDAYS(13)
COMMON /ISTART/ ATIME1,MMO,MDY,MYR,NDD
COMMON /IPR/ KMODE,IPRINT(20),IFREQT
COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQA,IFREQ1,IFREQ2
DO 10 II=1,NDD
   IF(ICOUNT.EQ.IPRINT(II)) GO TO 200
10 CONTINUE
100 IF(I.GT.1) GO TO 150
   IF((ICOUNT*IFREQT).NE.IFREQT) RETURN
   ATIME=ATIME1+ET
   CALL TIMDAX(ATIME,IDAY,MONTH,IYEAR)
   WRITE(6,999)ET,ICOUNT,MONTH,IDAY,IYEAR
999 FORMAT(///'/3X,**ELAPSED TIME=',F9.3,8X,'NO. TIME ',
,'STEP=',I4,8X,'DATE ',I2,12,'/',I2,12,'/',I4)
   IF((ICOUNT*IFREQA).NE.IFREQA) GO TO 150
   CALL PRINTA(ICOUNT)
150 GO TO (160,160,180),KMODE
160 IF((ICOUNT*IFREQ1).NE.IFREQ1) GO TO 170
   CALL PRINT1(ICOUNT,I)
170 IF(KMODE.EQ.1) RETURN
180 IF((ICOUNT*IFREQ2).NE.IFREQ2) RETURN
   CALL PRINT2(ICOUNT,I)
   RETURN
200 IF(I.GT.1) GO TO 250
   ATIME=ATIME1+ET
   CALL TIMDAX(ATIME,IDAY,MONTH,IYEAR)
   WRITE(6,999)ET,ICOUNT,MONTH,IDAY,IYEAR
RETURN
CALL PRINTA(ICOUNT)
250 GO TO (260,260,280),KMODE
260 CALL PRINT1(ICOUNT,I)
   IF(KMODE.EQ.1) RETURN
280 CALL PRINT2(ICOUNT,I)
   RETURN
END

SUBROUTINE PRHDG(I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTART(5),KOPERA,KCIRC(5)
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
                     DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
COMMON /ENTRN/ DSS(5),DS
COMMON /ETIME/ ET,NPOND
   KK=KCIRC(I)
WRITE (6,800) I
800 FORMAT (1H1 ,///5X, 'VERTICALLY MIXED REGION GEOMETRY' ,12X, 'POND',
                     ,/4)
   WRITE (6,810) VTOTAL(I)
810 FORMAT (10X,'TOTAL VOLUME' ,6X,5(11X,F12.0))
   WRITE (6,820) THETA(I)
820 FORMAT (10X,'HORIZONTALLY MIXED FRACTION' ,5(11X,F5.2))
   WRITE (6,825) VDF(I)
825 FORMAT (10X,'VOLUME DFR',8X,5(11X,F12.0))
   IF(KCIRC(I).EQ.2) WRITE(6,802)
802 FORMAT (//45X,'JET SIDE',11X,'RETURN SIDE')
   IF(KCIRC(I).EQ.1) WRITE (6,830) VFM(I)
   IF (KCIRC(I).EQ.2) WRITE (6,831) VFM(I)
830 FORMAT (10X,'VOLUME FM' ,9X,5(11X,F12.0))
831 FORMAT (10X,'VOLUME FM',32X,5(11X,F12.0))
   WRITE (6,835) (AREA(I,III),III=1,KK)
835 FORMAT (10X,'CROSS SECTIONAL AREA' ,5(11X,F12.2))
   WRITE(6,836) (DZ(I,III),III=1,KK)
836 FORMAT (10X,'DEPTH' ,15X,5(11X,F12.2))
   WRITE (6,837) (WDTH(I,III),III=1,KK)
837 FORMAT (10X,'WIDTH' ,15X,5(11X,F12.2))
   WRITE (6,838) (LENGTH(I,III),III=1,KK)
838 FORMAT (10X,'LENGTH' ,14X,5(11X,F12.2))
   WRITE (6,840) (NSEG(I,III),III=1,KK)
840 FORMAT (10X,'ELEMENTS IN DFR',5X,5(19X,I4))
   WRITE (6,845) (DXX(I,III),III=1,KK)
845 FORMAT (10X,'DISTANCE INCREMENT',2X,5(11X,F12.2))
   WRITE (6,850) DSS(I)
850 FORMAT (10X,'ENTRAINMENT',9X,5(17X,F6.2))
RETURN
END

SUBROUTINE PRINT1(ICOUNT,I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTART(5),KOPERA,KCIRC(5)
COMMON /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
                     DTQHIN
COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
                     DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1

186
COMMON /EQUIL/ TE,IDT
COMMON /ETIME/ ET,NPOND
COMMON /TENG/ TENRAT(5)
COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
COMMON /PRNTKT/ KT1,KT2,KTA
DIMENSION THLF(101,5)
DIMENSION DTVDF(5),DTVTTL(5)

C DEFINITION OF VARIABLES LISTED IN ALPHABETICAL ORDER
C DTVDF = THEORETICAL DETENTION TIME IN THE DIFFUSIVE "LOW REGION" - DA
C DTVTTL = THEORETICAL DETENTION TIME IN THE ENTIRE POND - DAYS
C ET = ELAPSED TIME IN DAYS
C FTE = EQUILIBRIUM TEMPERATURE IN F
C FTHIN = TEMPERATURE OF HEATED WATER ENTERING THE POND IN F
C NSEG = NUMBER OF SEGMENTS IN DISPERasive FLOW REGION
C MP1 = NSG+1 = NUMBER OF SEGMENTS IN THE POND
C QHIN = FLOW RATE OF HEATED WATER IN M3/DAY
C QHINB = FLOW RATE OF HEATED WATER ENTERING THE POND IN FT3/DAY
C TEMP = TEMPERATURE IN ELEMENT IN C
C THIN = TEMPERATURE OF HEATED WATER ENTERING POND IN C
C VDF = VOLUME OF DISPERSED FLOW REGION IN M3
C VEL = VELOCITY OF WATER THROUGH POND IN M/DAY
C VEL1 = VELOCITY OF WATER THROUGH POND IN F/DAY
C VFM = VOLUME OF FULLY MIXED REGION IN M3
C VTOTAL = TOTAL VOLUME OF POND IN M3

WRITE (6,123)
123 FORMAT (///5X,'VERTICALLY MIXED REGION')
GO TO (10,20), KUNITS

10 CONTINUE
IF (I.GT.1) GO TO 15
IF (NPOND.GT.1) WRITE (6,200)

200 FORMAT (1H1)
WRITE (6,260) THIN,QHIN

15 CONTINUE
WRITE (6,205) I,TENRAT(I)
DTVDF(I)=VDF(I)/QHIN
DTVTTL(I)=VTOTAL(I)/QHIN
KK=KCIRC(I)
DO 30 III=1,KK
NM=NSEG(I,III)+1
WRITE(6,240) (THLM(J,I,III),J=1,NM)
30 CONTINUE

260 FORMAT (/10X,'INFLOW TEMPERATURE',3X,F6.2,10X,'FLOW RATE',F16.1)
240 FORMAT(10(/,15X,10(F6.2,5X)))
205 FORMAT(15X,'FOR POND ',I2,3X,'ENERGY RATIO= ',F7.4,/15X,
,'TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:')
RETURN

