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**MATHEMATICAL PREDICTIVE MODELS FOR
COOLING PONDS AND LAKES**

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by

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**PART C: A TRANSIENT ANALYTICAL MODEL
FOR SHALLOW COOLING PONDS**

by

**E. Eric Adams
Antonis D. Koussis**

**Ralph M. Parsons Laboratory
For Water Resources and Hydrodynamics**

Report No. 262

**Prepared Under the Support of
Commonwealth Edison Company
Chicago, Illinois**

**NUS Corporation
Rockville, Maryland**

**Environmental Control Technology Division
U.S. Department of Energy
Washington, D.C.**

and

**Electric Power Research Institute
Palo Alto, California**

MIT

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April 1980

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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 physical and mathematical basis for the present computer code is developed in an earlier report entitled, "Mathematical Predictive Models for Cooling Ponds and Lakes, Part A: Model Development and Design Considerations," by G. Jirka, M. Watanabe, K.H. Octavio, C. Cerco and D.R.F. Harleman, R.M. Parsons Laboratory for Water Resources and Hydrodynamics, Technical Report No. 238, December 1978.

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.

ACKNOWLEDGEMENTS

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Minor additions and/or revisions to MITEMP were made in connection with contracts from the Environmental Control Technology Division, U.S. Department of Energy (under M.I.T. OSP 87067) and the Electric Power Research Institute, Palo Alto, California (under M.I.T. OSP 88945). The analytical model presented in Part C was developed as part of the DOE/ECT contract. The support of DOE/ECT and EPRI is also greatly appreciated.

A number of individuals at M.I.T. participated in this study. In Part B, the effort was distributed as follows: Chapters 2 and 3 were prepared by Ms. Kathleen Hurley Octavio, Research Engineer, Chapter 4 was prepared by Dr. Masataka Watanabe, Research Associate, and the two appendices were developed by Mr. Karl R. Helfrich, graduate Research Assistant. Research supervision and overall editorial work was provided by Dr. Gerhard H. Jirka and E. Eric Adams, Research Engineers, and Dr. Donald R.F. Harleman, Ford Professor of Engineering. Part C was developed by Dr. Eric Adams with the assistance of Dr. Antonis D. Koussis, Assistant Professor at Northeastern University. Typing was performed by Ms. Susan Johnson and Mrs. Beth Quivey. Computations were performed at the M.I.T. Information Processing Center.

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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

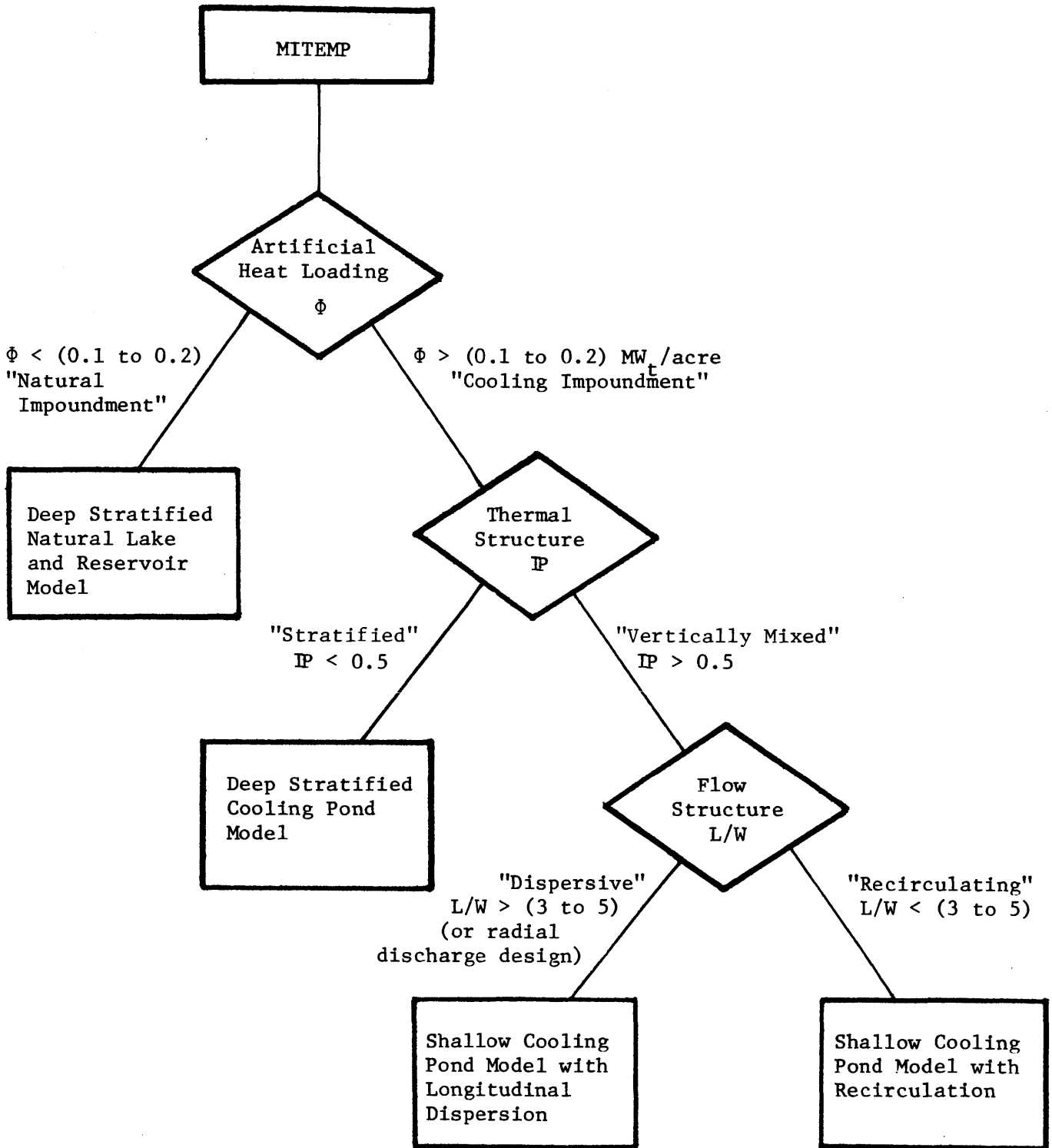


Figure 1-1: Hierarchical Structure of MITEMP and Decision Criteria

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 ϕ (MWt/acre), the pond number \mathbb{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 ϕ 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

$$\mathbb{P} = \left(\frac{f_1 Q_o^2}{4\beta\Delta T_o g H^3 W^2} D_v^3 \frac{L}{H} \right)^{1/4}$$

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, ΔT_o = condenser temperature rise, D_v = volumetric dilution produced by vertical entrance mixing, f_1 = interfacial friction factor, β = coefficient of thermal expansion and g = acceleration of gravity. \mathbb{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 \mathbb{P} decreases.

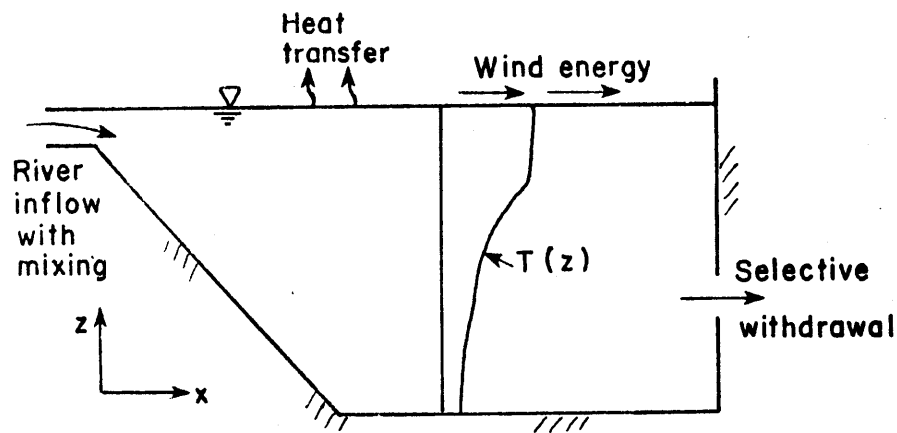
A criterion of $\mathbb{P} < 0.5$ is used to distinguish deep (vertically stratified) from shallow (vertically well-mixed) cooling ponds.

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.

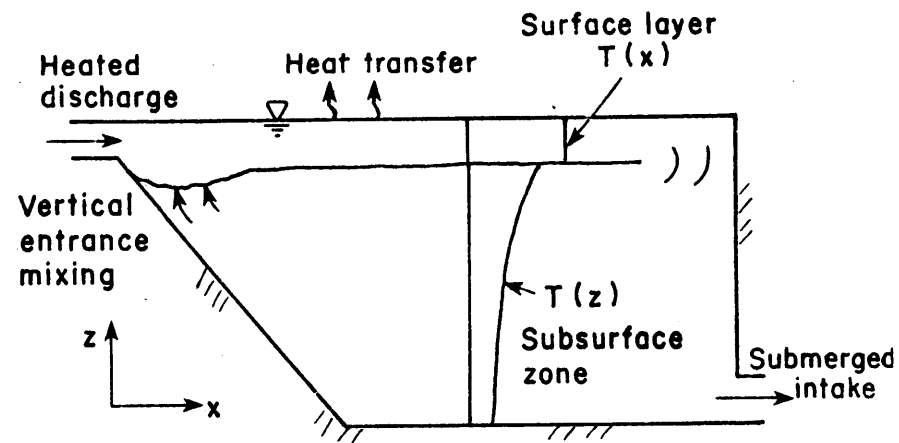
The four sub-models whose classification depends on ϕ , \mathbb{P} and L/W are illustrated in Figure 1-2 and are described briefly below. A more complete description is provided in Chapters 4 and 5 of Part A and in Jirka and Harleman (1979).

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

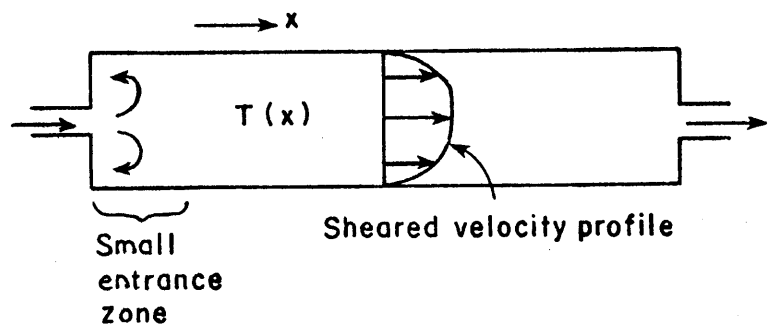


a) Natural deep lake or reservoir (side view)

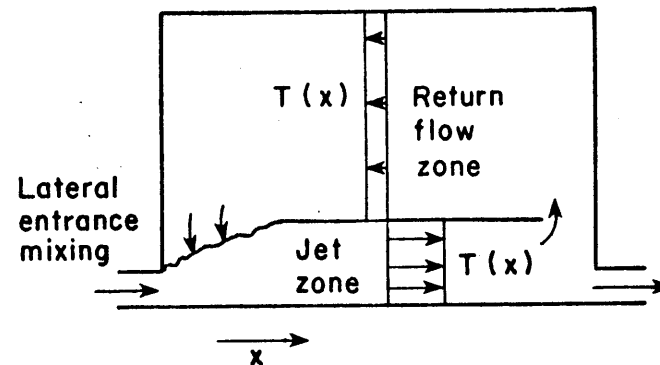


b) Deep stratified cooling pond (side view)

13



c) Shallow fully mixed pond with longitudinal dispersion (plan view)



d) Shallow fully mixed pond with lateral recirculation (plan view)

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 $h = \mathbb{P} H$) 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 ϕ , IP and L/W which place the pond in an inbetween classification, i.e. $\phi \sim 0.1$ to 0.2 , $IP \sim 0.5$ 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

$$\frac{\partial T}{\partial t} + U \frac{\partial T}{\partial x} = E_L \frac{\partial^2 T}{\partial x^2} - \frac{\phi_n}{\rho c H} \quad (2.1)$$

where T = cross-sectional mean temperature, U = cross-sectional mean velocity, x = longitudinal distance, t = time, E_L = longitudinal dispersion coefficient, H = mean depth, ϕ_n = net heat flux across the surface, ρc = 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

$$\frac{\partial T}{\partial t} + \frac{1}{A} \frac{\partial}{\partial z} (Q_v T) = \frac{E}{A} \frac{\partial}{\partial z} [A \frac{\partial T}{\partial z}] + \frac{B u_i T_i}{A} - \frac{B u_o T}{A} - \frac{1}{\rho c A} \frac{\partial (A \phi_z)}{\partial z} \quad (2.2)$$

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, ϕ_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 ρ = 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.