20 CONTINUE
IF (I.GT.1) GO TO 25
FTE=TE*9./5.+32
QHINB=QHIN/0.02832
FTHIN=THIN*9./5.+32.
WRITE (6,260) FTHIN,QHINB

25 CONTINUE
WRITE (6,205) I,TENRAT(I)
IF (QHIN .NE. 0.) GO TO 26
DTV TTL(I)=999.
DTV DF(I)=999.
GO TO 27

26 CONTINUE
DTV TTL(I)=VTOTAL(I)/QHIN
DTV DF(I)=VDF(I)/QHIN

27 CONTINUE
KK=KCIRC(I)
DO 40 III=1,KK
NM=NSEG(I,III)+1
DO 65 J=1,NM

65 TLMF(J,I)=TLM(J,I,III)*9./5.+32.
WRITE (6,240) (TLMF(J,I),J=1,NM)

40 CONTINUE
RETURN
END

SUBROUTINE PRINTA(ICOUNT)
COMMON /SWITCH/ KUNITS,KSTRAT,KHEAT,KSTRAT(5),KOPERA,KCIRC(5)
COMMON /TEMPA/ TEMP(100),TLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
,DTQHIN
COMMON /FLXES/ SR,EVAP,RAD,CONDC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),FF
COMMON /EQUIL/ TE,IDT
COMMON /ETIME/ ET,NPOND
COMMON /PRNTKT/ KT1,KT2,KTA
COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
DIMENSION TOUTF(3000,5)
DIMENSION EEE(5)

FLXOT=EVAP+CONDC+RAD
WRITE (6,949)
949 FORMAT (///5X,'METEORCLOGICAL DATA')
GO TO (50,60),KUNITS

50 WRITE (6,950) TE
WRITE (6,960) SR,AR,TAIR
WRITE (6,965) PSI,W,CC
WRITE (6,961) FLXOT
WRITE (6,952)
952 FORMAT (/10X,'POND CUMULATIVE EVAP MASS LOSS')
DO 66 LI=1,NPOND

66 WRITE(6,951)LI,EEMASS(LI)
951 FORMAT (11X,I2,12X,F15.1)
GO TO 70

DO 65 I=1,NPOND
TOUTF(ICOUNT,I)=TOUT(ICOUNT,I)*9./5.+32.
FTE=TE*9./5.+32.
THINF=THIN*9./5.+32.
SRF=SR/2.712
ARF=AR/2.712
WF=W/.447
FLXOTF=FLXOT/2.712
WRITE (6,950) FTE
WRITE (6,960) SRF,ARF,TAIRF

188
WRITE (6,965) PSI,WF,CC
WRITE (6,961) FLXOTF
WRITE (6,952)
DO 71 LI=1,NPOND
EEE(LI)=EEMASS(LI)*35.314
71 WRITE (6,951) LI,EEE(LI)
70 CONTINUE
950 FORMAT(/10X,'EQUILIBRIUM TEMPERATURE' ,5X,F6.1)
960 FORMAT (10X,'SOLAR RADIATION' ,10X,F7.0,8X,'ATMOS.' ,ADIATION',
,10X,F7.0,8X,'AIR TEMPERATURE' ,10X,F6.2)
961 FORMAT(10X,'HEAT LOSS=' ,5X,F7.0)
965 FORMAT (10X,'REL HUMIDITY',12X,F6.2,6X,'WIND SPEED',12X,
,F6.2,6X,'CLOUD COVER',11X,F6.2)
RETURN
END
SUBROUTINE PRINT2(ICOUNT,I)
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
,DTQHIN
COMMON /CONMIX/ DMIX,MIXH
COMMON /FLOWS/ QQIN(366,3,5),TTIN(366,3,5),TIN(3),QIN(3),
,QOUT(5),QNIN(3,5),DTQIN(3,5),NQO(3,5),DTQO(3,5),NOUT(5),NOUTI,
,LOUT(5,5),ELOUT(5,5),NIN(5),QO(366,3,5),NINI,NIN1
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
,DZ(5,2),WIDTH(5,2),AREA(5,2),DHL,THETA(5),NSEC(5,2),NAR,MP1
COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JP,JP1,YSUR,EL(100)
COMMON /ETIME/ ET,NPOND
COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
COMMON /FLVL/ JIN(3)
COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
COMMON /TENGY/ TENRAT(5)
COMMON /PRNTKT/ KT1,KT2,KTA
COMMON /SURFLR/ KSUR
DIMENSION TINF(3),QINB(3)
DIMENSION TININF(3),ELF(100),QOUTB(100),TOUTF(3)
IF (KT2.EQ.1) GO TO 5
WRITE (6,832)
KT2=0
5 CONTINUE
TOP=YSUR+DHL
WRITE (6,829)
829 FORMAT (///5X,'VERTICALLY STRATIFIED REGION')
WRITE (6,830)TENRAT(I)
830 FORMAT(/10X,'ENERGY RATIO= ',F7.4)
GO TO (10,20), KUNITS
10 CONTINUE
IF(KSUR.EQ.2) WRITE (6,801) TOP
801 FORMAT(///10X,'COMPUTED SURFACE ELEVATION ',F7.2)
WRITE (6,802)
802 FORMAT(///10X,'INFLOW LEVEL INFLOW TEMP ',
,'INFLOW RATE MIXED TEMP')
DO 280 K=1,NIN1
WRITE(6,803) K, JIN(K), TININ(K), QIN(K), TIN(K)
WRITE(6,804)
804 FORMAT(/10X, 'OUTFLOW LEVEL OUTFLOW TEMP OUTFLOW RATE')
DO 281 NN = 1, NOUTI
281 WRITE(6,803) NN, LOUT(NN, I), TOUTC(ICOUNT, NN), QOUT(NN)
WRITE(6,810)
NP = JM
IF (NP .GT. 10) NP = 10
DO 140 II = 1, NP
140 WRITE(6,820) (J, EL(J), TLOW(J, I), J = II, JM, 10)
IF (KHEAT .EQ. 2) KT2 = KT2 + 1
RETURN
C CONVERT UNITS IF NECESSARY
20 CONTINUE
TOPF = TOP / 0.3048
IF (KSUR .EQ. 2) WRITE(6, 801) TOPF
DO 210 J = 1, JM
TLOWF(J, I) = TLOW(J, I) * 9. / 5. + 32.
210 ELF(J) = EL(J) / 0.3048
DO 220 K = 1, NIN1
QINB(K) = QIN(K) / 0.02832
TININF(K) = TININ(K) * 9. / 5. + 32.
220 TINF(K) = TIN(K) * 9. / 5. + 32.
DO 277 NN = 1, NOUTI
TOUTF(NN) = TOUTC(ICOUNT, NN) * 9. / 5. + 32.
277 QOUTB(NN) = QOUT(NN) / 0.02832
WRITE(6,802)
DO 285 K = 1, NIN1
285 WRITE(6,803) K, JIN(K), TININF(K), QINB(K), TINF(K)
WRITE(6,804)
DO 260 NN = 1, NOUTI
260 WRITE(6,803) NN, LOUT(NN, I), TOUTF(NN), QOUTB(NN)
WRITE(6,810)
NP = JM
IF (NP .GT. 10) NP = 10
DO 240 II = 1, NP
240 WRITE(6,820) (J, ELF(J), TLOWF(J, I), J = II, JM, 10)
IF (KHEAT .EQ. 2) KT2 = KT2 + 1
832 FORMAT (1H1)
820 FORMAT (7(I3, F6.1, F6.2, 3X))
810 FORMAT (/7(' J ELEV TEMP ') )
RETURN
END
SUBROUTINE DAXIME(IDAY, MONTH, IYEAR, ANDAYS)
C
C SUBROUTINE TO CONVERT DATE INTO ABSOLUTE DAYS SINCE 1/1/1800
C
COMMON /NDY/ NDAYS(13)
NDAYS(1) = 0
NDAYS(2) = 31
NDAYS(3) = 59
NDAYS(4) = 90
NDAYS(5) = 120
NDAYS(6) = 151
NDAYS(7) = 181
NDAYS(8) = 212
NDAYS(9) = 243
NDAYS(10) = 273
NDAYS(11) = 304
NDAYS(12) = 334
NDAYS(13) = 365
JYEAR = IYEAR - 1800
NTDAY = JYEAR * 365.25 + NDAYS(MONTH) + IDAY - 1
IF (NTDAY .GT. 36524) NTDAY = NTDAY - 1
IF (MONTH .LT. 3) NTDAY = NTDAY - LEAP(IYEAR)
ANDAYS = NTDAY
RETURN
END
FUNCTION LEAP(IYEAR)
C
C COMPUTES LEAP YEAR DAY CORRECTION
C
LEAP = 0
IF (MOD(IYEAR, 4) .EQ. 0) LEAP = 1
IF (MOD(IYEAR, 100) .EQ. 0) LEAP = 0
IF (MOD(IYEAR, 400) .EQ. 0) LEAP = 1
RETURN
END
SUBROUTINE TIMDAX(ANDAYS, IDAY, MONTH, IYEAR)
C
C SUBROUTINE CONVERTS ABSOLUTE DAY SINCE 1/1/1800 TO DATE
C
COMMON /NDY/NDAYS(13)
IF (ANDAYS .GT. 365.0) GO TO 5
IYEAR = 1800
IDAY = ANDAYS
ILEAP = 0
GO TO 9
5 AN = ANDAYS - 365.0
IF (ANDAYS .GT. 36889.0) AN = AN + 1
IYEAR = AN / 365.25
IC = 365.25 * IYEAR
IDAY = AN - IC
IF (IDAY .LT. 1) GO TO 7
IYEAR = IYEAR + 1801
ILEAP = LEAP(IYEAR)
GO TO 9
7 IYEAR = IYEAR + 1800
MONTH = 12
IDAY = 31
RETURN
9 J = 2
IF (IDAY .LT. NDAYS(2)) GO TO 20
DO 10 J = 3, 12
   IF (IDAY .LT. NDAYS(J) + ILEAP) GO TO 20
10 CONTINUE
J = 13
20 MONTH = J - 1
       IDAY = IDAY - NDAYS(MONTH) + 1
       IF (MONTH .GT. 2) IDAY = IDAY - ILEAP
       RETURN
       END
APPENDIX B

PROGRAMMING EXAMPLES

The following pages contain input data and model printout for three sample calculations with MITEMP.

Run 1 consists of 2 parts and involves shallow ponds in series. The first pond is modeled as a shallow-dispersive pond while the second pond is modeled as a shallow-recirculating pond. For part 1 open cycle plant operation is assumed. Model data is input at 1 day intervals. Computations are made with a 3 hour time step and are continued for 8 days. Printed output is specified at 8 day intervals.

The second part of Run 1 is identical to the first part except that closed cycle operation is assumed.

Run 2 involves a deep-stratified cooling pond operated under closed cycle operation. Model data is input at 1 day intervals. Computations are made with a 1 day time step and are continued for 8 days. Printed output is specified at 8 day intervals.

Run 3 involves a natural lake operated under the same conditions as Run 2.
Run 1  Input Data

**EXAMPLE: SHALLOW COOLING PONDS, OPEN CYCLE OPERATION**

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57.2 55.9 59.1 64.9 63.8 53.9 59.6 65.6 70.1 76.4 70.9 71.0 68.8 67.3 59.6 61.2
62.2 59.2 58.6 59.4 63.5 61.9 64.1 69.0 66.9 61.8 52.9 61.1 62.7 63.6 67.3 68.0

32 1.0

.51 .40  .47  .62  .89  .97  .67  .74  .77  .82  .82  .90  .94  .94  .84  .70

.53 .48  .68  .89  .80  .89  .79  .87  .92  .72  .89  .97  .80  .99  .98  .89

32 1.0

4.04 5.29 4.34 5.85 5.85 4.31 4.48 4.99 4.57 4.40 4.77 3.36 3.76 3.60 4.01 3.64

6.35 7.79 7.67 8.54 3.69 3.63 4.22 5.07 5.57 6.24 7.53 6.44 5.35 3.90 3.91 3.43

7.0

32 1.0

2629.6 2512.3 2490.3 1119.1 860.3 2485.8 2160.7 2331.0

2136.4 2105.4 2041.3 2114.3 1032.8 827.1 597.1 2262.5

2576.5 2634.0 1866.6 933.3 2134.2 962.0 1702.9 1218.9

878.9 1716.7 2263.8 1479.7 1731.6 2398.6 1956.5 896.1

32 1.0

.00 .00  .00  .00  .90  .90  .00  .30  .10  .38  .40  .50  .40  .90  1.00  1.00  .30

.00 .00  .80  1.00  .50  .90  .70  .90  1.00  .70  .40  .80  .70  .30  .60  1.00

.03 .05

.125 8.00  64  64  64

5/16/1979

5/24/1979

9

8.0  1200.0  24000.0

92.0 91.9 91.8 91.7 91.6 91.5 91.4 91.3 91.2 91.1

0.0  0.0

42 250

155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0

155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0

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155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0

92.0 92.5 93.0 93.5 94.0 90.0 91.6 94.0 93.5 93.2 92.5 91.5 90.0 89.0 88.0 90.0

91.5 92.8 92.9 93.4 95.6 95.9 92.7 92.1 93.0 90.0 90.0 90.0 91.7 89.8 88.0 87.0

95.5 96.0 95.5 95.0 95.6 95.0 95.6 95.0 95.0 95.0 95.0 95.0 95.0 95.0 95.0 95.0

6 10.0 2250.0  9000.0

7 91.1 89.5 89.0 88.5 85.0 87.5 87.0

6 10.0 2250.0  9000.0

7 87.0 86.5 86.0 85.5 85.0 84.5 84.0  .05 1.0

**EXAMPLE: SHALLOW COOLING PONDS, CLOSED CYCLE OPERATION**
Run 1 Output

EXAMPLE: SHALLOW COOLING PONDS, OPEN CYCLE OPERATION

**-------------------------------**
KFIN 1 KATRAD 2 KUNITS 2 KSUR 1 KHEAT 1 KOPERA 2
TIME INCREMENT 0.125 MAXIMUM TIME 8.000 IFREQ1 64 IFREQ2 64 IFREQA 64
UNITS ARE BTU, FEET, DAY, DEG.F. MPH(WIND SPEED ONLY)

STARTING DATE FOR THE RUN 5/16/1979

ETA= 0.300 BETA= 0.500

VERTICALLY MIXED REGION GEOMETRY

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<th>POND</th>
<th>TOTAL VOLUME</th>
<th>HORIZONTALLY MIXED FRACTION</th>
<th>VOLUME DFR</th>
<th>CROSS SECTIONAL AREA</th>
<th>DEPTH</th>
<th>WIDTH</th>
<th>LENGTH</th>
<th>ELEMENTS IN DFR</th>
<th>DISTANCE INCREMENT</th>
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INITIAL TEMPERATURE DISTRIBUTION IN POND 1