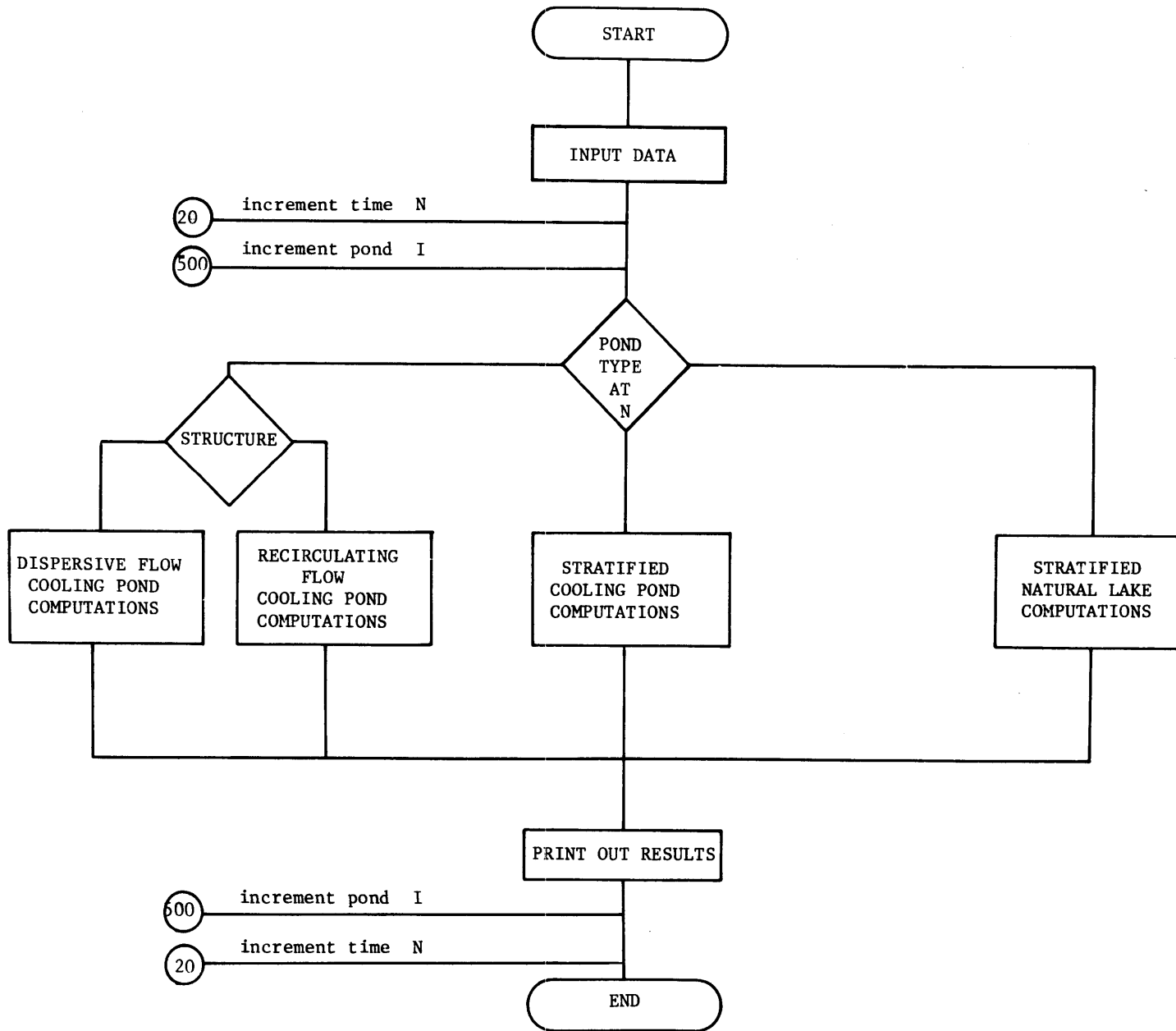


Figure 2-1: General Model Structure

Figure 2-2: MAIN Program Flow Chart

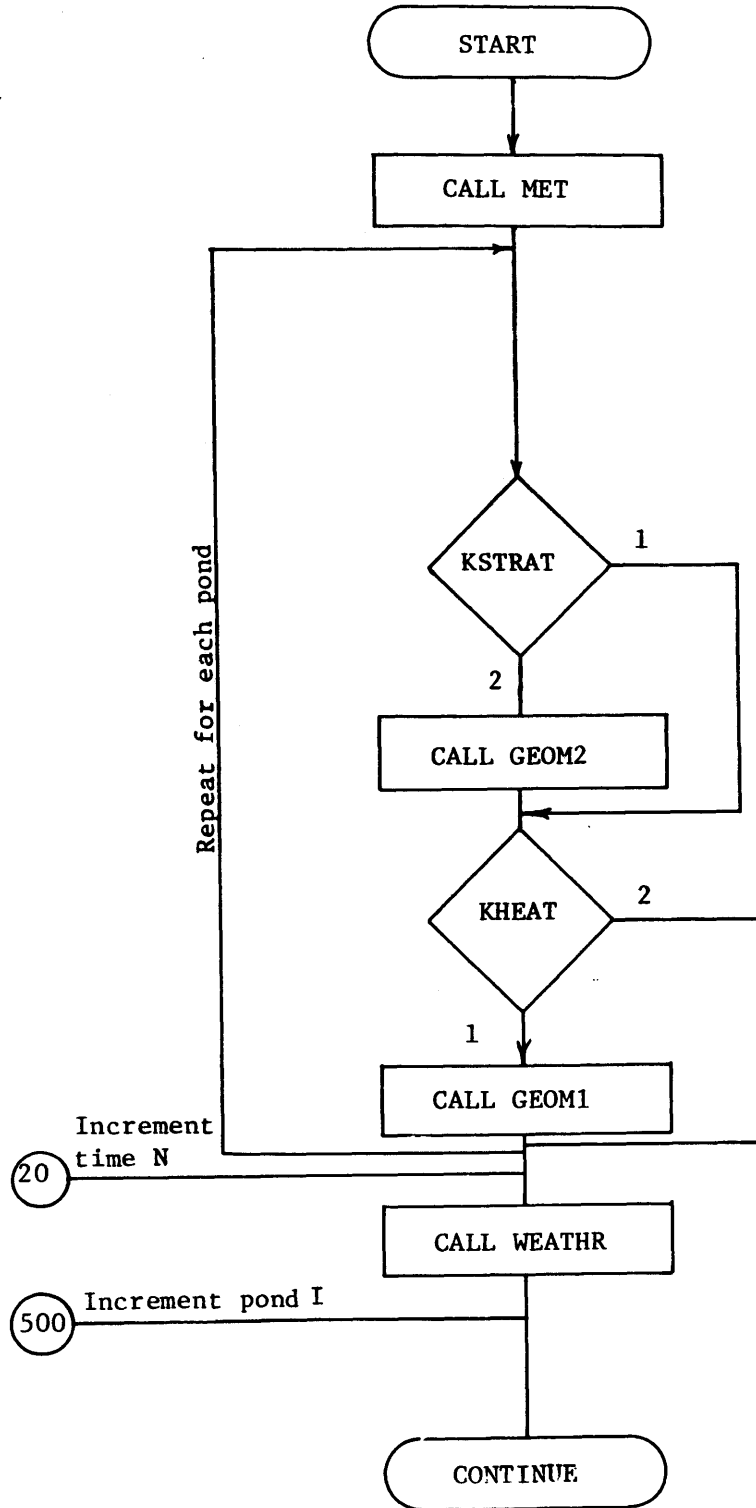


Figure 2-2 Cont'd

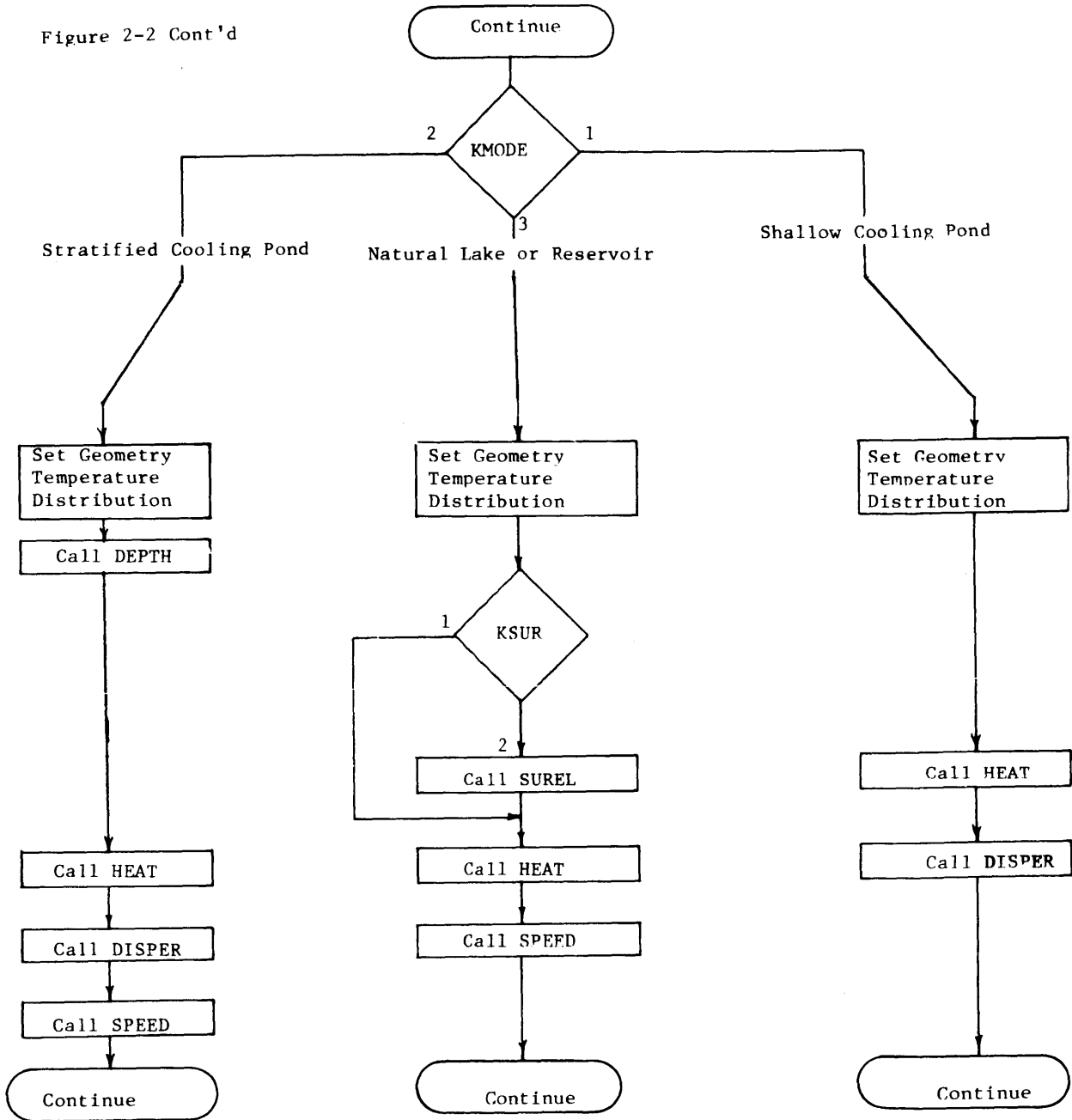


Figure 2-2 Cont'd

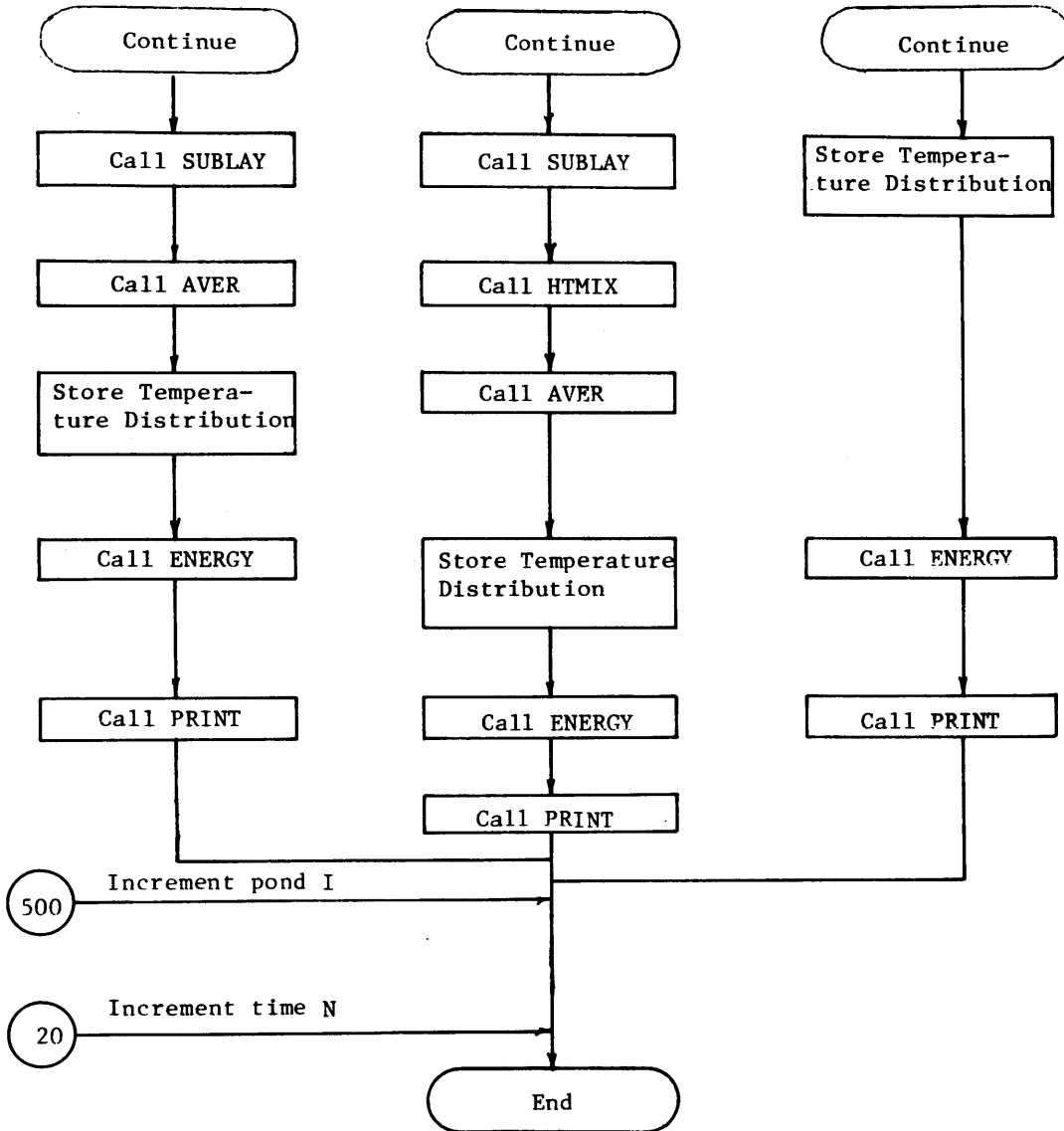


Figure 2-3: Subroutine MET Flow Chart

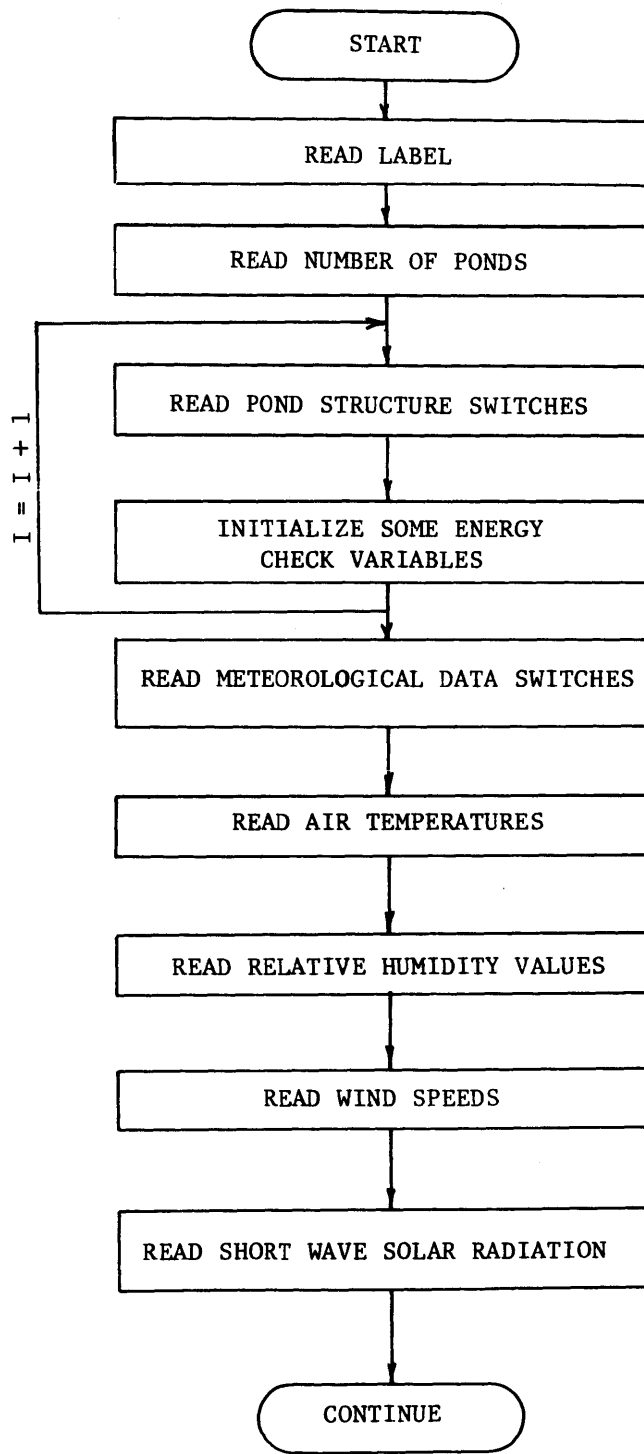


Figure 2-3 cont'd

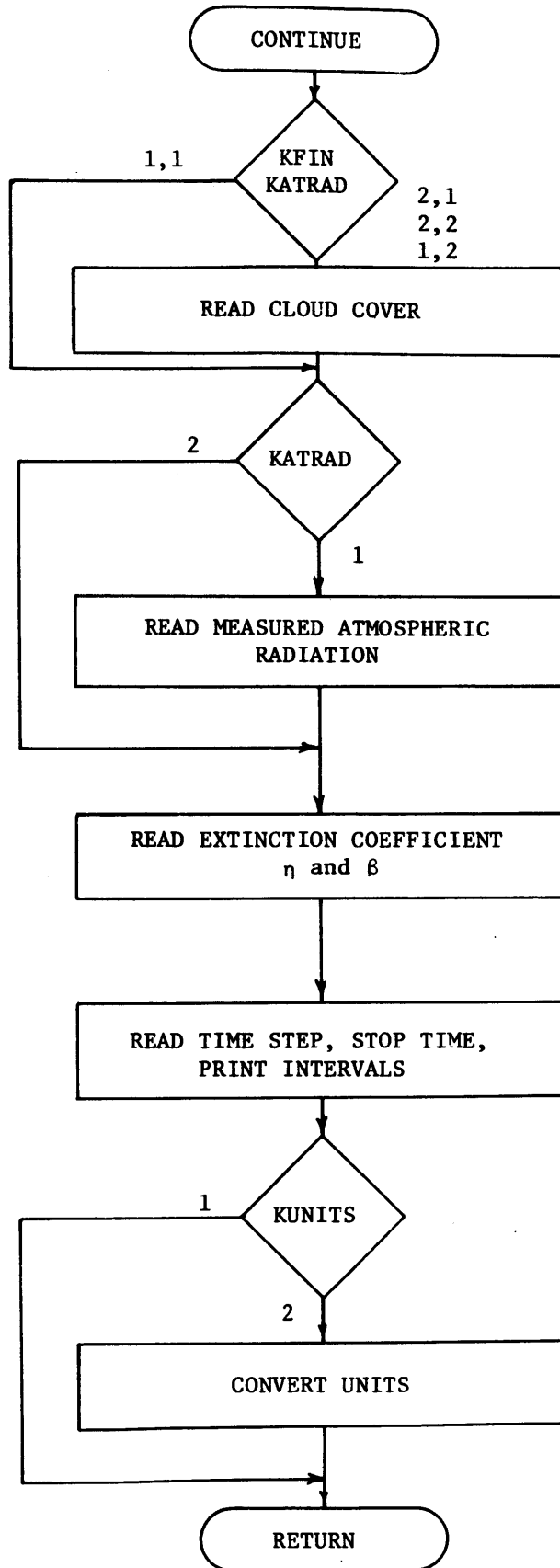


Figure 2-4: Subroutine GEOM1 Flow Chart

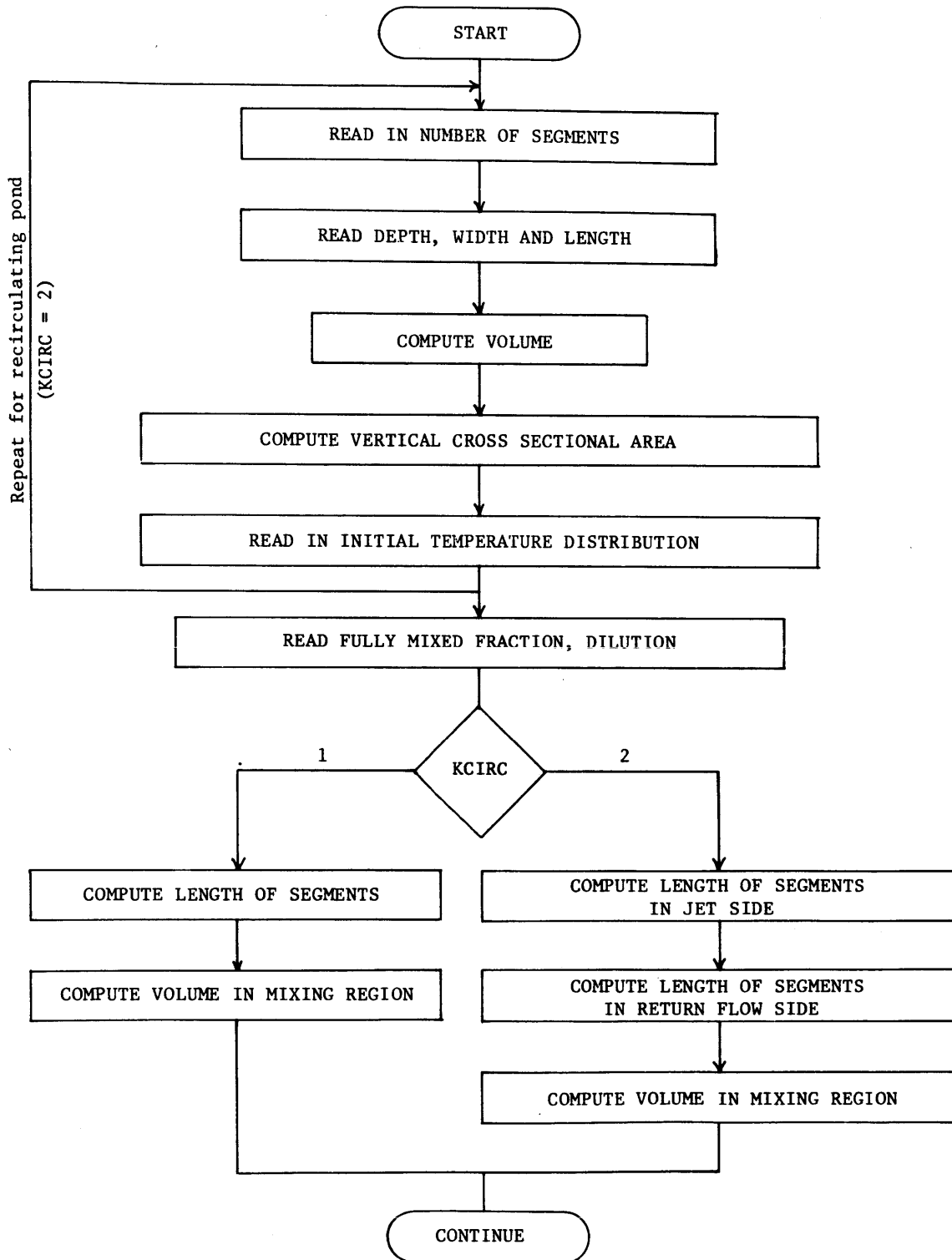


Figure 2-4 Cont'd

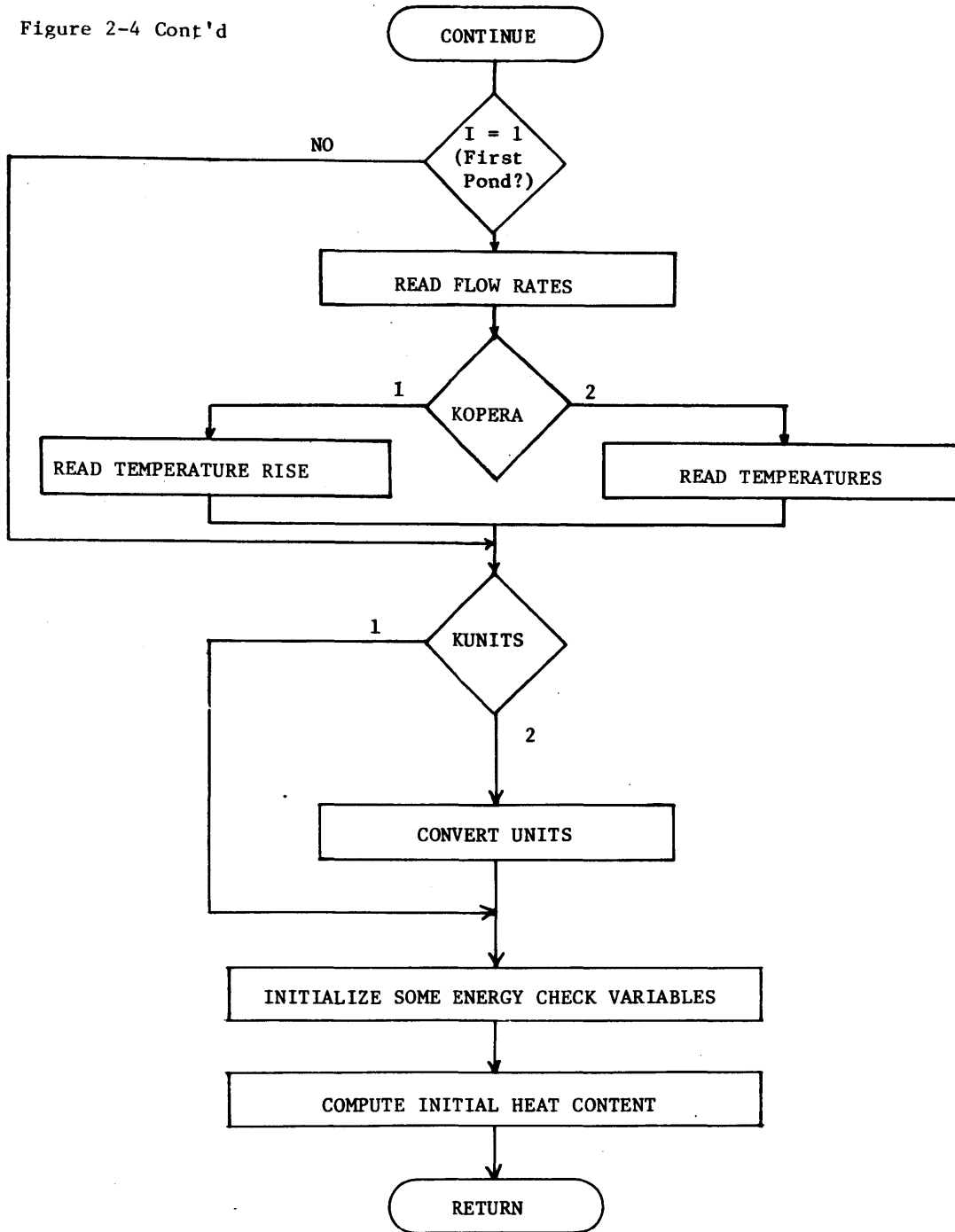


Figure 2-5: Subroutine GEOM2 Flow Chart

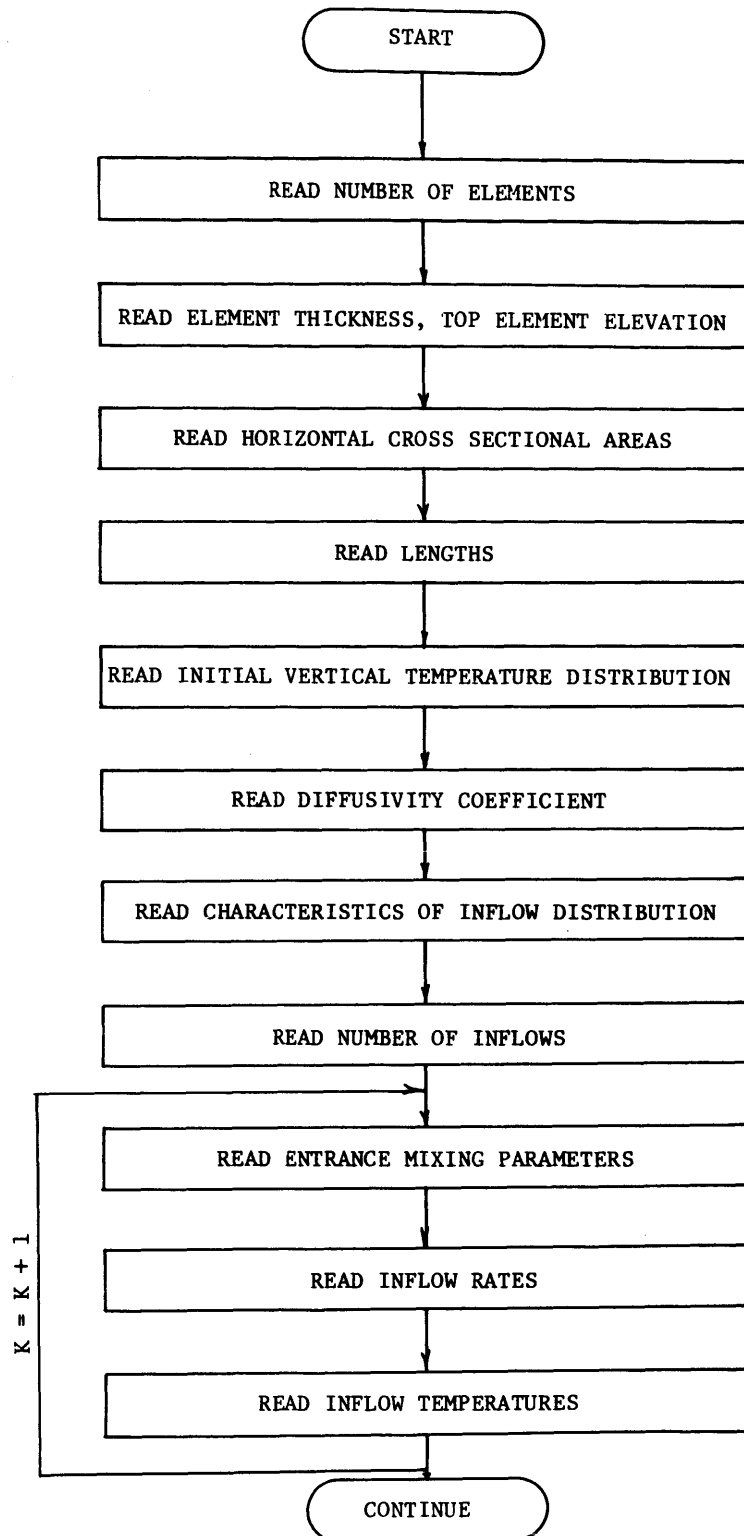


Figure 2-5 Cont'd

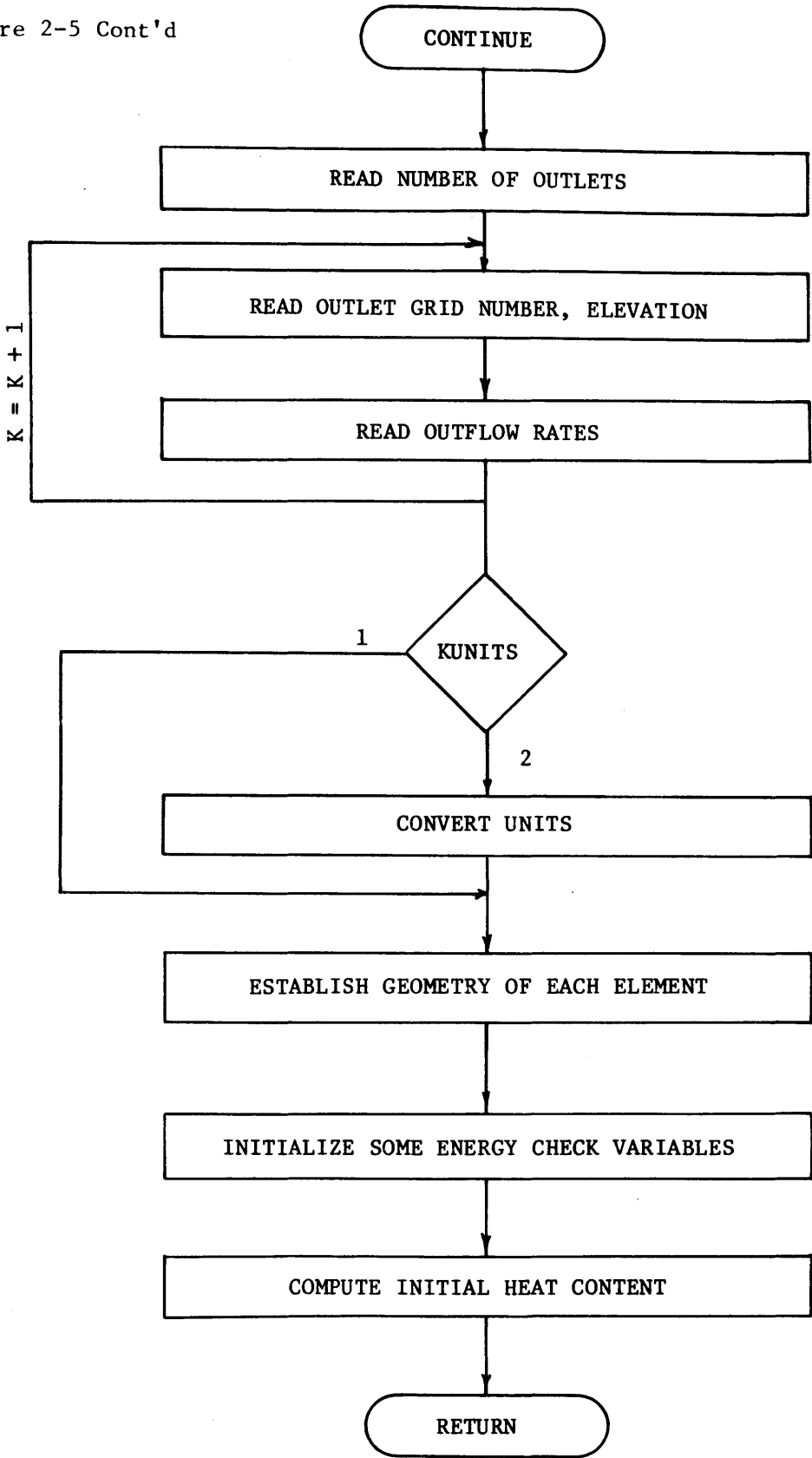


Figure 2-6: Subroutine WEATHR Flow Chart

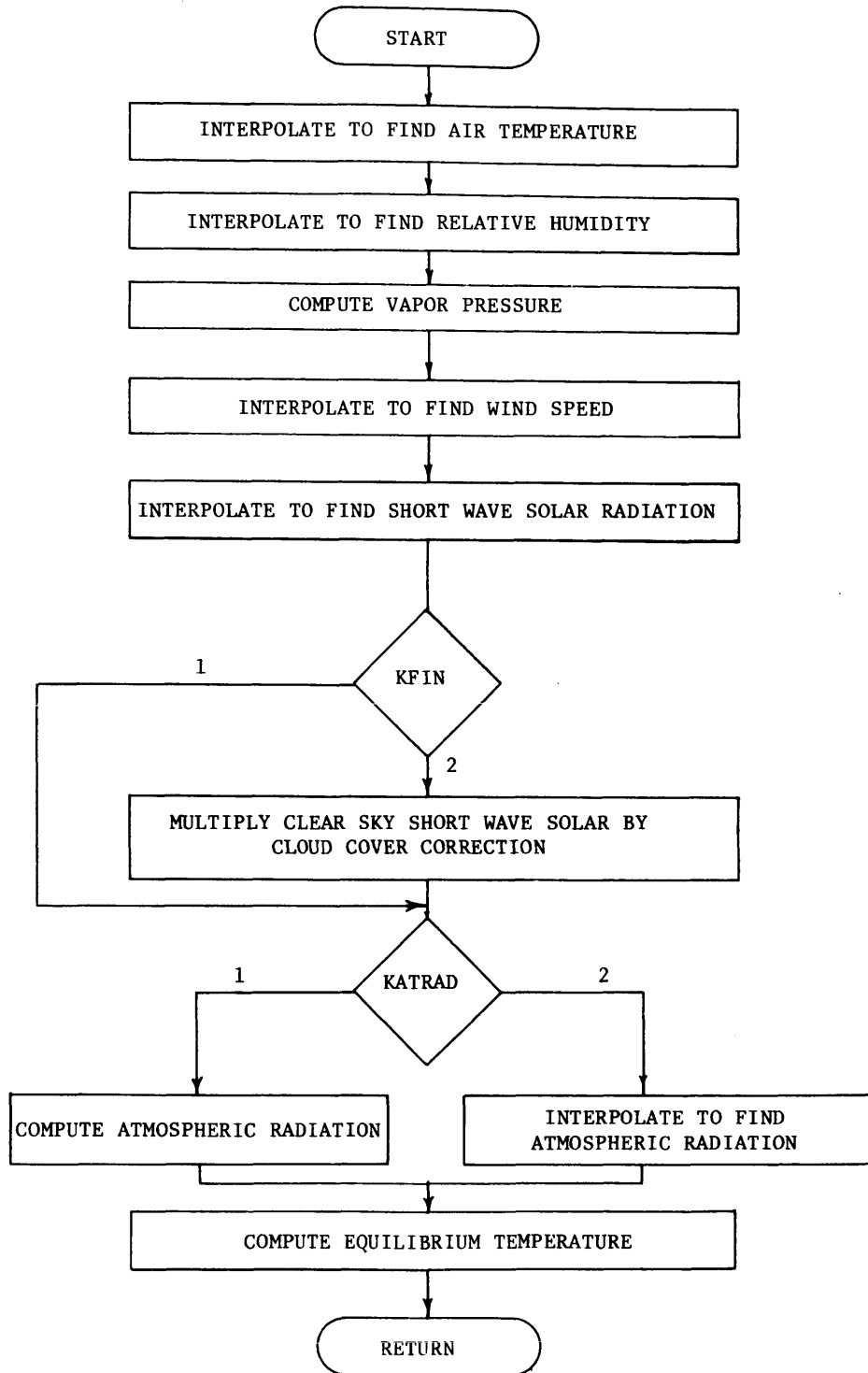


Figure 2-7: Subroutine HEAT Flow Chart

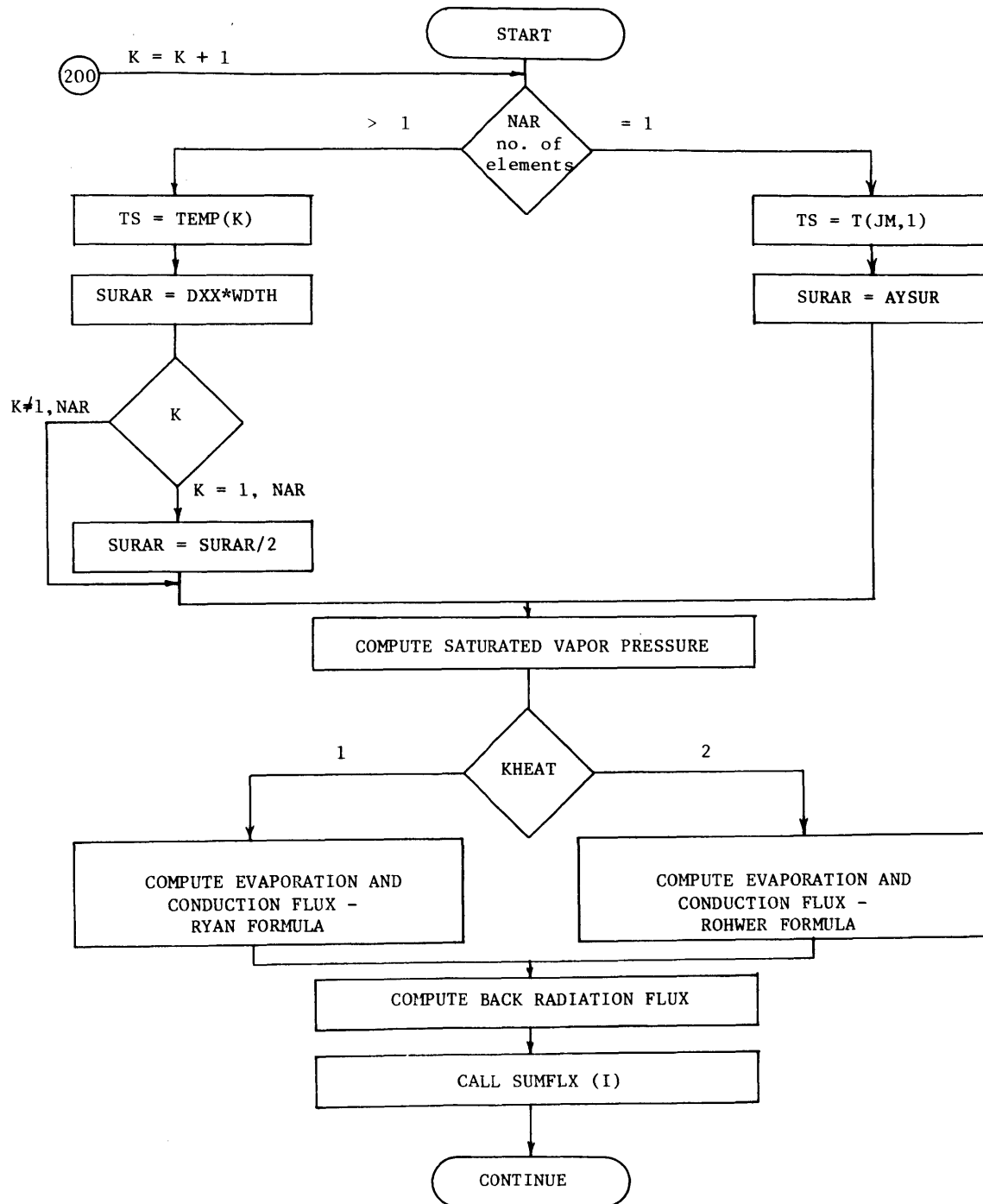


Figure 2-7 Cont'd

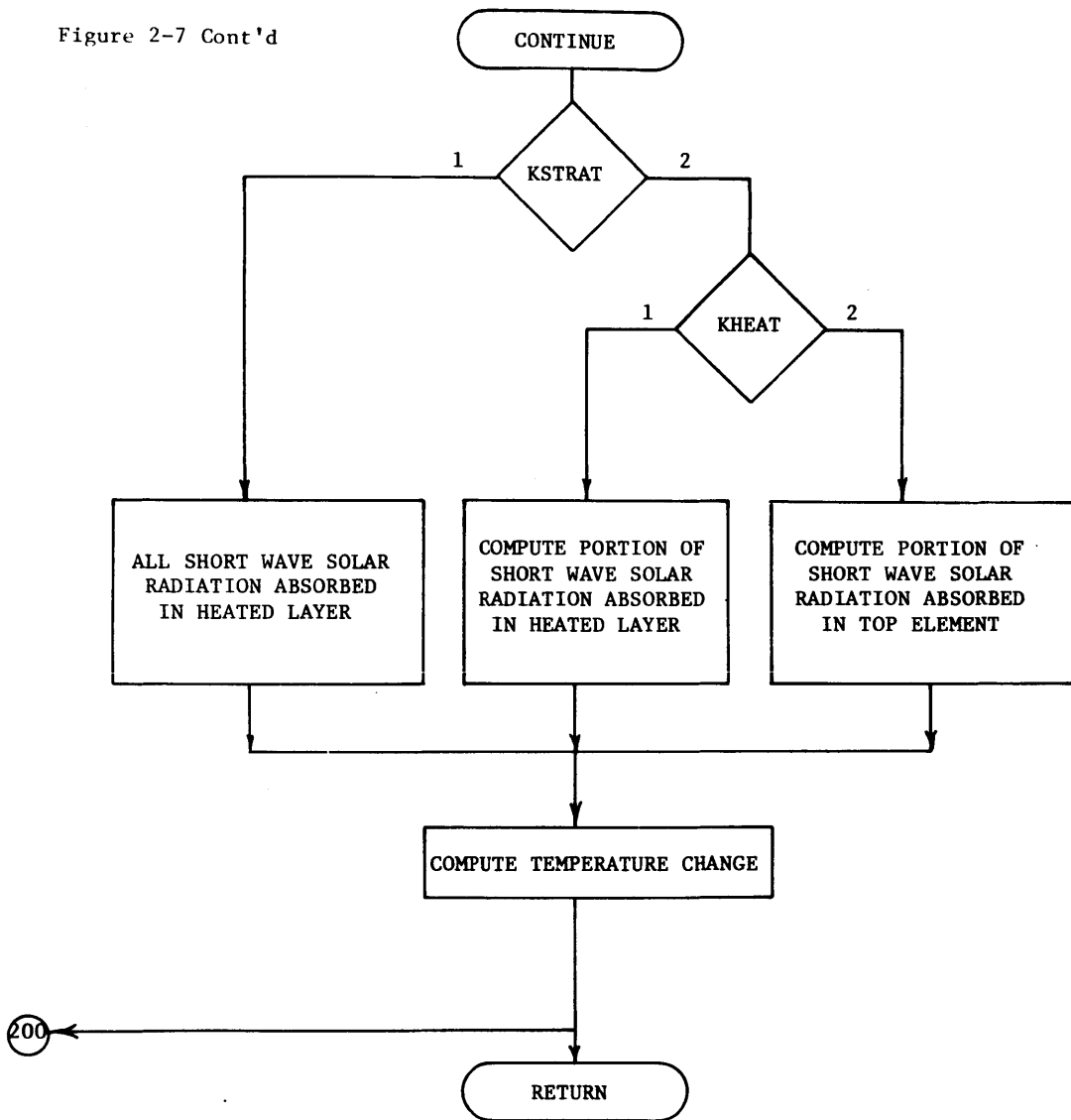


Figure 2-8 Subroutine DISPER Flow Chart

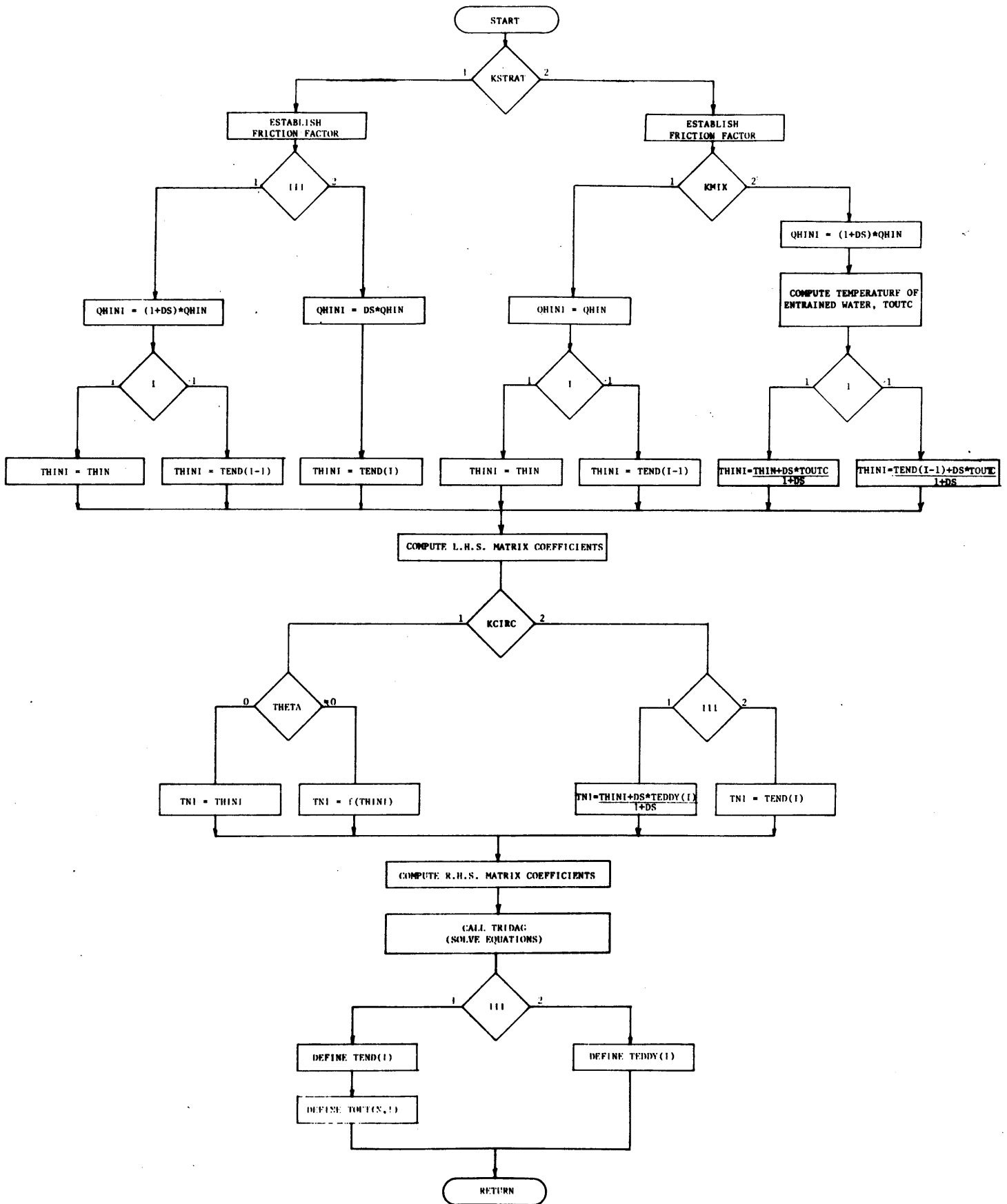


Figure 2-9: Subroutine SUREL Flow Chart

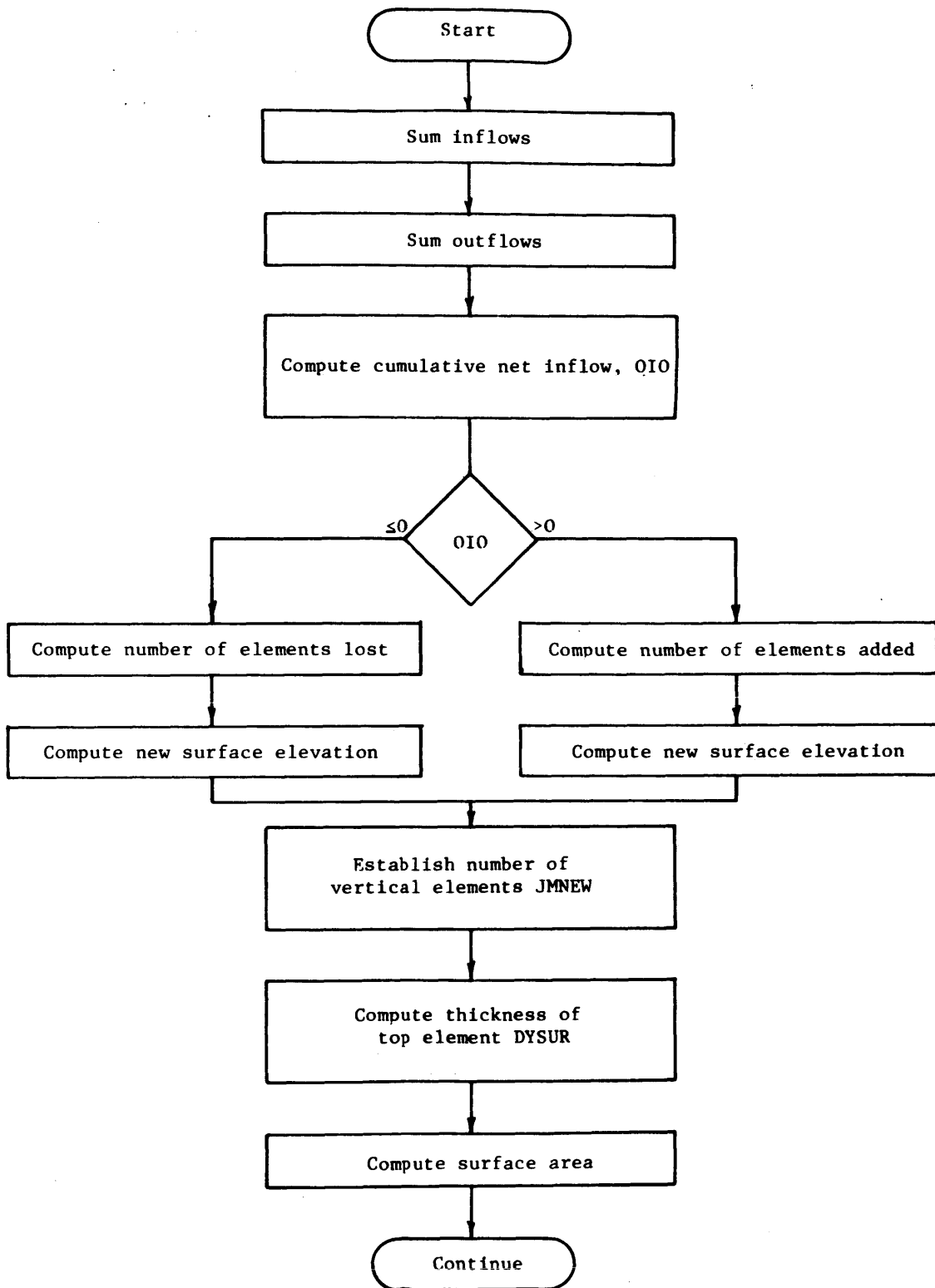


Figure 2-9 Cont'd

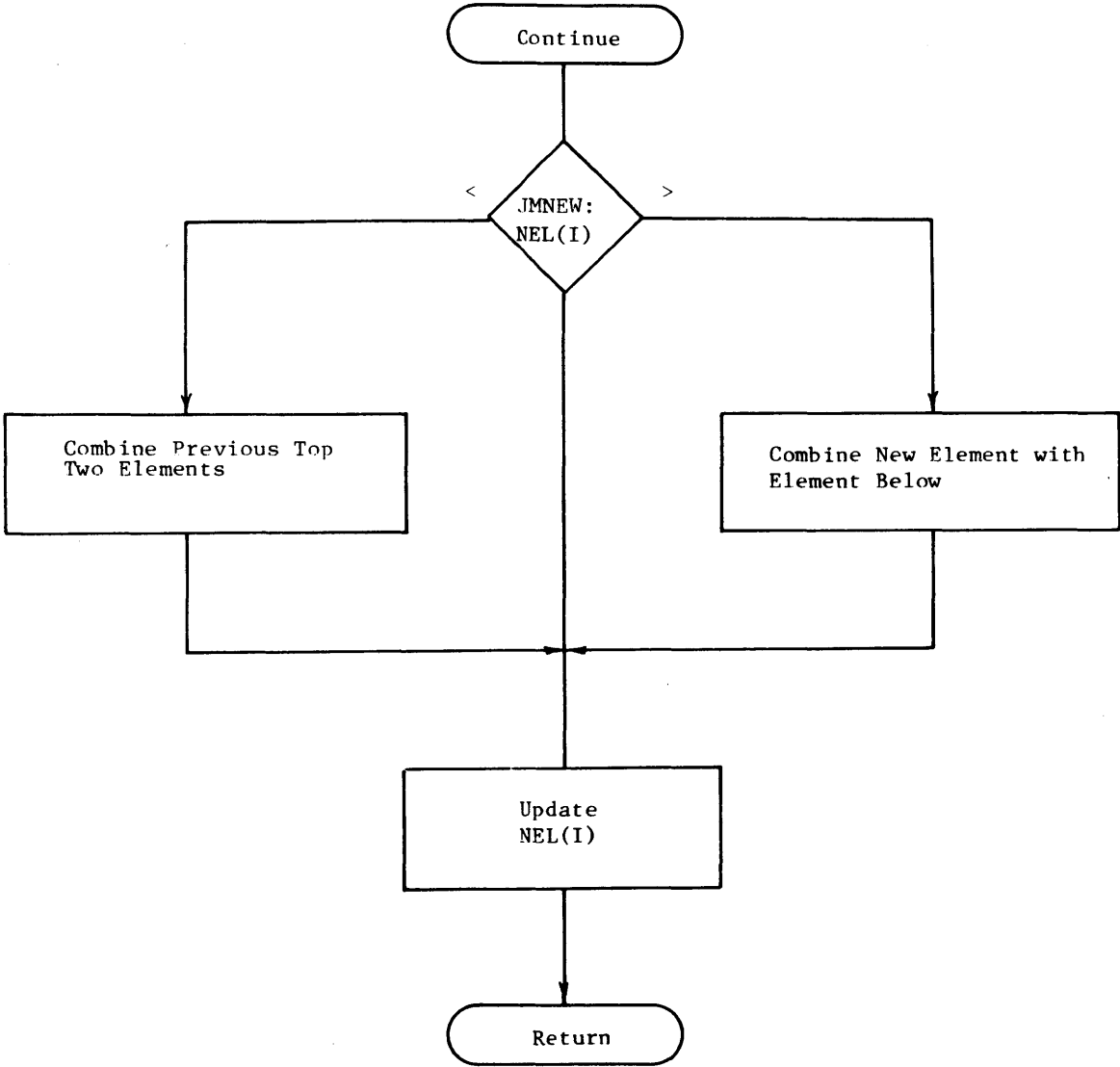


Figure 2-10: Subroutine SPEED Flow Chart

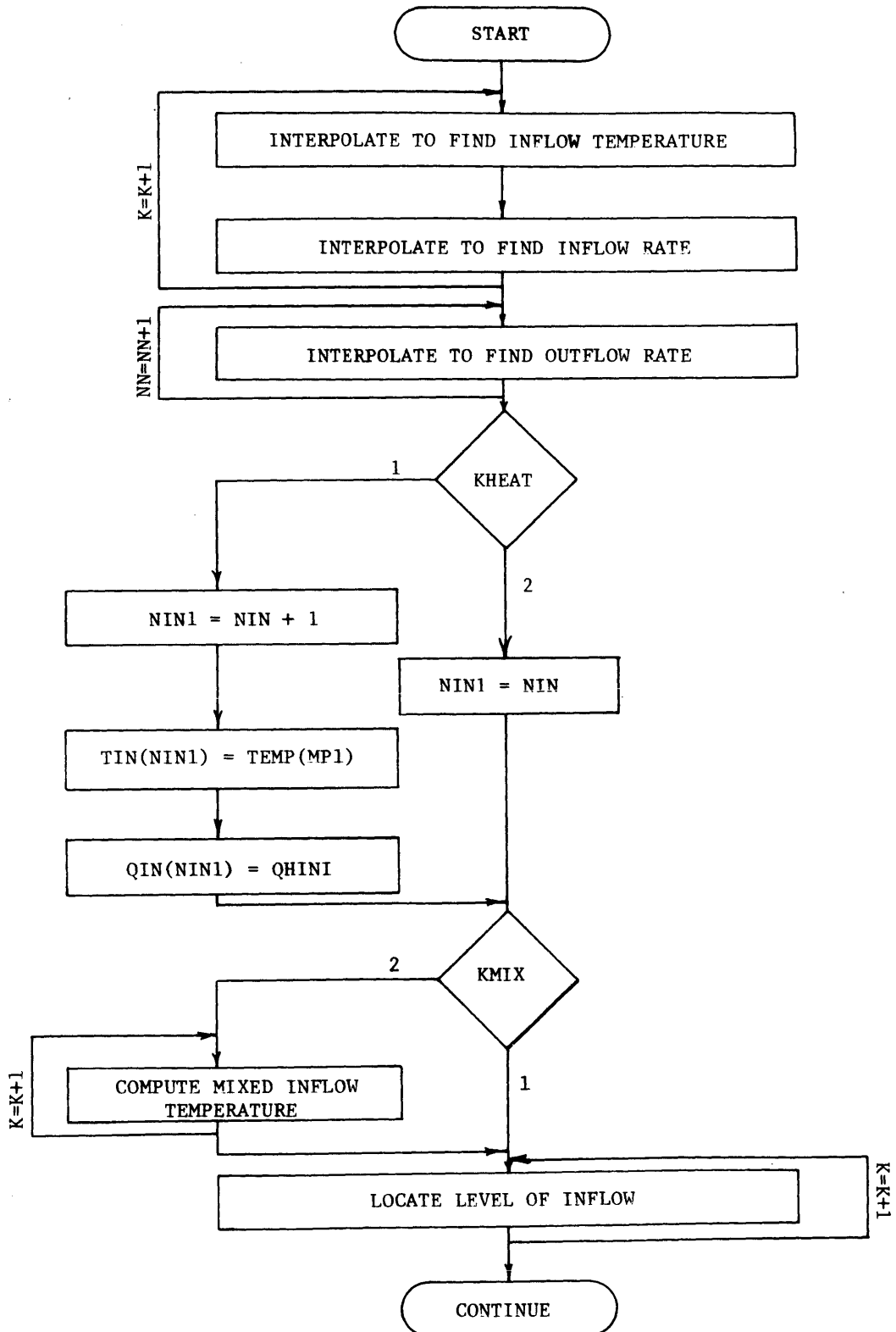


Figure 2-10 Cont'd

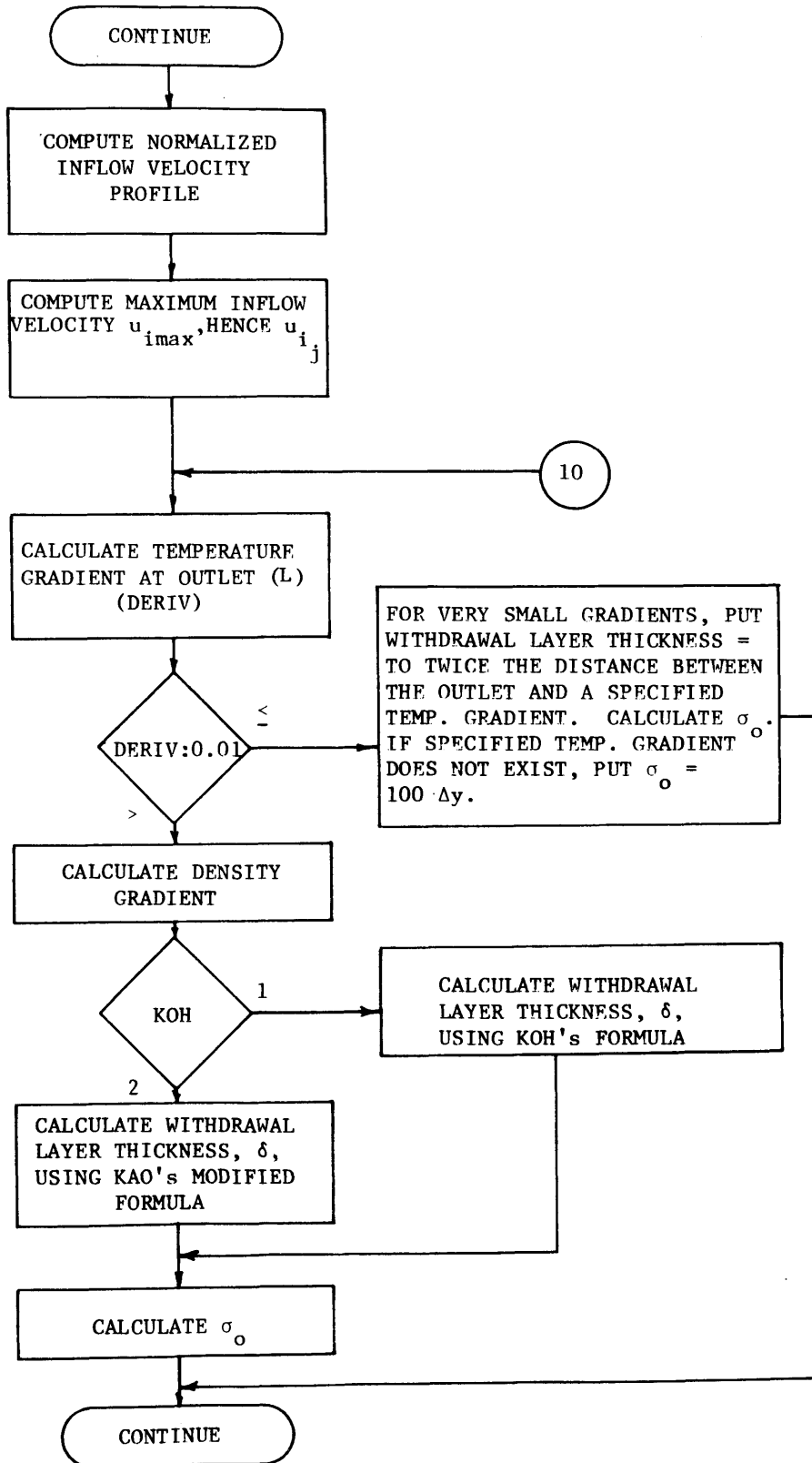


Figure 2-10 Cont'd

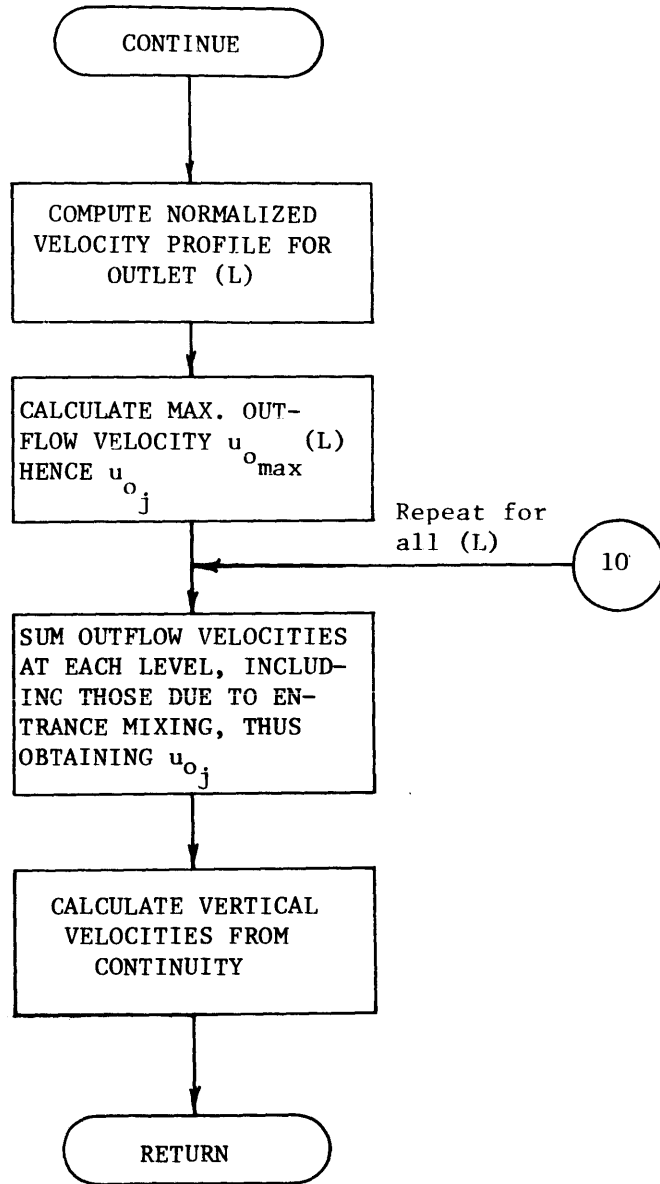


Figure 2-11: Subroutine SUBLAY Flow Chart

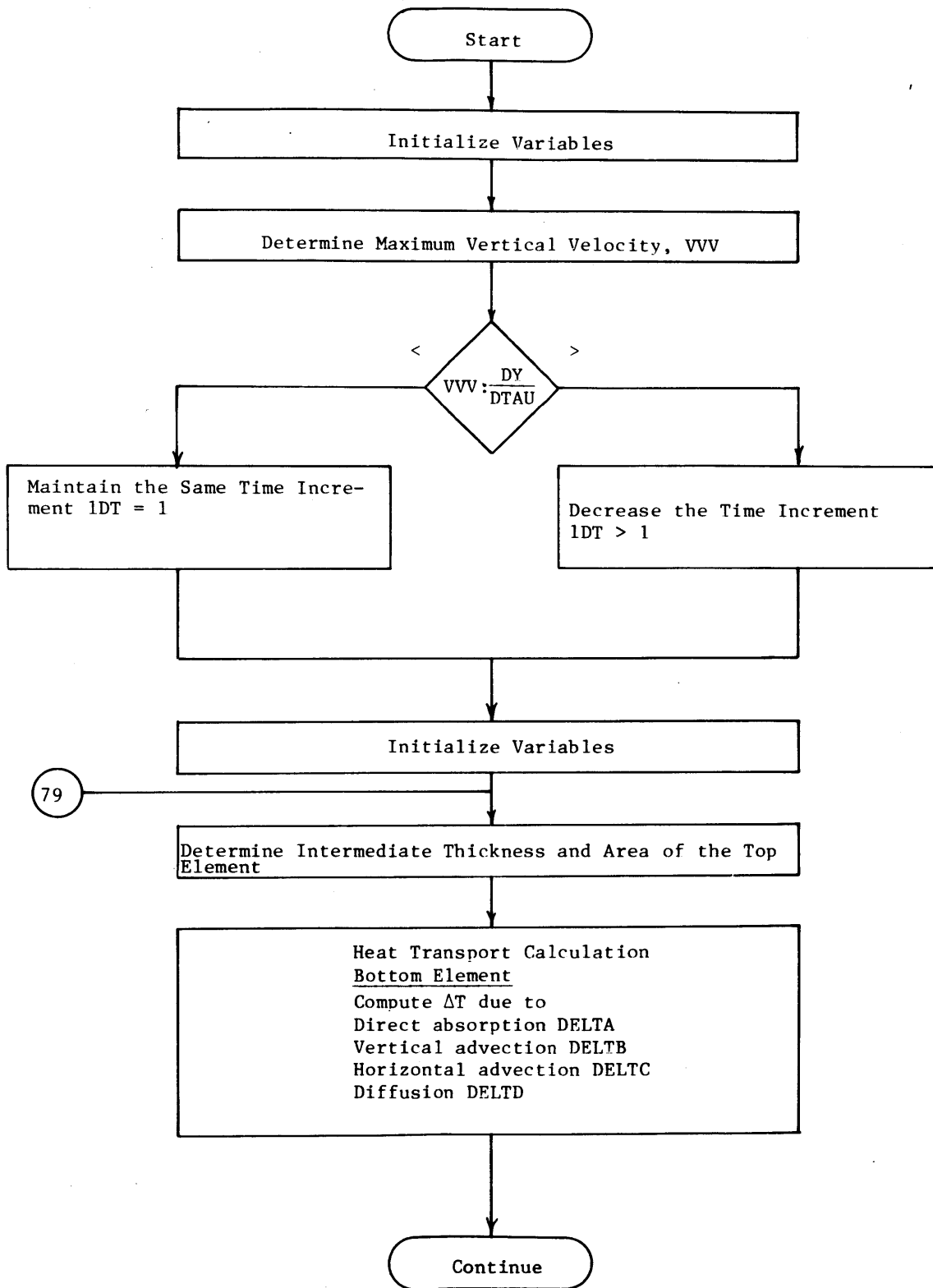


Figure 2-11 Cont'd

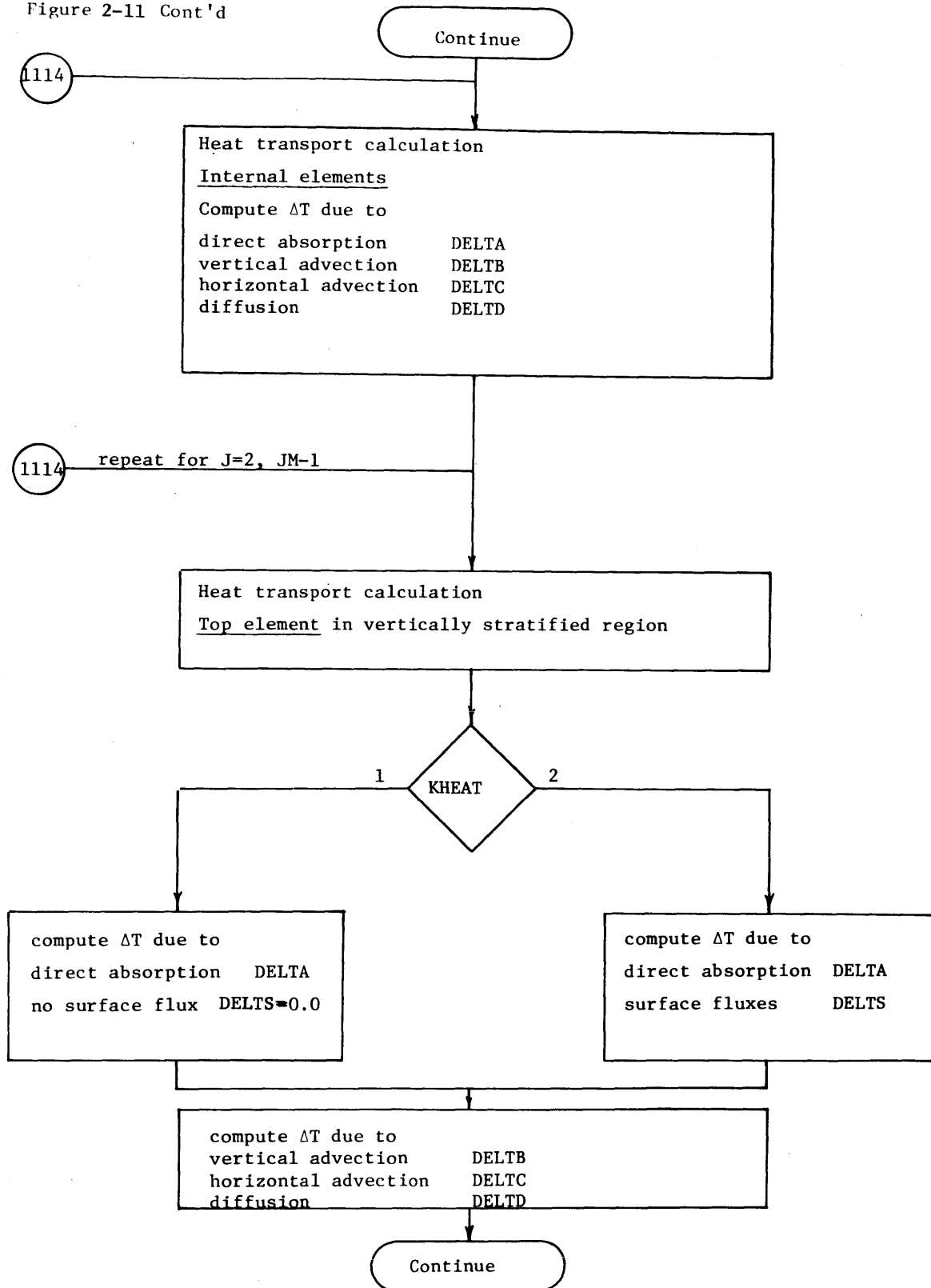


Figure 2-11 Cont'd

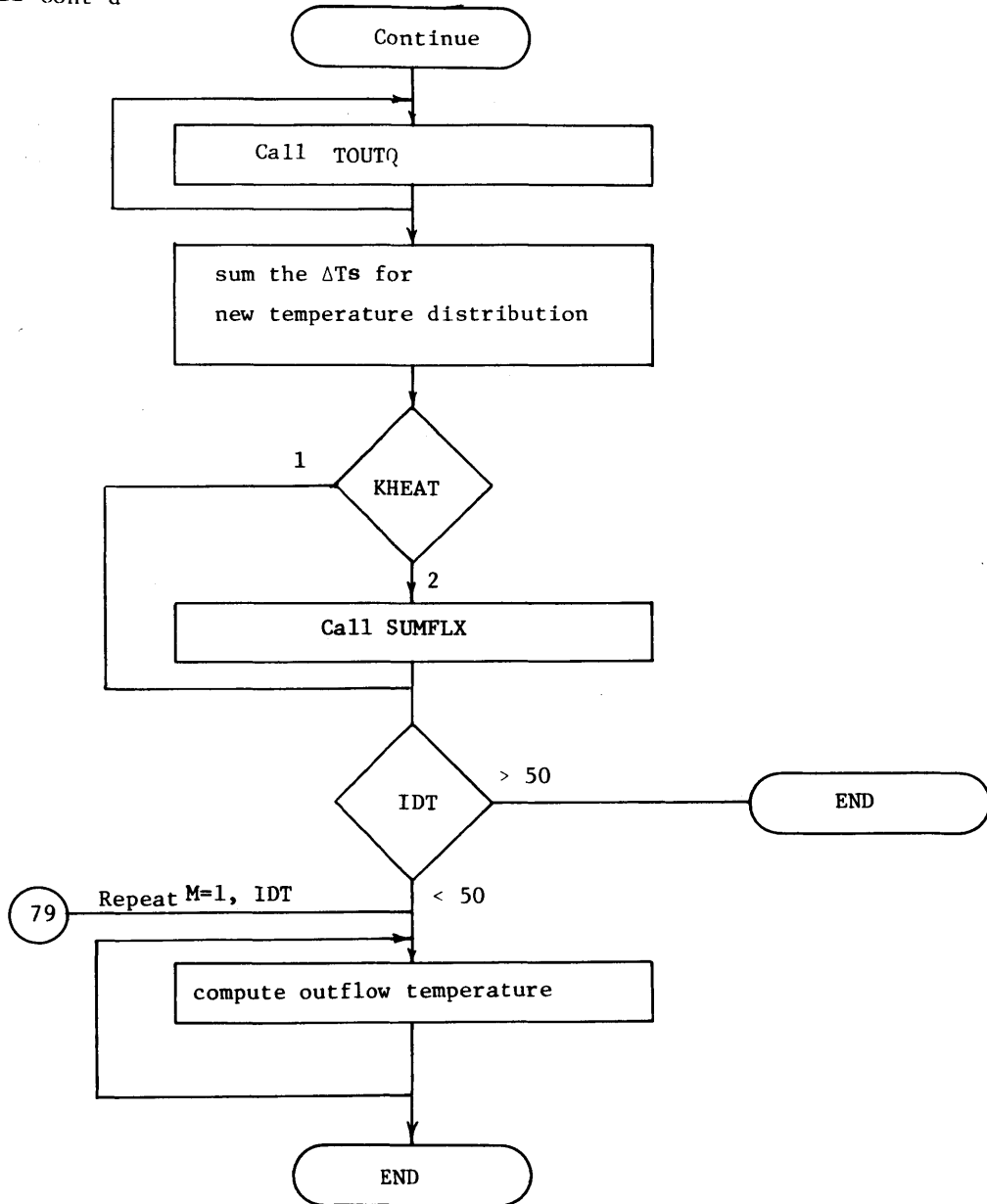


Figure 2-12: Subroutine HTMIX Flow Chart

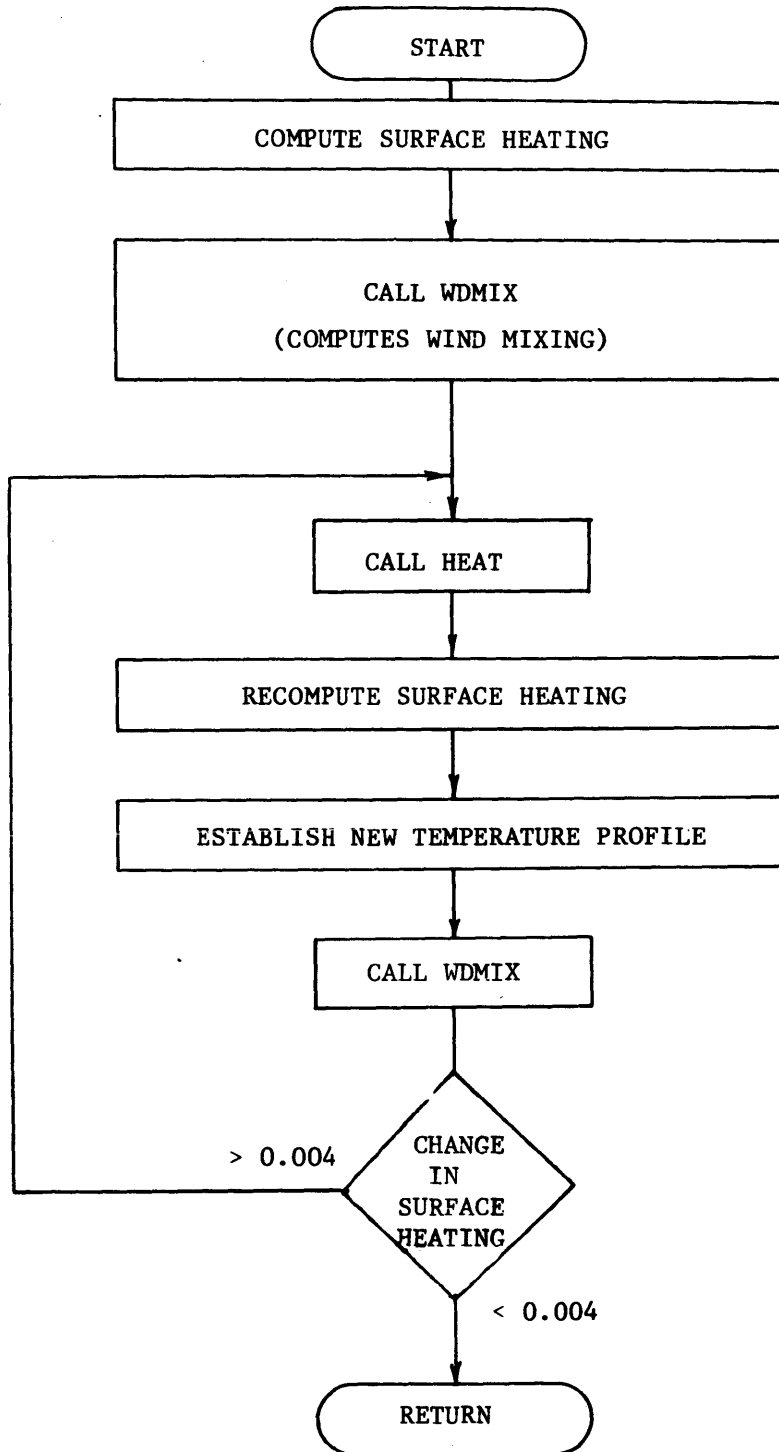


Figure 2-13: Subroutine WDMIX Flow Chart

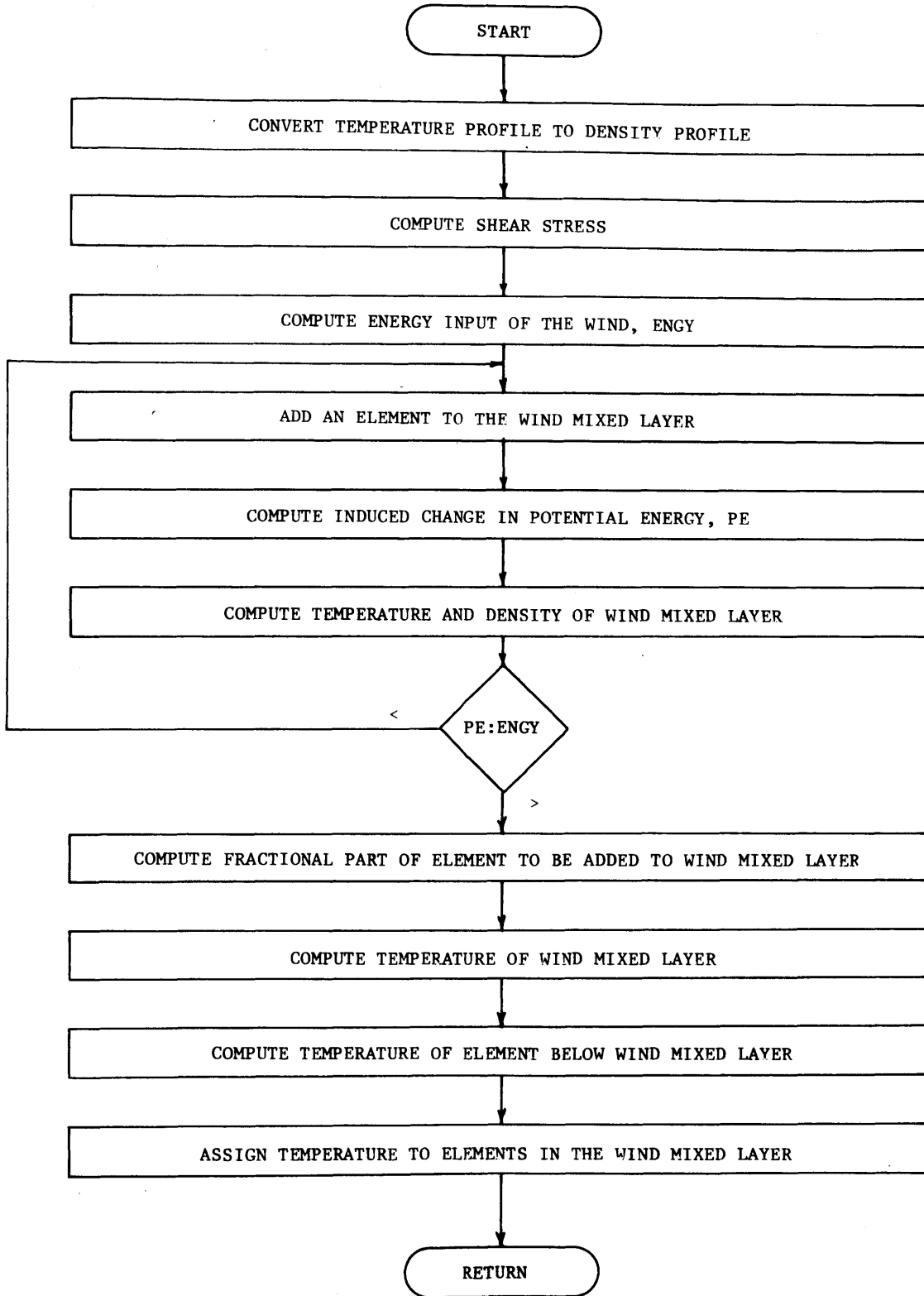


Figure 2-14: Subroutine AVER Flow Chart

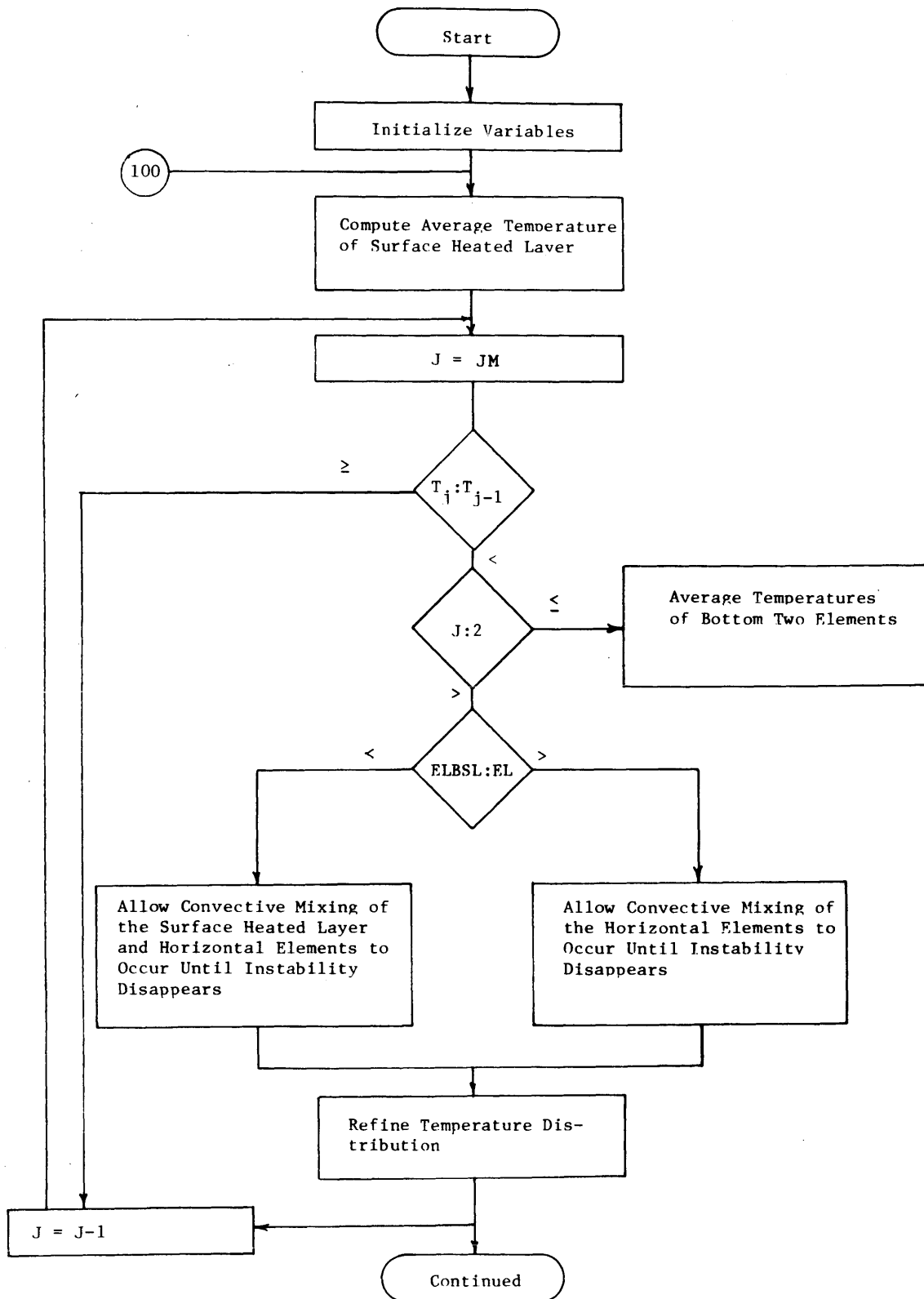


Figure 2-14 Cont'd

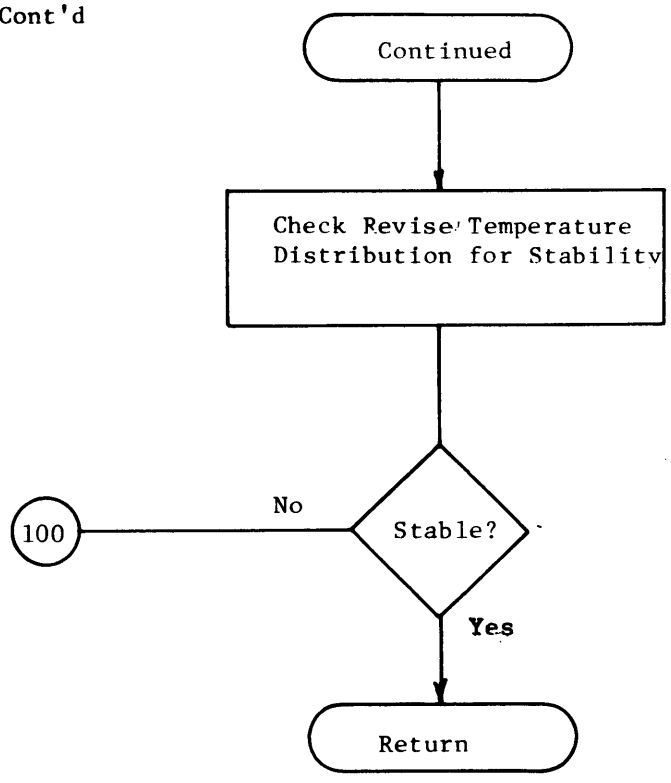
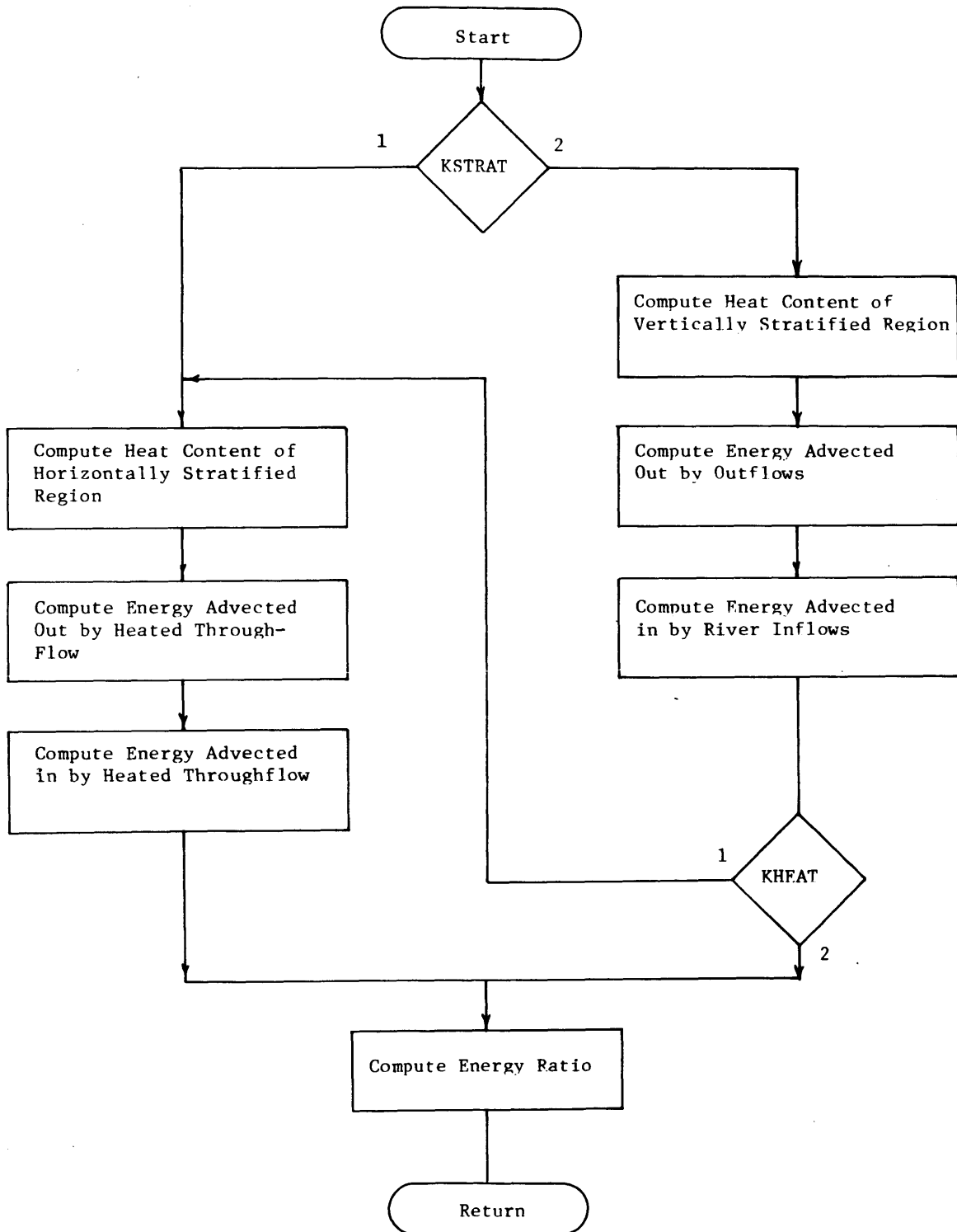


Figure 2-15: Subroutine ENERGY Flow Chart



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)

NNNRUN							
I5							
	10	20	30	40	50	60	70
							80

56

NNNRUN = Number of runs

CARD
1

Table 3.1 Preparation of Input Data for Subroutine MET
System Structure and Meteorological Data

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

TITLE CARD															
WH(M)															
20A4															
	10		20		30		40		50		60		70		80

58

WH(M) = Alphanumeric Heading

MEET
1

SYSTEM SIZE PARAMETER							
NPOND							
5x, I5							
	10	20	30	40	50	60	70
							80

NPOND = number of ponds in series