92.00 91.90 91.80 91.70 91.60 91.50 91.40 91.30 91.20 91.10
DISTANCE INCREMENT 1500.00 1425.00
ENTRAINMENT 1.00

INITIAL TEMPERATURE DISTRIBUTION IN POND 2

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***ELAPSED TIME= 8.000 NO. TIME STEPS= 64 DATE 5/24/1979

MeteOROLOGICAL DATA

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<td>ATMOS RADIATION</td>
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<td>AIR TEMPERATURE</td>
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CUMULATIVE EVAP MASS LOSS

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VERTICALLY MIXED REGION

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VERTICALLY MIXED REGION

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EXAMPLE: SHALLOW COOLING PONDS, CLOSED CYCLE OPERATION
KFIN 1  KATRAD 2  KUNITS 2  KSUR 1  KHEAT 1  KOPERA 1

TIME INCREMENT 0.125  MAXIMUM TIME 8.000  IFREQ1 64  IFREQ2 64  IFREQA 64

UNITS ARE BTU, FEET, DAY, DEG.F. MPH(WIND SPEED ONLY)

STARTING DATE FOR THE RUN  5/16/1979

ETA= 0.300  BETA= 0.500

VERTICALLY MIXED REGION GEOMETRY

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VERTICALLY MIXED REGION GEOMETRY

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87.00  86.50  86.00  85.50  85.00  84.50  84.00

***ELAPSED TIME=  8.000  NO. TIME STEPS=  64  DATE  5/24/1979

METEOROLOGICAL DATA

EQUILIBRIUM TEMPERATURE  78.7
SOLAR RADIATION  2161.
ATMOS RADIATION  2586.
REL HUMIDITY  0.73
WIND SPEED  4.58
AIR TEMPERATURE  69.54
HEAT LOSS=  6986.
CLOUD COVER  0.34

POND  CUMULATIVE EVAP MASS LOSS
1  14648437.0
2  11045575.0

VERTICALLY MIXED REGION

INFLOW TEMPERATURE  103.56  FLOW RATE  155692784.
FOR POND 1  ENERGY RATIO=  1.0065
TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:

103.56  99.58  98.14  96.81  95.58  94.45  93.43  92.55  91.86  91.43

VERTICALLY MIXED REGION
FOR POND 2  ENERGY RATIO=  1.0022
TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:

85.97  84.33  84.17  84.03  83.92  83.85  83.81
83.81  81.45  81.23  81.04  80.90  80.80  80.75
### Run 2 Input Data

**EXAMPLE: VERTICALLY STRATIFIED COOLING POND**

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Run 2 Output

EXAMPLE: VERTICALLY STRATIFIED COOLING POND

KFIN 1  KATRAD 2  KUNITS 2  KSUR 1  KHEAT 1  KOPERA 1
TIME INCREMENT 1.000  MAXIMUM TIME 8.000  IFREQ1 8  IFREQ2 8  IFREQA 8
UNITS ARE BTU, FEET, DAY, DEG.F, MPH(WIND SPEED ONLY)

STARTING DATE FOR THE RUN  5/16/1975

ETA= 0.300  BETA= 0.500

VERTICAL DIFFUSION COEFF.= 1.29000

STRATIFIED PORTION INFLOW PARAMETERS
KOH 2  KMIX 2  MIXED(1) 4  RMIX(1) 2.00

STRATIFIED PORTION GEOMETRY

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VERTICALLY MIXED REGION GEOMETRY

TOTAL VOLUME 57600000.0
HORIZONTALLY MIXED FRACTION 0.10
VOLUME DFR  518399744.  
VOLUME FM  57600000.  
CROSS SECTIONAL AREA  24000.00  
DEPTH  4.00  
WIDTH  6000.00  
LENGTH  24000.00  
ELEMENTS IN DFR  12  
DISTANCE INCREMENT  1800.00  
ENTRAINMENT  0.30  

INITIAL TEMPERATURE DISTRIBUTION IN POND 1  
75.00  74.50  74.00  72.50  71.00  70.00  69.00  68.00  67.00  66.00  
65.00  64.00  63.00  

***ELAPSED TIME= 8.000  NO. TIME STEPS= 8  DATE 5/24/1979  

MeteoroLOGICAL DATA  
EQUILIBRIUM TEMPERATURE 75.0  
SOLAR RADIATION 2331.  
ATMOS RADIATION 2428.  
REL HUMIDITY 0.63  
WIND SPEED 4.95  
CLOUD COVER 0.10  
HEAT LOSS= 3981.  

POND CUMULATIVE EVAP MASS LOSS  
1  18150400.0  

VERTICALLY MIXED REGION  
INFLOW TEMPERATURE 81.55  
FLOW RATE 172799952.  
ENERGY RATIO= 0.9975  
TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:  
75.94  76.50  76.40  75.92  75.37  74.69  74.40  73.93  73.41  72.71  
72.21  71.85  71.59  

VERTICALLY STRATIFIED REGION  
ENERGY RATIO= 0.9975  
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Run 3 Input Data

EXAMPLE: NATURAL LAKE

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Run 3 Output Data

EXAMPLE: NATURAL LAKE

KFIN 1  KATRAD 2  KUNITS 2  KSUR 2  KHEAT 2  KOPERA 1

TIME INCREMENT 1.000  MAXIMUM TIME  8.000  IFREQ1 8  IFREQ2 8  IFREQA 8

UNITS ARE BTU, FEET, DAY, DEG.F, MPH(WIND SPEED ONLY)

STARTING DATE FOR THE RUN  5/1/1979

ETA= 0.300  BETA= 0.500

VERTICAL DIFFUSION COEFF.= 1.29000

STRATIFIED PORTION INFLOW PARAMETERS
KOH 2  KMIX 2  MIXED(1) 4  RMIX(1) 2.00

STRATIFIED PORTION GEOMETRY

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**METEOROLOGICAL DATA**

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SOLAR RADIATION        2331.  ATMOS RADIATION   2428.  AIR TEMPERATURE    65.60
REL HUMIDITY                    0.63  WIND SPEED       4.95  CLOUD COVER        0.10
HEAT LOSS                      3933.

POND CUMULATIVE EVAP MASS LOSS
1 15810770.0

**VERTICALLY STRATIFIED REGION**

ENERGY RATIO = 0.9987

COMPUTED SURFACE ELEVATION 99.98

INFLOW  LEVEL  INFLOW TEMP  INFLOW RATE  MIXED TEMP
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PART C: TRANSIENT ANALYTICAL MODEL FOR SHALLOW COOLING PONDS
I. INTRODUCTION

In Part B of this report a user's manual is presented for the transient computer code MITEMP. The code relies on a pond classification scheme based on relative pond depth and the extent of horizontal circulation which are dependent on two dimensionless parameters: a "Pond Number" \( P \), and a horizontal aspect ratio \( L/W \). The former is defined as

\[
P = \left( \frac{f_1 Q_0^2}{4 \beta \Delta T_o g H^3 W^2 \frac{D_v}{v H}} \right)^{\frac{3}{2}}
\]

where \( L \) = pond length along flow path, \( W \) = pond width \((W = A/L)\), \( A \) = pond surface area, \( H \) = pond depth, \( Q_0 \) = condenser flow rate, \( \Delta T_o \) = condenser temperature rise, \( D_v \) = volumetric dilution produced by entrance mixing, \( f_1 \) = interfacial friction factor, \( \beta \) = coefficient of thermal expansion and \( g \) = acceleration of gravity. Three pond classes are identified:

1. deep stratified cooling ponds \((P \leq 0.5)\),
2. shallow cooling ponds with longitudinal dispersion \((P \geq 0.5; L/W \geq 4)\) and
3. shallow cooling ponds with lateral recirculation \((P \geq 0.5; L/W \leq 4)\). Identification of the appropriate pond class allows one to capture the essential spatial structure of a pond in a numerically one-dimensional framework, thus avoiding expensive computations.