AIR TEMPERATURE INPUT PARAMETERS									
NTA		DTTA							
5x, I5		F10.5							
		days							
10		20		30		40		50	
								60	
								70	
								80	

62 NTA = Number of Air Temperature Values

DTTA = Time Interval Between Values of TA

MET
5

AIR TEMPERATURE WITH TIME

TA(M) TA(M+1)		TA(M+2) TA(M+3)		TA(M+4) TA(M+5)		TA(M+6) TA(M+7)		TA(M+8) TA(M+9)		TA(M+10) TA(M+11)		TA(M+12) TA(M+13)		TA(M+14) TA(M+15)	
F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1
°C or °F															
10		20		30		40		50		60		70		80	

63

TA(M), TA(M+1), etc = Air Temperature Values

RELATIVE HUMIDITY INPUT PARAMETERS									
NSIGH	DTSIGH								
5x, I5	F10.5								
	days								
	10	20	30	40	50	60	70	80	

64

NSIGH = Number of Relative Humidity Values

DTSIGH = Time Intervals Between Values of SIGH

MET
7

RELATIVE HUMIDITY WITH TIME

SIGH(M) SIGH(M+1)		SIGH(M+2) SIGH(M+3)		SIGH(M+4) SIGH(M+5)		SIGH(M+6) SIGH(M+7)		SIGH(M+8) SIGH(M+9)		SIGH(M+10) SIGH(M+11)		SIGH(M+12) SIGH(M+13)		SIGH(M+14) SIGH(M+15)	
F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1
	10		20		30		40		50		60		70		80

65

SIGH(M), SIGH(M+1), etc. = Relative Humidity Values (0.0 to 1.0)

WIND SPEED INPUT PARAMETERS

NWIND		DTWIND							
5x, 15		F10.5							
		days							
	10		20		30		40		50
									60
									70
									80

66

NWIND = Number of Wind Speed Values

DTWIND = Time Interval Between Values of WIND

WIND SPEED WITH TIME															
WIND(M) WIND(M+1)		WIND(M+2) WIND(M+3)		WIND(M+4) WIND(M+5)		WIND(M+6) WIND(M+7)		WIND(M+8) WIND(M+9)		WIND(M+10) WIND(M+11)		WIND(M+12) WIND(M+13)		WIND(M+14) WIND(M+15)	
F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1
meters/sec or miles/hr															
	10		20		30		40		50		60		70		80

67

WIND(M), WIND(M+1), etc. = Wind Speed Values

MET
10

WIND HEIGHT									
WHGT									
5x, F5.1									
meters or feet									
	10	20	30	40	50	60	70	80	

68

WHGT = Measurement Height for Wind Speed

MET
11

SHORT WAVE SOLAR RADIATION INPUT PARAMETERS

NFIN	DTFIN						
5x, I5	F10.5						
	days						
	10		20		30		40
							50
							60
							70
							80

69

NFIN = Number of Short Wave Solar Radiation Values

DTFIN = Time Interval Between Values of FIN

SHORT WAVE SOLAR RADIATION WITH TIME							
FIN(M)	FIN(M+1)	FIN(M+2)	FIN(M+3)	FIN(M+4)	FIN(M+5)	FIN(M+6)	FIN(M+7)
F10.1	F10.1	F10.1	F10.1	F10.1	F10.1	F10.1	F10.1
Kcal/m ² /day or BTU/ft ² /day							
10	20	30	40	50	60	70	80

70

FIN(M), FIN(M+1), etc. = Short Wave Solar Radiation Values

CLOUD COVER INPUT PARAMETERS							
(Use this card only if KFIN = 2 or KATRAD = 2)							