The object of the present section of the report is to explore, analytically, the transient response of a pond and to suggest how linearized steady-state models may be combined with appropriately filtered meteorological and plant operation data to closely approximate the performance of the transient numerical models. Such quasi-steady models have use at the preliminary design stage where many pond designs must be
simulated over long periods of time or in situations where a truly transient model is not feasible. Examples of the latter case include cooling impoundments which are formed by damming a river or stream and which frequently include a main pond connected to one or more side arms; while an acceptable steady state analysis is available to describe the convective side arm flow (Brocard et al., 1977), a corresponding transient analysis is not available.

The analysis herein is developed for the case of a shallow pond with longitudinal dispersion. However similar analysis can be applied to any closed cycle pond which can be considered vertically well-mixed (i.e. shallow) and results are presented for the shallow pond with lateral recirculation. The analysis is not directly applicable to deep stratified ponds, but qualitatively similar results would apply.

The analysis begins by reviewing the transient numerical formulation with non-linear heat loss. An analytical model is then developed based on linear heat transfer with a constant surface heat transfer coefficient. The approach is extended to non-linear heat transfer and is evaluated in the context of a case study.

II. MATHEMATICAL MODEL FOR SHALLOW PONDS WITH LONGITUDINAL DISPERSION

2.1 Model Formulation with Non-linear Heat Loss

Fig. 1 depicts schematically a shallow dispersive closed cycle cooling pond of uniform cross section. The transient numerical model for this pond is described in Parts A and B of this report and is summarized briefly here. One example of a shallow pond with longitudinal dispersion - the Dresden Cooling Pond in Illinois - is shown in Fig. 4.4 of Part B of this report. Note that this pond could be treated as one
long pond or a series of three shorter ponds.

The pond is represented by the variables L, W, H, Qo and ΔT_o. The jet entrance mixing region is a small fraction of the total pond area with the major through flow portion of the pond being characterized by a longitudinal dispersion process. Temperatures within the pond are governed by a one-dimensional bulk-dispersion equation with cross-sectionally averaged variables:

\[
\frac{\partial T(x,t)}{\partial t} + U \frac{\partial T(x,t)}{\partial x} = E_{L} \frac{\partial^{2} T(x,t)}{\partial x^{2}} - \frac{\phi_n}{\rho c H}
\]

with boundary conditions

\[
U T(0,t) - E_{L} \frac{\partial T(0,t)}{\partial x} = U[T(L,t) + \Delta T_o] \quad \text{at} \quad x = 0
\]

\[
\frac{\partial T(L,t)}{\partial x} = 0 \quad \text{at} \quad x = L
\]

where \( T(x,t) \) = the cross sectionally averaged temperature, \( U \) = the cross-sectional mean velocity \( Q_o/WH \), \( x \) = longitudinal distance, \( t \) = time,
\( E_{L} \) = longitudinal dispersion coefficient, \( \phi_n \) = net surface heat flux to the atmosphere, \( \rho \) = density and \( c \) = the specific heat of water. \( E_{L} \) is based on Fischer's dispersion analysis (1967) and is given by

\[
E_{L} = \frac{0.3 \sqrt{f_o/8} U(H/2)^2}{\kappa^2 H}
\]

where \( \kappa \) is von Karman's constant (-0.4) and \( f_o \) is a bottom friction factor. The surface heat transfer includes short and long wave net radiation into the water and evaporation, conduction and back radiation out of the water; the expression of Ryan, Harleman and Stolzenbach (1974) is used herein. The boundary conditions are specified to ensure conservation
of thermal energy and the equation is solved with an implicit numerical scheme. Further model details can be found in Part A and B.

A comparison of predicted and observed temperatures at the Dresden, Illinois Cooling Pond (Fig. 4-6 of part B) indicates good agreement under highly transient conditions. A sensitivity study to identify the sensitivity of pond intake temperatures to various pond parameters has been presented in Adams et al., (1978).

2.2 Transient Analysis with Linearized Heat Loss

Transients may enter the analysis from two sources: variable plant operation and variable meteorological conditions. These effects can be analyzed most easily by first linearizing the surface heat transfer term, using the equilibrium temperature $T_E$ as a reference, as suggested by Edinger and Geyer (1965). Thus

$$\phi_n = K(T - T_E)$$  \hspace{1cm} (6)

and Eq. 2 is rewritten

$$\frac{\partial T(x,t)}{\partial t} + U \frac{\partial T(x,t)}{\partial x} = E_L \frac{\partial^2 T(x,t)}{\partial x^2} - \frac{K}{\rho c H} [T(x,t) - T_E]$$  \hspace{1cm} (7)

Eq. 7 would be identical to Eq. 2 if an appropriate choice of $K$ as a function of time and space were made; it is an approximation when a constant value is used. The determination of $K$ and $T_E$ is discussed below.

Variable plant operation would be represented by variation in $\Delta T_o$ (appearing in Eq. 3), $U$, or both $\Delta T_o$ and $U$. For most design problems it would be appropriate to assume constant (e.g., full load operation) values for these variables but for actual operation they may vary signi-
Thomann (1973) has analyzed the frequency response of an open cycle system which can be represented by constant values of $U$, $T_E$, and $K$, and sinusoidal variation of $\Delta T_o$ with a frequency $\omega$. One finds that the amplitude response at the intake ($x=L$) is negligible if the characteristic time needed for dispersion to damp the longitudinal periodicity, $U^2/\omega^2 E_L$, is small compared with the pond residence time $L/U$. For plants whose discharge temperatures vary with a period of about one day ($\omega = 2\pi \text{day}^{-1}$) or less, this is generally the case, indicating that use of daily averaged plant operation data should be adequate. If the discharge temperature varies with a periodicity substantially greater than one day, or if the discharge flow rate varies, the assumption of constant plant operation may not be adequate. At any rate, the remaining analysis is performed for constant plant operation which is consistent with its use for design purposes.

To analyze the effect of variable meteorology, $U$, $E_L$, and $K$ are assumed to be constant while the equilibrium temperature fluctuates. A solution to Eq. 7, subject to the boundary conditions of Eqs. 3 and 4, is found by assuming a solution composed of a steady-state component and a transient component, or

$$T(x,t) = T_{ss}(x) + \Delta T_t(x,t)$$ (8)

Similarly the equilibrium temperature is written

$$T_E(t) = T_{ss} + \Delta T_{t}$$ (9)

The steady state solution is found by setting $\partial \Delta T_t/\partial t$ and $\Delta T_{t} = 0$ in Eq. 7 leaving
\[ \frac{\partial T_{ss}(x)}{\partial x} - \frac{E}{L} \frac{\partial^2 T_{ss}(x)}{\partial x^2} + \frac{K}{\rho c H} T_{ss}(x) = \frac{K T_{E ss}}{\rho c H} \]  
\( U \)  

\[ \frac{\partial T_{te}(0)}{\partial x} - \frac{E}{L} \frac{\partial T_{te}(0)}{\partial x} = U[T_{ss}(L) + \Delta T] \text{ at } x = 0 \]  

\[ \frac{\partial T_{ss}(L)}{\partial x} = 0 \text{ at } x = L \]

for which a solution is given by Wehner and Wilhelm (1956):

\[ T_{ss}(x) - T_{E ss} \]
\[ \frac{T_o}{T} \]

\[ \frac{r_1 r_2 x/L}{r_1 e^r_1 e^{r_2 r_1 x/L}} \]
\[ \frac{r_2 r_1 x/L}{r_2 e^{r_2 e^{r_1 r_2 x/L}}} \]

\[ r_1 e^{r_1 (1 - E_L r_2/UL - e^{r_2})} - r_2 e^{r_2 (1 - E_L r_1/UL - e^{r_1})} \]

In Eq. 13 \( r_1 = (1 + a)/(2E_L/UL) \), \( r_2 = (1 - a)/(2E_L/UL) \), and

\[ a = \sqrt{1 + 4KAEL/\rho cQ U L} \].

The solution for the steady state intake temperature \( T_{ss} \) is found by setting \( x/L = 1 \), yielding the solution reported in Appendix B to Part A of this report.

\[ \frac{T_{i ss} - T_{E ss}}{\Delta T_o} = \frac{UL/2E_L}{4a e} \]
\[ \frac{aUL/2E_L}{(1+a)^2 e} - \frac{aUL/2E_L}{(1-a)^2 e} \]

\[ \frac{UL/2E_L}{4a e} \]

The transient solution, \( \Delta T_{t} \), is found by substituting Eqs. 8 and 9 into Eqs. 7, 3 and 4, and subtracting the corresponding Eqs. 10, 11 and 12. The spatial dependence of \( \Delta T_{t} \) can be shown to vanish (after any transient adjustment following station start-up) resulting in the equivalent equation:

\[ \frac{\partial \Delta T_{t}(t)}{\partial t} = - \frac{K}{\rho c H} [\Delta T_{t}(t) - \Delta T_{E t}] \]  

(15)
The solution to Eq. 15 for an arbitrary input $\Delta T_{E_0}(t)$ can be found by a convolution integral based on the unit impulse response. However, because meteorological data is typically discretized in intervals of one or three hours, it is more convenient to consider the convolution sum based on the unit step response. The response at time $t$ to a unit change in equilibrium temperature at time $t - n\Delta t$ is $[1 - \exp(-Kn\Delta t/\rho c H)]$. Thus if $T_E(t - n\Delta t)$ represents the equilibrium temperature between time $t-(n+1)\Delta t$ and $t-n\Delta t$, the transient response at time $t$ may be approximated as

$$\Delta T_0^L(t) = \left[1 - \exp(-K\Delta t/\rho c H)\right] \sum_{n=0}^{\infty} T_E(t-n\Delta t) \exp(-\kappa K\Delta T/\rho c H) \quad (16)$$

The longitudinal temperature distribution within the pond is thus given by Eqs. 8, 13 and 16, while the intake temperature is given by Eqs. 8, 14 and 16.

2.3 Discussion

Because the value of $K$, as defined by Eq. 6, is expected to vary with time, the above model which assumes a constant $K$ is clearly approximate. Nonetheless it provides some useful insights and can be used for initial pond design.

The steady-state part of the solution, Eq. 13 or 14, depends primarily on the pond area $A$, and the discharge flow rate and temperature rise $Q_o$ and $\Delta T_o$. The pond shape (i.e., the aspect ratio $L/W$) and depth $H$, exert secondary influence through their effect on the dimensionless dispersion coefficient $E_L/U_L$. In this regard the often-used plug flow and well-mixed models are seen to result from the limits of $E_L = 0$ and $\infty$ respectively.

The equation for the transient response, Eq. 15, and its solution
Eq. 16, are noteworthy because they contain no spatial dependence. They are the same equations which would govern a well-mixed tank, which means that the advection and dispersion processes of Eq. 7 and the heat loading represented in the boundary condition of Eq. 3 do not affect the transient response of the pond. It also means that the same transient response would govern shallow ponds with other shapes such as those characterized by lateral recirculation or those with sufficiently irregular cross section to recommend a numerical solution for the steady state response.

The time constant of the pond response, like that of a well-mixed tank, is $\rho c H/K$; in other words, the pond's thermal inertia is governed solely by its water depth. For typical values of $K = 100 - 300 \text{ BTU-ft}^{-2} \text{-°F-1-day}^{-1}$ (25-75 W-m$^{-2}$-°C$^{-1}$) and $H = 5$ to 12 ft. (1.5 to 4 m.), this constant ranges between about one day and one week which, significantly, is in the same range of time scales associated with synoptic weather changes. Coincidentally it is also in the same range as typical pond residence times given by $L/U$. The fact that $H$ is the only pond variable which affects the transient response suggests, from a practical view, that initial pond design could proceed efficiently by selecting one or more water depths, evaluating their transient response, and then superimposing the steady-state response associated with particular choices of $L$, $W$, $Q_o$ and $\Delta T_o$.

It is instructive to look at the transient solution of Eq. 16 from another perspective. The solution depends on the equilibrium temperature at the present and past times with the weighting on past times decaying exponentially. Thus the transient solution could be viewed as a time series of steady state responses to an input series of equilibrium...
temperatures which have been passed through an exponential filter.
Equivalently, it could be viewed as a similarly filtered time series of steady state responses to an input series of unfiltered equilibrium temperatures. The exponential filter is discussed in Koopmans (1974), and can be written

\[ <y(t)> = (1-\alpha) \sum_{n=0}^{\infty} y(t-n\Delta t)\alpha^n \]  

where \( y(t) \) is the input series with time interval \( \Delta t \), \( <y(t)> \) is the output series and \( \alpha \) is a filter parameter equal, in the present context, to \( K\Delta t/\rho cH \) or the time interval divided by the time constant. The equivalent forms of Eqs. 8 and 16 corresponding to the above two interpretations would be

\[ T(x,t) = T_{ss}(x,T_{E}(t)) + <\Delta T_{E}(t)> \]  

and

\[ T(x,t) = <T_{ss}(x,T_{E}(t))> \]  

where the term \( <T_{ss}(x,T_{E}(t))> \) in Eq. 18b is evaluated from Eq. 13 using the time-varying value of \( T_{E}(t) \) in place of \( T_{E}^{ss} \). The term quasi-steady is used to describe either view of the model because model output is based on the steady state response to model input.

Variable rates of heat transfer can be considered by allowing the filter parameter \( \alpha \) (or \( K \)) to vary with time. Since both \( K \) and \( T_{E} \) depend on the same meteorology, one logical approach is to compute \( K \) at each time step and then to filter both \( K \) and \( T_{E} \). The following procedure, based on the non-linear expression for \( \phi_n \) given by Ryan et al., (1974) is used in the case study example. \( T_{E} \) is determined at daily time steps as the temperature at which \( \phi_n = 0 \). \( K \) is then determined such that Eq. 6 is
satisfied based on an average water temperature

\[ T = T_E + \frac{\rho c Q_0}{K A} \Delta T_o \]  

(19)

Since K appears in both Eqs. 6 and 19, its value must be determined by iteration. Steady state pond temperatures are then computed from Eq. 18b using the daily value of K to compute the filter parameter \( \alpha \).