N CLOUD	D CLOUD						
5x, I5	F10.5						
	days						
	10	20	30	40	50	60	70
							80

71

N CLOUD = Number of Cloud Cover Values

D CLOUD = Time Interval Between Values of CLOUD

MET
14

CLOUD COVER WITH TIME

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

CLOUD(M) CLOUD(M+1)		CLOUD(M+2) CLOUD(M+3)		CLOUD(M+4) CLOUD(M+5)		CLOUD(M+6) CLOUD(M+7)		CLOUD(M+8) CLOUD(M+9)		CLOUD(M+10) CLOUD(M+11)		CLOUD(M+12) CLOUD(M+13)		CLOUD(M+14) CLOUD(M+15)	
F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2	F5.2
	10		20		30		40		50		60		70		80

72

CLOUD(M), CLOUD(M+1), etc. = Cloud Cover Values (0.0 to 1.0)

MET
15

LONG WAVE ATMOSPHERIC RADIATION INPUT PARAMETERS

(use this card only if KATRAD = 1)

NATRAD		DATRAD							
5x, I5		F10.5							
		days							
	10		20		30		40		50
									60
									70
									80

73

NATRAD = Number of Atmospheric Radiation Values

DATRAD = Time Interval Between Values of ATRAD

NET
16

LONG WAVE ATMOSPHERIC RADIATION WITH TIME

(use this card group only if KATRAD = 1)

ATRAD(M)	ATRAD(M+1)	ATRAD(M+2)	ATRAD(M+3)	ATRAD(M+4)	ATRAD(M+5)	ATRAD(M+6)	ATRAD(M+7)
F10.1	F10.1	F10.1	F10.1	F10.1	F10.1	F10.1	F10.1
Kcal/m ² /day or BTU/ft ² /day							
10	20	30	40	50	60	70	80

74 ATRAD(M), ATRAD(M+1), etc. = Long Wave Atmospheric Radiation Values

MET
17

SHORT WAVE SOLAR RADIATION ABSORPTION COEFFICIENTS

ETA	BETA						
F10.1	F10.1						
meters ⁻¹ or feet ⁻¹							
		10	20	30	40	50	60
							70
							80

75

ETA = Extinction Coefficient of Light in Water

BETA = Fraction of Solar Radiation Absorbed at the Surface

MET
18

TIME PARAMETERS									
DTAU		TAUMAX		IFREQ1		IFREQ2		IFREQA	
F10.2		F10.2		I10		I10		I10	
days		days							
10		20		30		40		50	
								60	
								70	
								80	

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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

MET
19

NUMBER OF DATES ON WHICH OUTPUT IS REQUIRED							
NDD							
5x, I5							
	10	20	30	40	50	60	70
							80

77

NDD = Number of Dates on which Output is Required

MET
20

STARTING DATE OF RUN									
MMO	MDY	MYR							
I2	1x,I2	1x,I4							
	10	20	30	40	50	60	70	80	

78

MMO = Starting Date Month
 MDY = Starting Date Day
 MYR = Starting Date Year

 MMO/MDY/MYR

MET
21

DATES OUTPUT IS REQUIRED FOR
 (Repeat Card NPD Times)

IPDAT(1,I)	IPDAT(2,I)	IPDAT(3,I)					
I2	1x,I2	1x,I2					
10	20	30	40	50	60	70	80

79

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

<u>CARD</u>		<u>TYPE</u>
GEOM2	1	Vertical Grid Parameters
GEOM2	2	Vertical Grid Parameters
GEOM2	3	Cross Sectional Area Input Parameters
GEOM2	4	Cross Sectional Areas with Depth
GEOM2	5	Length Input Parameters
GEOM2	6	Lengths with Depth
GEOM2	7	Initial Vertical Temperature Distribution
GEOM2	8	Vertical Diffusivity
GEOM2	9	Inflow Distribution Parameters
GEOM2	10	Number of River Inflows
GEOM2	11	Inflow Mixing Parameters
GEOM2	12	Inflow Input Parameters
GEOM2	13	Inflow Rate with Time
GEOM2	14	Inflow Temperature with Time
GEOM2	15	Number of Outlets
GEOM2	16	Outlet Parameters
GEOM2	17	Outflow Input Parameters
GEOM2	18	Outflow Rates with Time

VERTICAL GRID PARAMETERS

DYY(I)	YSURI(I)						
F10.5	F10.5						
meters or feet	meters or feet						
10	20	30	40	50	60	70	80

82

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)

CROSS SECTIONAL AREA INPUT PARAMETERS									
NAA(I)	DAA(I)	AAB(I)							
5x,I5	F10.5	F10.5							
	meters or feet	meters or feet							
	10	20	30	40	50	60	70	80	

83

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							
AA(J,I)	AA(J+1,I)	AA(J+2,I)	AA(J+3,I)	AA(J+4,I)	AA(J+5,I)	AA(J+6,I)	AA(J+7,I)
F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2
meters or feet							
	10	20	30	40	50	60	70
							80

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

LENGTH INPUT PARAMETERS										
NXXL(I)	DXXL(I)		XXLB(I)							
5x,I5	F10.5		F10.5							
	meters or feet		meters or feet							
	10	20	30	40	50	60	70	80		

85

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)

LENGTHS WITH DEPTH							
XXL(J,I)	XXL(J+1,I)	XXL(J+2,I)	XXL(J+3,I)	XXL(J+4,I)	XXL(J+5,I)	XXL(J+6,I)	XXL(J+7,I)
F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2	F10.2
meters or feet							
10	20	30	40	50	60	70	80

86

XXL(J,I), XXL(J+1,I), etc. = Values of Horizontal Lengths for Pond I

INITIAL VERTICAL TEMPERATURE DISTRIBUTION

TLOW(J,I) TLOW(J+1,I)	TLOW(J+2,I) TLOW(J+3,I)	TLOW(J+4,I) TLOW(J+5,I)	TLOW(J+6,I) TLOW(J+7,I)	TLOW(J+8,I) TLOW(J+9,I)	TLOW(J+10,I) TLOW(J+11,I)	TLOW(J+12,I) TLOW(J+13,I)	TLOW(J+14,I) TLOW(J+15,I)
F5.1 F5.1	F5.1 F5.1	F5.1 F5.1	F5.1 F5.1	F5.1 F5.1	F5.1 F5.1	F5.1 F5.1	F5.1 F5.1
°C or °F							
10	20	30	40	50	60	70	80

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

VERTICAL DIFFUSIVITY							
DD(1,I)							
F10.5							
m ² /day or ft ² /day							
	10	20	30	40	50	60	70
							80

88

DD(1,I) = Value of Vertical Diffusion Coefficient in Pond I

INFLOW DISTRIBUTION PARAMETERS							
SPREAD	SIGMAI						
F10.5	F10.5						
	10		20		30		40
					50		60
							70
							80

89

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

SIGMAI = Inflow Standard Deviation

NUMBER OF RIVER INFLOWS									
NIN(I)									
5x, I5									
	10	20	30	40	50	60	70		80

90