While this approach increases the computational effort somewhat, it reduces the non-linear errors associated with widely varying values of \( T - T_E \) in Eq. 6; these errors are often cited as a basis of criticism of the \( K/T_E \) approach (Yotsukura, et al., 1973).

Finally, it is worthwhile to contrast this approach with an approximation which is commonly used and is based on an averaging filter rather than an exponential filter. A filter which averages over \( N \) data points may be defined as

\[ \langle y(t) \rangle = \frac{1}{N} \sum_{n=0}^{N-1} y(t-n\Delta t) \]  

(20)

and is used implicitly whenever averaged input data are used. In the case study example, meteorological variables used to compute \( \phi_n \) are averaged over different periods of time and the pond temperature is computed based on the corresponding values of K and \( T_E \). If \( \chi \) represents the meteorological variables used to compute \( T_E \), this means

\[ T(x,t) = T_{ss}(x,T_E(<\chi(t)\/))) \]  

(21)
III. MATHEMATICAL MODEL FOR SHALLOW PONDS WITH LATERAL RECIRCULATION

As stated previously, similar analysis can be applied to any shallow pond operated as a closed cycle system. Thus, before continuing with the case study, analogous results are developed for the shallow pond with lateral recirculation - the other class of shallow pond which has been discussed in Parts A and B of this report. Figure 2 illustrates such a pond schematically. A prototype example involving a series of shallow ponds, each exhibiting lateral recirculation, is the Powerton Cooling Pond in Illinois shown in Figure 4-8 of Part B of this report.

In addition to the variables defined in Fig. 1, the major parameters used to describe this pond include the lateral entrance dilution, $D_s$, and the jet area fraction $q$. Neglecting longitudinal dispersion, which is of secondary importance for this case in view of the bulk recirculation, the governing equations for the forward zone, denoted by subscript $f$, are

\[
\begin{align*}
\frac{\partial T_f(x,t)}{\partial t} + U_f \frac{\partial T_f(x,t)}{\partial x} &= - \frac{K}{\rho c H} [T_f(x,t) - T_E] \\
\end{align*}
\]

while the equation for the reverse flow zone, denoted by subscript $r$, is

\[
\begin{align*}
\frac{\partial T_r(x,t)}{\partial t} + U_r \frac{\partial T_r(x,t)}{\partial x} &= - \frac{K}{\rho c H} [T_r(x,t) - T_E(t)] \\
\end{align*}
\]

with

\[
\begin{align*}
U_f &= \frac{D_s Q_o}{q WH} \\
U_r &= \frac{-(D_s - 1) Q_o}{(1-q) WH} \\
\end{align*}
\]

Boundary conditions for the two zones are

\[
D_s Q_o T_f(0,t) = Q_o [T_f(L,t) + \Delta T_o] + (D_s - 1) Q_o T_r(0,t) \\
\]

and

\[
T_f(L,t) = T_r(L,t) \\
\]

At this point it is noted that the functional form of Eq.'s 22 and 23 is similar to that of Eq. 7. An analogous solution can thus be obtained by considering steady-state and transient components for $T_f$, $T_r$, and $T_E$. The steady state equations, analogous to Eq. 10, are

$$U_f \frac{\partial T_f}{\partial x} + \frac{K}{\rho c H} T_f(x) = \frac{K T_E}{\rho c H}$$

(28)

and

$$U_r \frac{\partial T_r}{\partial x} + \frac{K}{\rho c H} T_r(x) = \frac{K T_E}{\rho c H}$$

(29)

with

$$D_s Q_{o f} T_f(0) = Q_o [T_f(L) + \Delta T_o] + (D_s - 1) Q_o T_r (0)$$

(30)

and

$$T_f(L) = T_r(L)$$

(31)

The solution to this set of equations is

$$\frac{T_f(x) - T_E}{\Delta T_o} = \frac{-rq/D_L}{e^{\frac{-rq/D_s}{s-(D_s-1)e}}}$$

(32)

and

$$\frac{T_f(x) - T_E}{\Delta T_o} = \frac{r}{e^{\frac{-(1-q)/D_s}{(1-q)(x/L)}}}$$

(33)

The steady state intake temperature, $T_{i ss}$ = $T_f(x=L)$ = $T_r(x=L)$, as reported in Appendix B of Part A, is given by
\[
\frac{T_{ss} - T_E}{\Delta T_o} = \frac{-rq/D_s}{D_s - e^{-(D_s-1)e}} - \frac{e^{-r[(1-q/D_s)/(D_s-1)]}}{D_s - e^{-(D_s-1)e}}
\]

Eq. 15 governs the transient response for this pond so that the transient solution, like that for a shallow-dispersive pond, is given by Eq. 16. The longitudinal temperature is thus given by Eqs. 8, 32, 33 and 16, while the intake temperature is given by Eqs. 8, 34 and 16. As with the shallow pond with longitudinal dispersion, these solutions can be viewed in any of the ways discussed in Section 2.3.

IV. CASE STUDY

Using an example of a shallow pond with longitudinal dispersion, plant intake temperatures based on the quasi-steady models discussed in Section II were compared with those based on the analogous transient model with non-linear heat loss for a typical pond located in the midwestern U.S. Pond variables included \(L = 22863\) ft. (6969 m), \(W = 1905\) ft. (581 m), \(H = 9\) ft. (2.7 m), \(Q_o = 1800\) cfs. (51 m\(^3\)/s) and \(\Delta T_o = 20^\circ F\) (11.1°C). For this pond \(P = 0.51\), \(L/W = 12\), \(A = 1000\) acres (405 ha) and \(E_L/UL = 0.41\). Heat rejection corresponds approximately to that of a 1200 MWe nuclear plant and the areal loading corresponds to approximately 2.4 MWt/acre. Meteorological data at three hour intervals was obtained for the summer of 1970 from the National Weather Service station at Moline, Illinois.

Table 1 summarizes the eight sets of calculations which were made. Each involved calculations of intake temperature for the 88 day period of June 1, 1970 to August 27, 1970. For the numerical model, Run 1, a three hour time step was used to solve Eqs. 2, 3 and 4 and the computed
Table 1  Summary of Case Study Calculations