NIN(I) = Number of River Inflows into Pond I

GEOM2
10

INFLOW INPUT PARAMETERS

NQIN(K, I)	DTQIN(K, I)														
5x, I5	F10.5														
	days														
	10		20		30		40		50		60		70		80

92

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)

INFLOW RATE WITH TIME						
QQIN(M,K,I)	QQIN(M+1,K,I)	QQIN(M+2,K,I)	QQIN(M+3,K,I)	QQIN(M+4,K,I)	QQIN(M+5,K,I)	
F12.1	F12.1	F12.1	F12.1	F12.1	F12.1	
m ³ /day or ft ³ /day						
	10		20		30	
				40		50
					60	
						70
						80

93 QQIN(M,K,I), QQIN(M+1,K,I), etc. = Inflow Rates for River Inflow K in Pond I

INFLOW TEMPERATURE WITH TIME

TTIN(M,K,I)		TTIN(M+2,K,I)		TTIN(M+4,K,I)		TTIN(M+6,K,I)		TTIN(M+8,K,I)		TTIN(M+10,K,I)		TTIN(M+12,K,I)		TTIN(M+14,K,I)	
TTIN(M+1,K,I)		TTIN(M+3,K,I)		TTIN(M+5,K,I)		TTIN(M+7,K,I)		TTIN(M+9,K,I)		TTIN(M+11,K,I)		TTIN(M+13,K,I)		TTIN(M+15,K,I)	
F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1
°C or °F															
10		20		30		40		50		60		70		80	

94

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

GEOM2
14

NUMBER OF OUTLETS							
NOUT(I)							
5x, I5							
	10	20	30	40	50	60	70
							80

95

NOUT(I) = Number of Outlets in Pond I

GEOM2
15

OUTFLOW INPUT PARAMETERS

OUTFLOW INPUT PARAMETERS									
NQO(K,I)		DTQO(K,I)							
5x,I5		F10.5							
		days							
	10		20		30		40		50
									60
									70
									80

97 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)

OUTFLOW RATES WITH TIME						
QO(M,K,I)	QO(M+1,K,I)	QO(M+2,K,I)	QO(M+3,K,I)	QO(M+4,K,I)	QO(M+5,K,I)	
F12.1	F12.1	F12.1	F12.1	F12.1	F12.1	
m ³ /day or ft ³ /day						
	10		20		30	
				40		
					50	
						60
						70
						80

98 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

<u>CARD</u>	<u>TYPE</u>
GEOM1 1	Horizontal Grid Parameter
GEOM1 2	Heated Layer Geometry Parameters
GEOM1 3	Horizontal Temperature Distribution Parameter
GEOM1 4	Initial Horizontal Temperature Distribution
GEOM1 5	Entrance Mixing Parameters
GEOM1 6	Heated Inflow Input Parameters
GEOM1 7	Heated Inflow Rate with Time
GEOM1 8	Heated Inflow Temperature with Time

HORIZONTAL GRID PARAMETER

(cards GEOM1-1, GEOM1-2, GEOM1-3 and GEOM1-4 form a package and must be repeated KCIRC(I) times)

NSEG(I, III)									
5x, I5									
	10	20	30	40	50	60	70	80	

100

NSEG(I, III) = Number of Segments in Dispersive Flow Region of Pond I, Side III

GEOM1
1

HEATED LAYER GEOMETRY PARAMETERS

HEATED LAYER GEOMETRY PARAMETERS										
DZ(I,III)	WDTH(I,III)		LENGTH(I,III)							
F15.3	F15.3		F15.3							
meters or feet	meters or feet		meters or feet							
	10		20		30		40		50	
									60	
										70
										80

101

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

HORIZONTAL TEMPERATURE DISTRIBUTION PARAMETER									
NTO(I, III)									
5x, I5									
	10		20		30		40		50
									60
									70
									80

102

NTO(I, III) = Number of Initial Temperatures to be Read in for Pond I, Side III

INITIAL HORIZONTAL TEMPERATURE DISTRIBUTION																	
THLM(J,I,III)		THLM(J+2,I,III)		THLM(J+4,I,III)		THLM(J+6,I,III)		THLM(J+8,I,III)		THLM(J+10,I,III)		THLM(J+12,I,III)		THLM(J+14,I,III)			
THLM(J+1,I,III)		THLM(J+3,I,III)		THLM(J+5,I,III)		THLM(J+7,I,III)		THLM(J+9,I,III)		THLM(J+11,I,III)		THLM(J+13,I,III)		THLM(J+15,I,III)			
F5.1 F5.1		F5.1 F5.1		F5.1 F5.1		F5.1 F5.1		F5.1 F5.1		F5.1 F5.1		F5.1 F5.1		F5.1 F5.1			
°C or °F																	
		10		20		30		40		50		60		70		80	

103 THLM(J,I,III) = Initial Temperature Distribution in the Heated Layer of Pond I, Site III

ENTRANCE MIXING PARAMETERS

THETA(I)		DSS(I)							
F10.5		F10.5							
	10		20		30		40		50
									60
									70
									80

104

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

DSS(I) = Entrainment Coefficient for Pond I

GEOM1
5

HEATED INFLOW INPUT PARAMETERS
 (use this card only for Pond 1)

NQHIN	DTQHIN								
5x, 15	F 10.5								
	days								
	10		20		30		40		50
									60
									70
									80

105

NQHIN = Number of Heated Inflow Rate Values

DTQHIN = Time Interval Between Values of QQHIN

HEATED INFLOW RATE WITH TIME
 (use this card only for Pond 1)

QQHIN(M)	QQHIN(M+1)	QQHIN(M+2)	QQHIN(M+3)	QQHIN(M+4)	QQHIN(M+5)	
F12.1	F12.1	F12.1	F12.1	F12.1	F12.1	
m ³ /day or ft ³ /day						
10	20	30	40	50	60	70 80

106

QQHIN(M), QQHIN(M+1), etc. = Heated Inflow Rates

GEOM1
7

TEMPERATURE RISE ACROSS CONDENSER

(use this card only for Pond 1 and only when KOPERA = 1)

DTEMP							
F5.1							
°C or °F							
	10	20	30	40	50	60	70
							80

107

DTEMP = Temp rise across condenser

GEOM1
8

HEATED INFLOW TEMPERATURE WITH TIME

(use this card only for Pond 1 and only when KOPERA = 2)

TTHIN(M)		TTHIN(M+2)		TTHIN(M+4)		TTHIN(M+6)		TTHIN(M+8)		TTHIN(M+10)		TTHIN(M+12)		TTHIN(M+14)	
TTHIN(M+1)		TTHIN(M+3)		TTHIN(M+5)		TTHIN(M+7)		TTHIN(M+9)		TTHIN(M+11)		TTHIN(M+13)		TTHIN(M+15)	
F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1	F5.1
°C or															
°F															
10		20		30		40		50		60		70		80	

198 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 modular 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 4.1 Summary of Physical Characteristics of Cooling Lakes and Ponds Discussed in Chapter IV

Lake or Pond	Surface Area (acres)	Station Capacity (MWe)	Thermal Loading (MWt/acre)	No. of Major Compartments	P	L/W	Classification (each compartment)
Lake Anna ¹	4300	3784 (nuclear)	0.5	1	0.3	~3	deep stratified
Dresden	1275	1600 (nuclear)	2.1	3	0.9	5-20	vert. mixed dispersive
Powerton	1442	1670 (fossil)	1.7	3	0.5	~2	vert. mixed recirculating
Collins	2009	2520 (fossil)	1.5	2	0.7	6-10	vert. mixed dispersive
La Salle	2058	2156 (nuclear)	2.1	3	0.4	3	bracket between vert. mixed recirculating and deep stratified
Braidwood	2539	2200 (nuclear)	1.8	2	0.6	1.3 (1st) 10 (2nd)	vert. mixed recirculating(1st) vert. mixed dispersive(2nd)
Merom Lake	1550	980 (fossil)	0.9	1	0.3	3	deep stratified

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 10.6×10^9 ft³, 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 2.66×10^9 ft³ 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

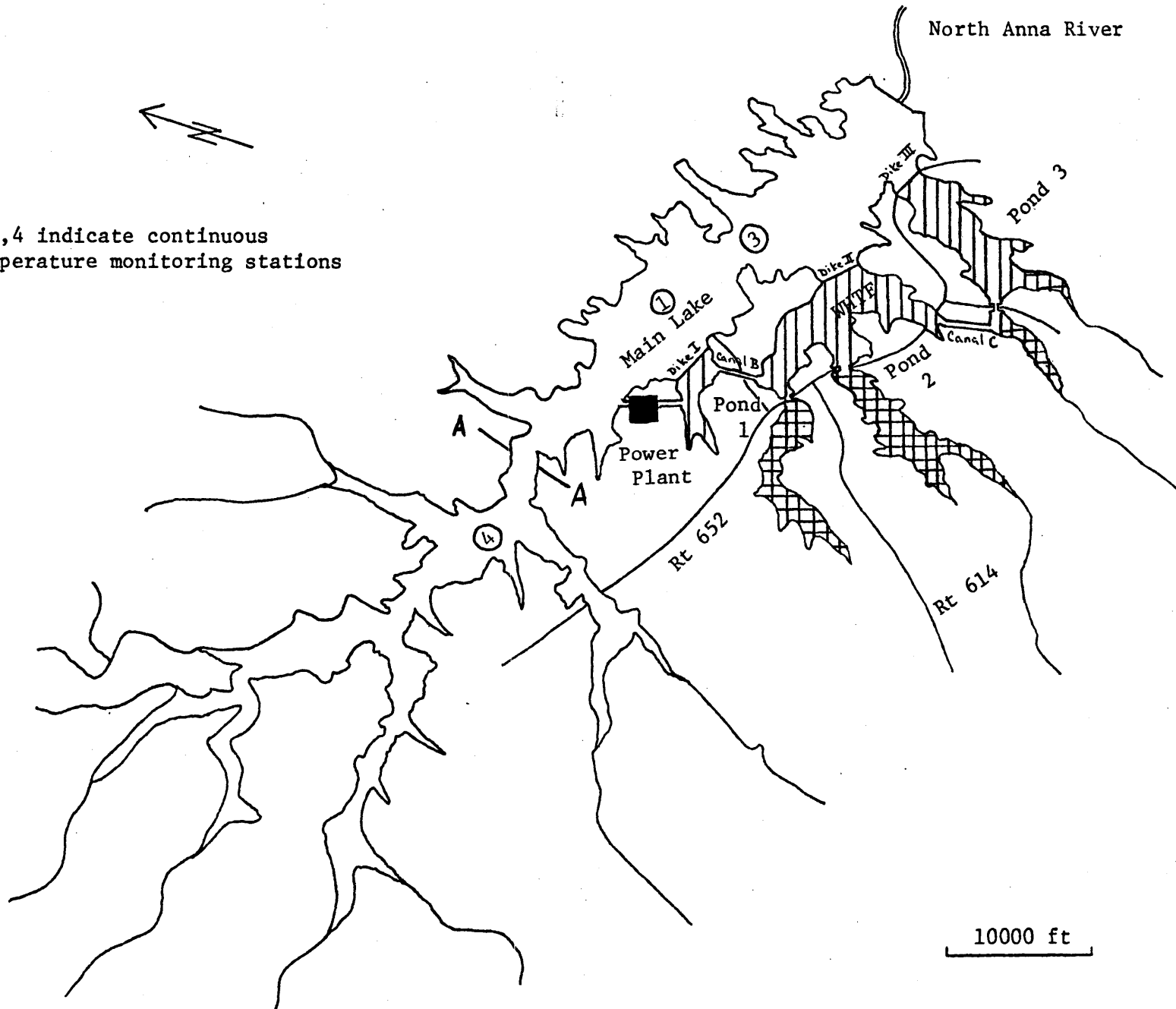


Figure 4-1: Map of the North Anna Cooling System

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 MW_e, 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", that 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 ($Q_0 = 8,400$ cfs):

$$\begin{aligned}L &= 25,000 \text{ ft} \\W &= 7,500 \text{ ft} \\H_{\text{ave}} &= 40 \text{ ft}\end{aligned}$$

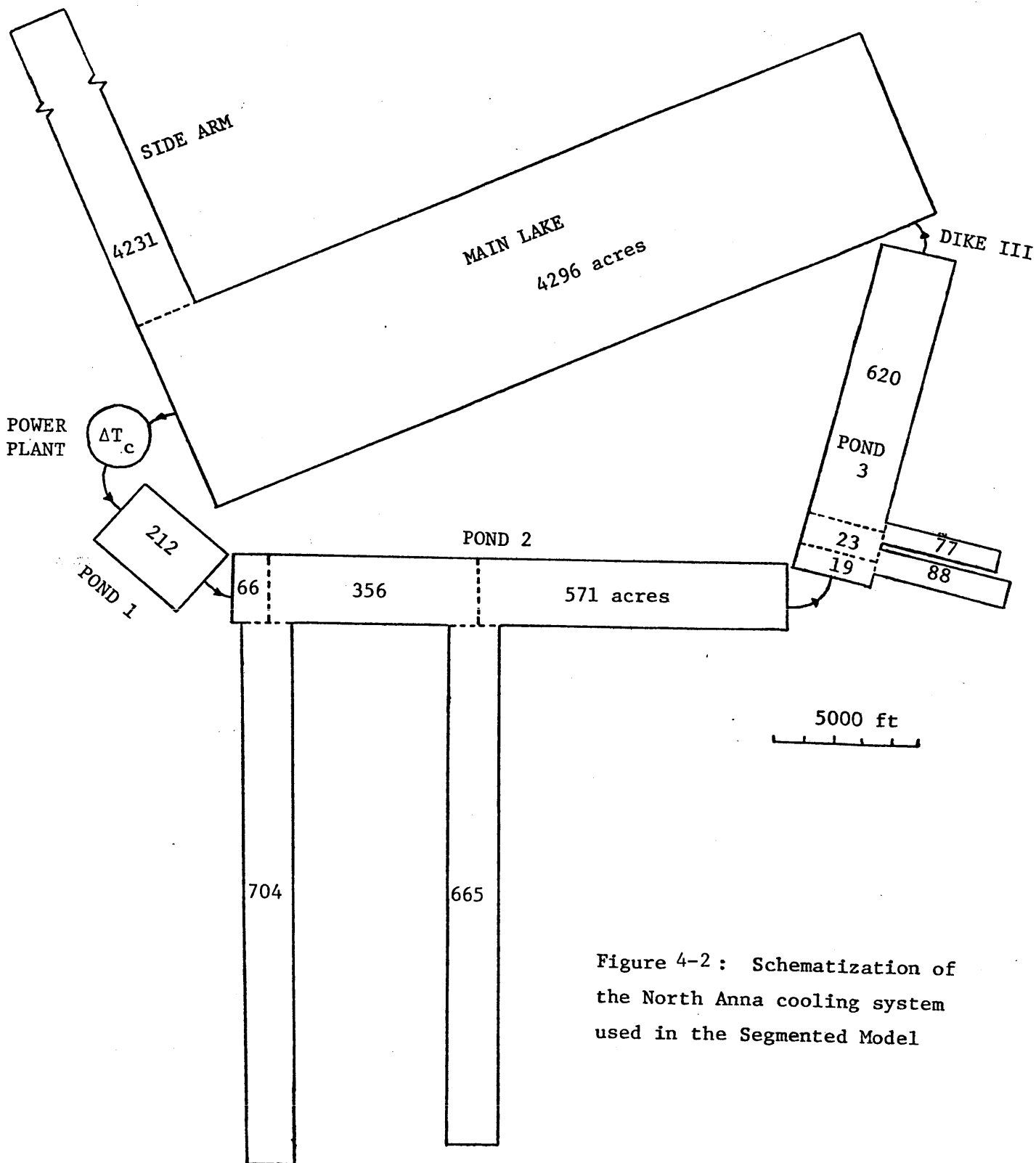


Figure 4-2 : Schematization of the North Anna cooling system used in the Segmented Model

$$D_v = 1.5^*$$

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

$$(\beta\Delta T_o \approx 0.0005)$$

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

(c) Model Predictions

The predictive model was applied to natural conditions ($\Phi = 0$ MW_t/acre) and to plant operating conditions ($\Phi = 0.58$ MW_t/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.

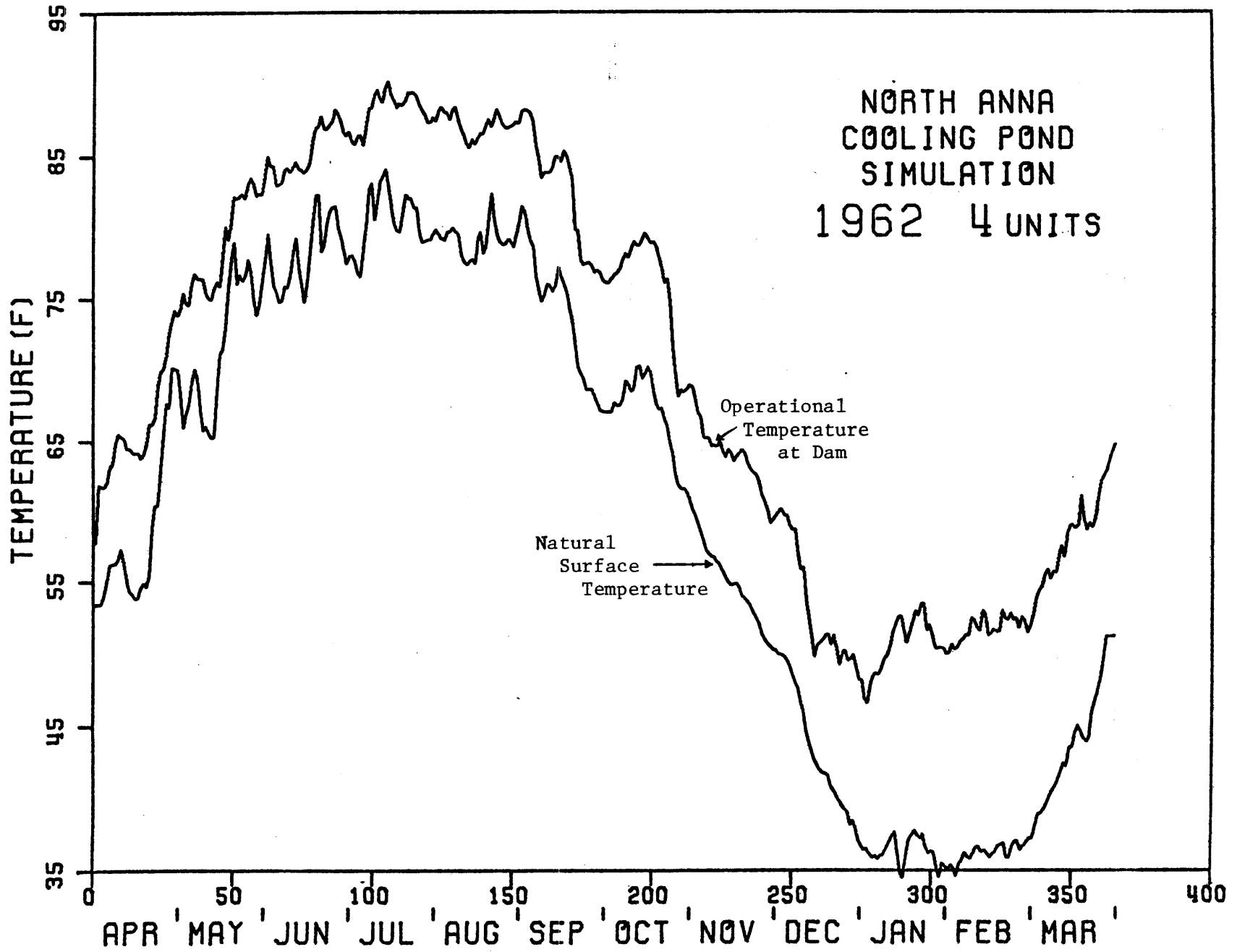


Figure 4-3: Loaded and Unloaded Temperature Variations at North Anna in 1962 with 4 Units Operational (After Jirka et al., 1977)

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_e and the condenser flow rate is 2102 cfs and the temperature rise is approximately 23^oF. 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 IP = 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 $\Delta T = 12^{\circ}\text{F}$ has been used to evaluate IP. In a predictive mode, ΔT has to be estimated (for example, by using a steady-state approximation; see Appendix B of Part A).