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Designation</th>
<th>Maximum Intake Temperature in Degrees Fahrenheit (Celsius)</th>
<th>Minimum Intake Temperature in Degrees Fahrenheit (Celsius)</th>
<th>Maximum minus Minimum in Degrees Fahrenheit (Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transient</td>
<td>97.8(36.6)</td>
<td>78.3(25.7)</td>
<td>19.5(10.9)</td>
</tr>
<tr>
<td>2</td>
<td>Q-S, filtered $T_E$</td>
<td>99.7(37.6)</td>
<td>76.7(24.8)</td>
<td>23.0(12.8)</td>
</tr>
<tr>
<td>3</td>
<td>Q-S, filtered $K, T_E$</td>
<td>97.1(36.2)</td>
<td>77.4(25.2)</td>
<td>19.7(11.0)</td>
</tr>
<tr>
<td>4</td>
<td>Q-S, 1-day data average</td>
<td>102.1(38.9)</td>
<td>73.7(23.2)</td>
<td>28.4(15.7)</td>
</tr>
<tr>
<td>5</td>
<td>Q-S, 3-day data average</td>
<td>99.2(37.3)</td>
<td>76.7(24.8)</td>
<td>22.5(12.5)</td>
</tr>
<tr>
<td>6</td>
<td>Q-S, 5-day data average</td>
<td>96.7(35.9)</td>
<td>80.3(26.8)</td>
<td>16.4(9.1)</td>
</tr>
<tr>
<td>7</td>
<td>Q-S, 10-day data average</td>
<td>95.8(35.4)</td>
<td>83.9(28.8)</td>
<td>11.9(6.6)</td>
</tr>
<tr>
<td>8</td>
<td>Q-S, 30-day data average</td>
<td>92.6(33.7)</td>
<td>86.4(30.2)</td>
<td>6.2(3.5)</td>
</tr>
</tbody>
</table>
intake temperatures were averaged over a day. The remaining 7 calculations were based on Eqs. 8, 14 and 18b. In Run 2, values of $T_E$ were passed through an exponential filter (Eq. 17) using a constant value of $K$, 234 BTU-ft$^{-2}$-°F$^{-1}$-day$^{-1}$ (55 W-m$^{-2}$-°C$^{-1}$), obtained by averaging values of $K$ computed for each of 88 days. In Run 3, both $K$ and $T_E$ were passed through the filter using variable $K$ as discussed in Section 2.3.

In Runs 4-8, the various meteorological parameters were passed through the averaging filter (Eq. 20) with intervals of $N = 1, 3, 5, 10$ and 30 days. The average values at each time step were used to compute $K$ and $T_E$ for use in Eqs. 14 and 21.

Fig. 3 compares the computed intake temperatures for Runs 1, 2, and 3 for July 1970 while the maximum and minimum intake temperatures for the entire three month period are summarized in Table 1. A comparison of Runs 1 and 2 indicates that calculations based on a constant (seasonal average) value of $K$ tend to slightly overpredict maximum intake temperatures and underpredict minimum intake temperatures because the generally positive correlation between $K$ and $T_E$ has not been accounted for. However, the differences in corresponding maximum temperatures ($1.9°F, 1.0°C$) and corresponding minimum temperatures ($-1.6°F, -0.9°C$) are quite acceptable and within the general range of accuracy expected of the transient model itself. Furthermore the tendency to overpredict the maximum intake temperature makes the model consecutive, and hence attractive for design purposes. A comparison of Runs 1 and 3 indicates that accuracy may be improved, for a small increase in computational effort, if both $K$ and $T_E$ are filtered.

Runs 4-8 were included to show the effects of averaging meteorological
Fig. 3 Comparison of Transient and Quasi-Steady Models for July 1970
data prior to the use of a steady state model. Because the averaging filter differs from the exponential filter, such a procedure is not expected to result in meaningful comparison of time series predictions. However, calculations of maximum and minimum temperatures - useful results for design purposes - can be compared. Table 1 indicates that use of either 3 or 5 day averaged data results in reasonable values of these quantities. By contrast, results for one day averaging show greater extremes in temperature suggesting that the averaging has not adequately filtered the high frequency fluctuations, while the results for 10 and 30 day averaging show less extremes, suggesting that the averaging of input data over these intervals provides more filtering than the transient model. One would conclude from these results that, for this site and pond, an averaging interval of between 3 and 5 days will provide reliable estimates of maximum and minimum pond temperatures. These intervals are between one and two times the average value of \( \rho c\bar{H}/K = 2.4 \) days computed with the seasonal average value of \( K = 234 \text{ BTU} - \text{ft}^{-2} - \text{oF}^{-1} \text{-day}^{-1}(55 \text{ W} - \text{m}^{-2} - \text{oC}^{-1}) \).

Since the purpose of the quasi-steady models is to provide design tools, the case study can be used to provide a useful comparison with two other commonly used design tools: a steady state plug flow model (\( E_L = 0 \) in Eq. 14) and a steady state well-mixed model (\( E_L \to \infty \) in Eq. 14). Based on seasonal average meteorology, \( T_E = 77^\circ \text{F}(25^\circ \text{C}) \) and \( K = 234 \text{ BTU} - \text{ft}^{-2} - \text{oF}^{-1} \text{-day}^{-1}(55 \text{ W} - \text{m}^{-2} - \text{oF}^{-1}) \), the intake temperature rise above equilibrium temperature, \( T_i - T_E \), is tabulated in Table 2 for these two limiting conditions as well as for the dispersive model using \( E_L/UL = 0.41 \) computed from Eq. 5. The difference between the well-mixed and the plug-flow model predictions of \( 8.3^\circ \text{F}(4.6^\circ \text{C}) \) suggests the range of error which
Table 2  Steady State Temperatures

<table>
<thead>
<tr>
<th>$E_{L}/UL$</th>
<th>Designation</th>
<th>$T_{i} - T_{E_{SS}}$ in degrees Fahrenheit (Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Plug-flow</td>
<td>10.8 (6.0)</td>
</tr>
<tr>
<td>0.41</td>
<td>Dispersive</td>
<td>14.8 (8.2)</td>
</tr>
<tr>
<td>$\infty$</td>
<td>Well-mixed</td>
<td>19.1 (10.6)</td>
</tr>
</tbody>
</table>
can be made by incorrectly specifying a pond's spatial structure. By contrast, the importance of accounting for the proper transient response can be gauged by comparing the predicted maximum intake temperatures using highly filtered (30-day average) data and lightly filtered (1-day average) data. The difference of 9.5°F(5.2°C) indicates that, even at the design stage, recognition of the correct transient response is at least as important as identification of the correct spatial structure.

V. SUMMARY AND CONCLUSIONS

Transient models of cooling pond performance, based on linearized heat transfer (using \( K \) and \( T_E \)), have been used to explore the transient response of shallow cooling ponds subject to fluctuating meteorology. This response was shown to be similar to that of a well-mixed water body, and governed by the time constant \( \rho c H/K \). This indicates that the main design variable affecting the transient response is the pond depth; variables characterizing the station heat rejection and the horizontal size and shape of the pond affect mainly the steady state response. In the case study example the transient response of a shallow, longitudinally dispersive, pond was shown to be as important as the variation in the steady state response which would result from various pond shapes ranging from those characterized by plug flow to those characterized by horizontally well-mixed conditions.

The transient models were than viewed as quasi-steady models in which steady state pond temperatures are computed as a function of filtered meteorology. For linear heat transfer, a constant heat transfer coefficient \( K \) is used while equilibrium temperatures \( T_E \) are filtered exponentially. Non-linear heat transfer can be treated by filtering both
K and $T_E$. Comparison of model results with those from the numerical model MITEMP with fully non-linear heat loss suggests that the simpler model, involving constant K and filtered $T_E$, provides acceptable results and errors on the conservative side of overpredicting extreme temperatures. More accurate, though not necessarily conservative, results are obtained with the non-linear approximation using filtered K and $T_e$. Acceptable results can also be obtained using a steady state model with averaged meteorology if an averaging interval of between one and two times the time constant $\rho c H / K$ is used.

It is suggested that any of these models would be useful at the preliminary design stage where many potential ponds must be evaluated, or in situations where, for other reasons, a steady state formulation is required. As part of the design process, however, it is recommended that the more accurate transient model with non-linear heat transfer be used to simulate the final design choice(s).
REFERENCES FOR PART C


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