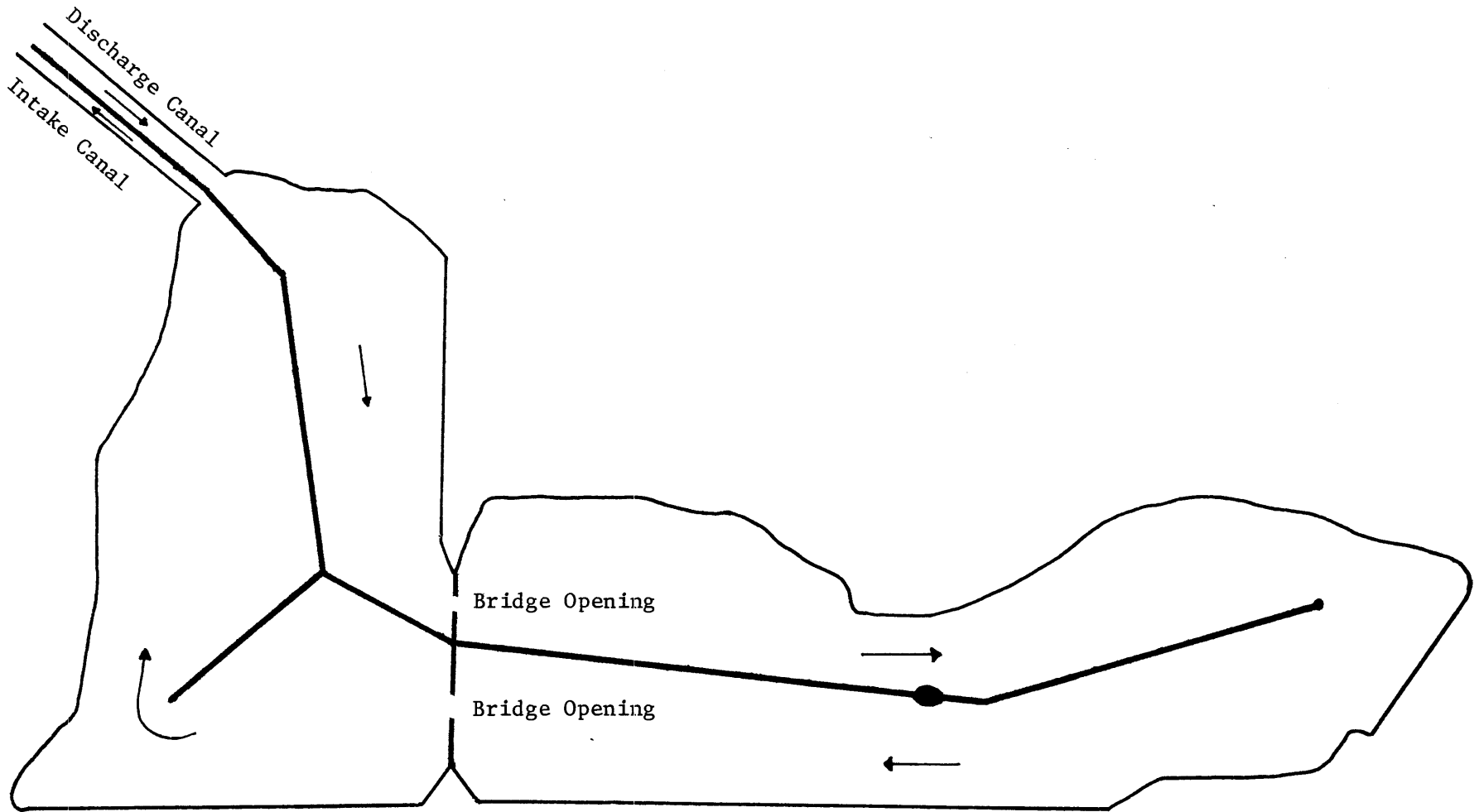


Figure 4-4: Plan View of Dresden Cooling Pond, Illinois

Date: 10-21-1975 1000 to 1300 hrs
 Operation: 2 units

0 3000 ft

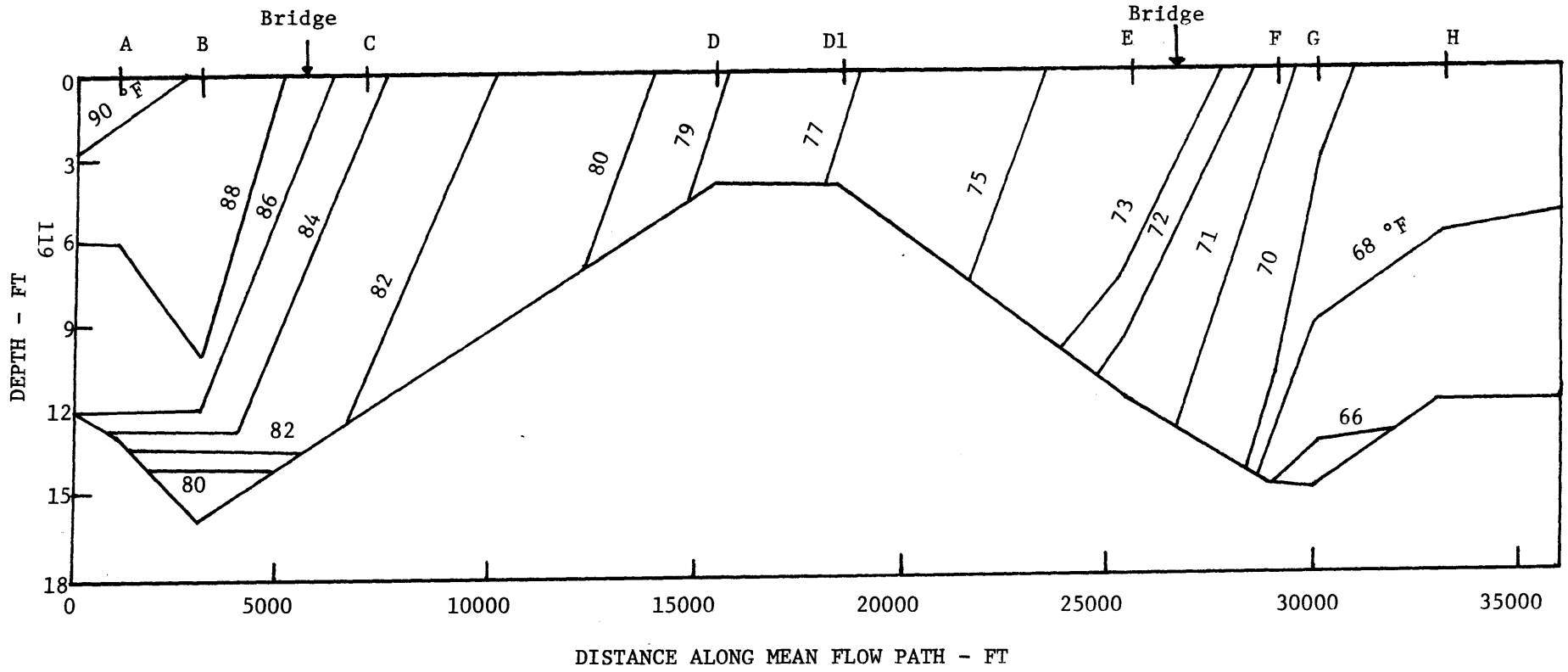
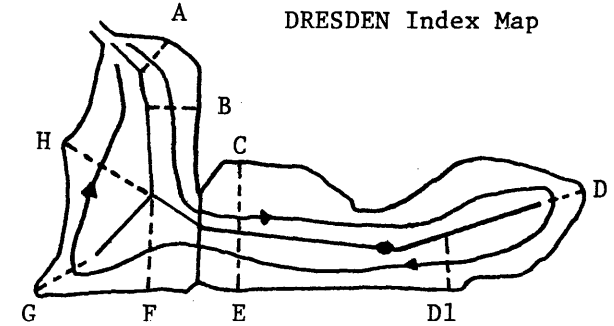


Figure 4-5: Longitudinal Temperature Profiles Indicating the Absence of Vertical Stratification in Dresden Cooling Pond

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_o (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 ft³/sec with a temperature increase of approximately 23°F through the condensers.

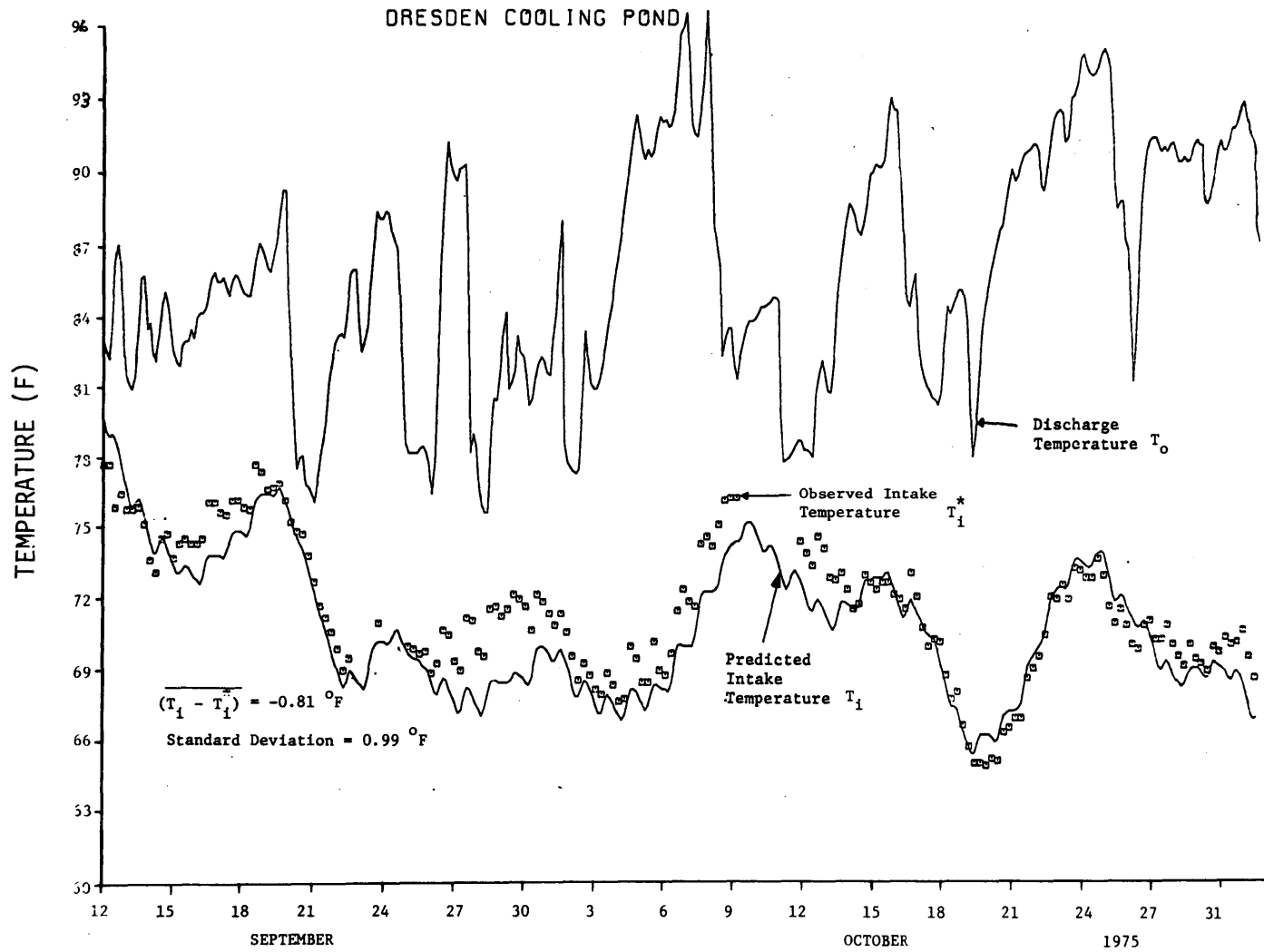


Figure 4-6: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from September 12 to October 31, 1975

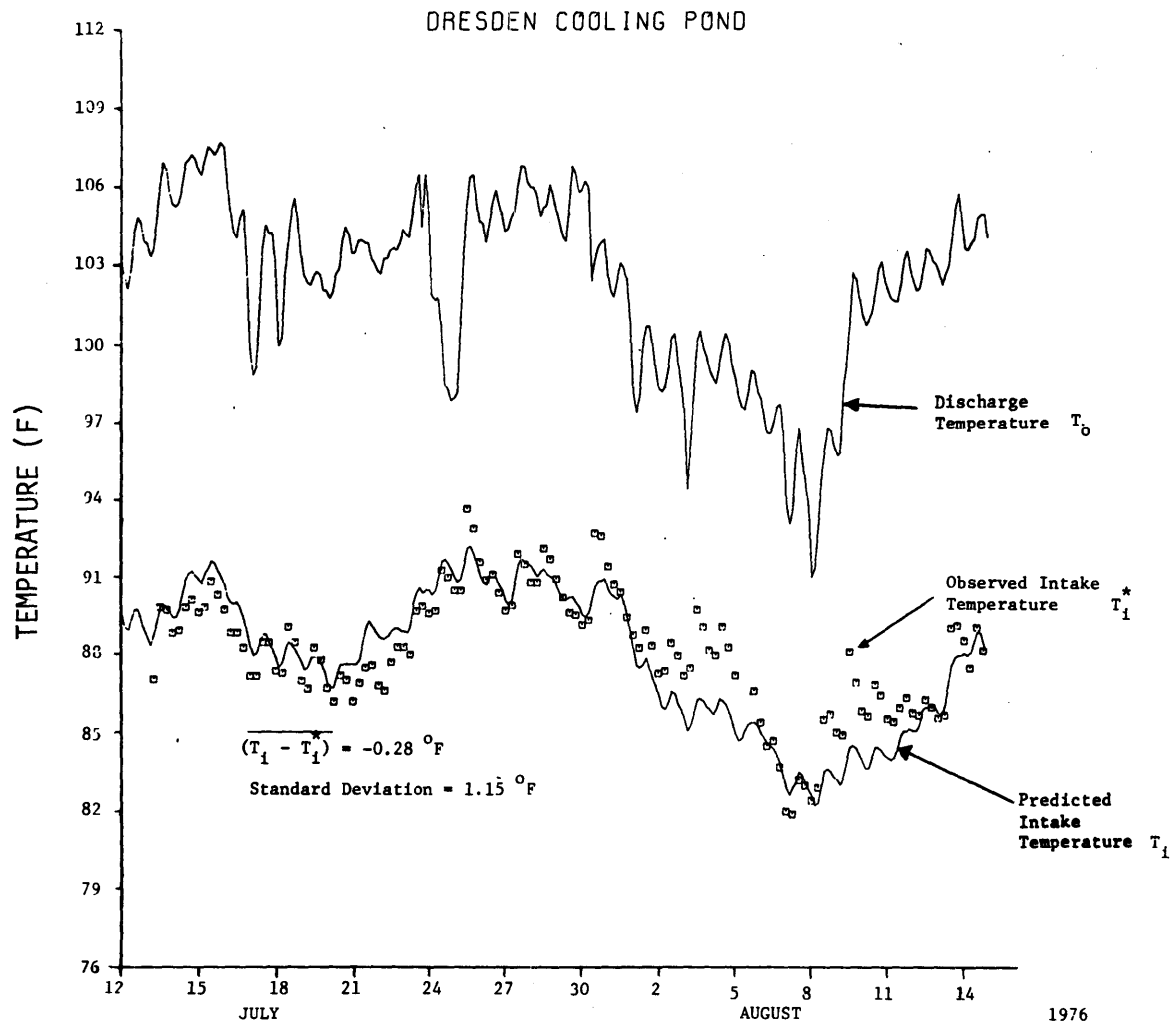


Figure 4-7: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from July 12 to August 15, 1976

b) Schematization and Classification

A pond number $IP = 0.5$ has been computed for the Powerton Cooling Pond (see Section 5.2.4 of Part A). This criterion together with the length/width ratio $L/W \approx 2$ 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.

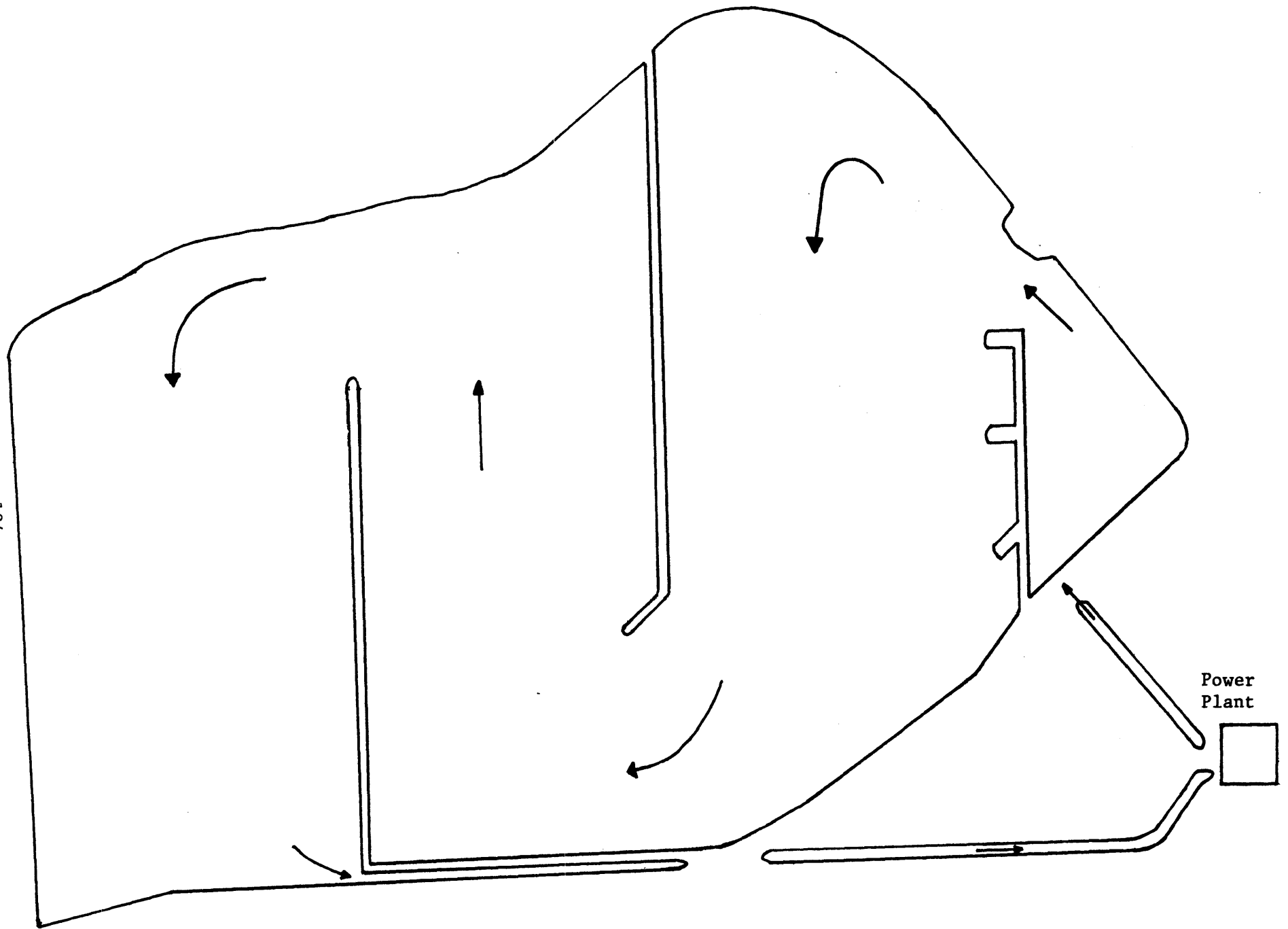


Figure 4-8: Plan View of Powerton Cooling Pond

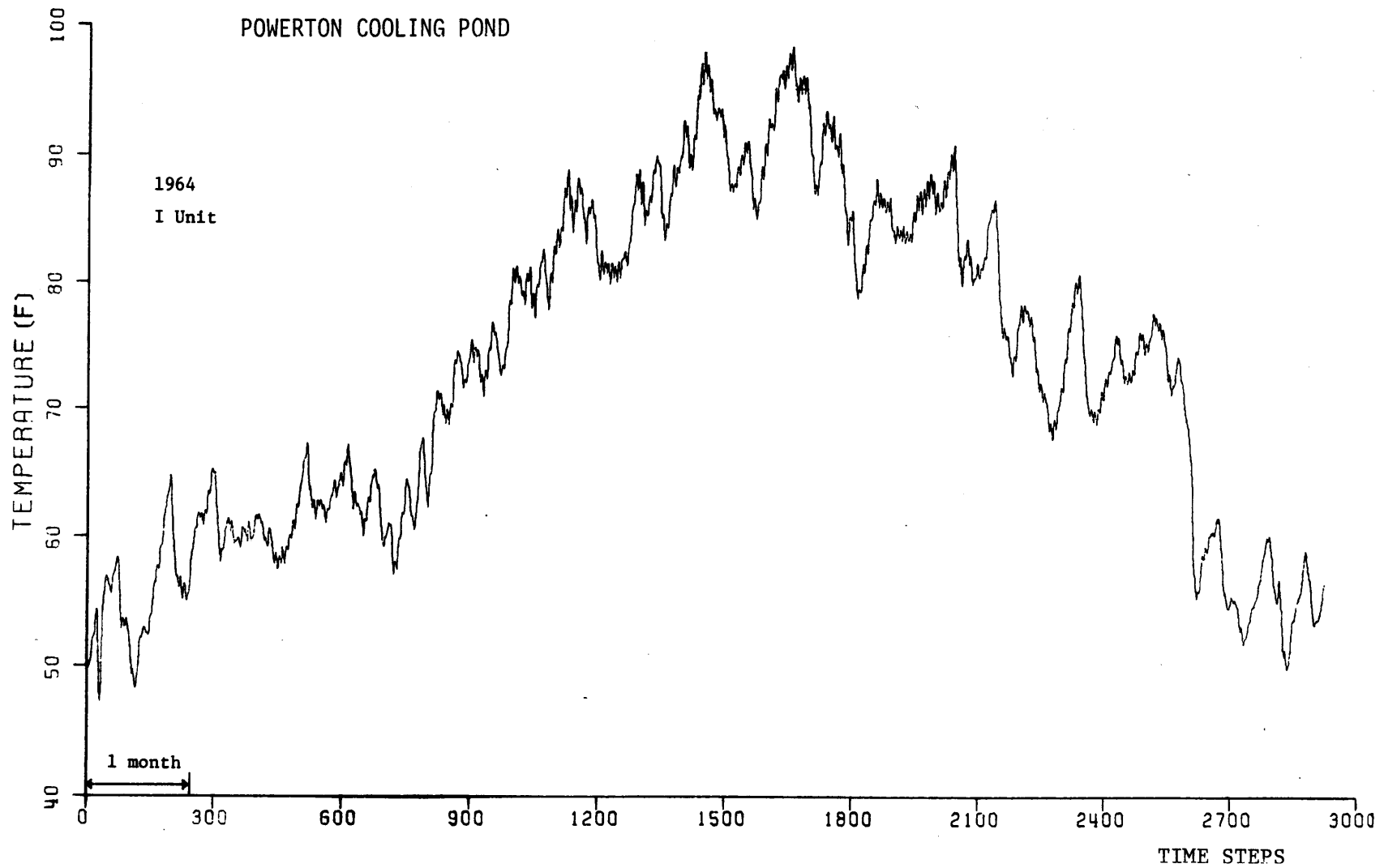


Figure 4-9: Simulated Intake Temperatures for 1 Unit Operation at Powerton Station, Illinois using 1964 Meteorological Data

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:

	<u>Surface Area (Acres)</u>	<u>Average width (ft)</u>	<u>Average Depth (ft)</u>	<u>Average Length (ft)</u>
Discharge Channel	109.4	250.	10.	19063.
Entrance Mixing Zone	231.4	1750.	12.	5759.
Pond 1	749.0	1862.	12.	17500.
Pond 2	919.5	3333.	10.	12000.
Total:	<u>2009.3 acres</u>			

For full load operation, the fossil-fired station produces 2520 MW_e 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 ($\beta\Delta T_o \approx 0.001$) and some minimal entrance dilution $D_v = 1.25$, 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

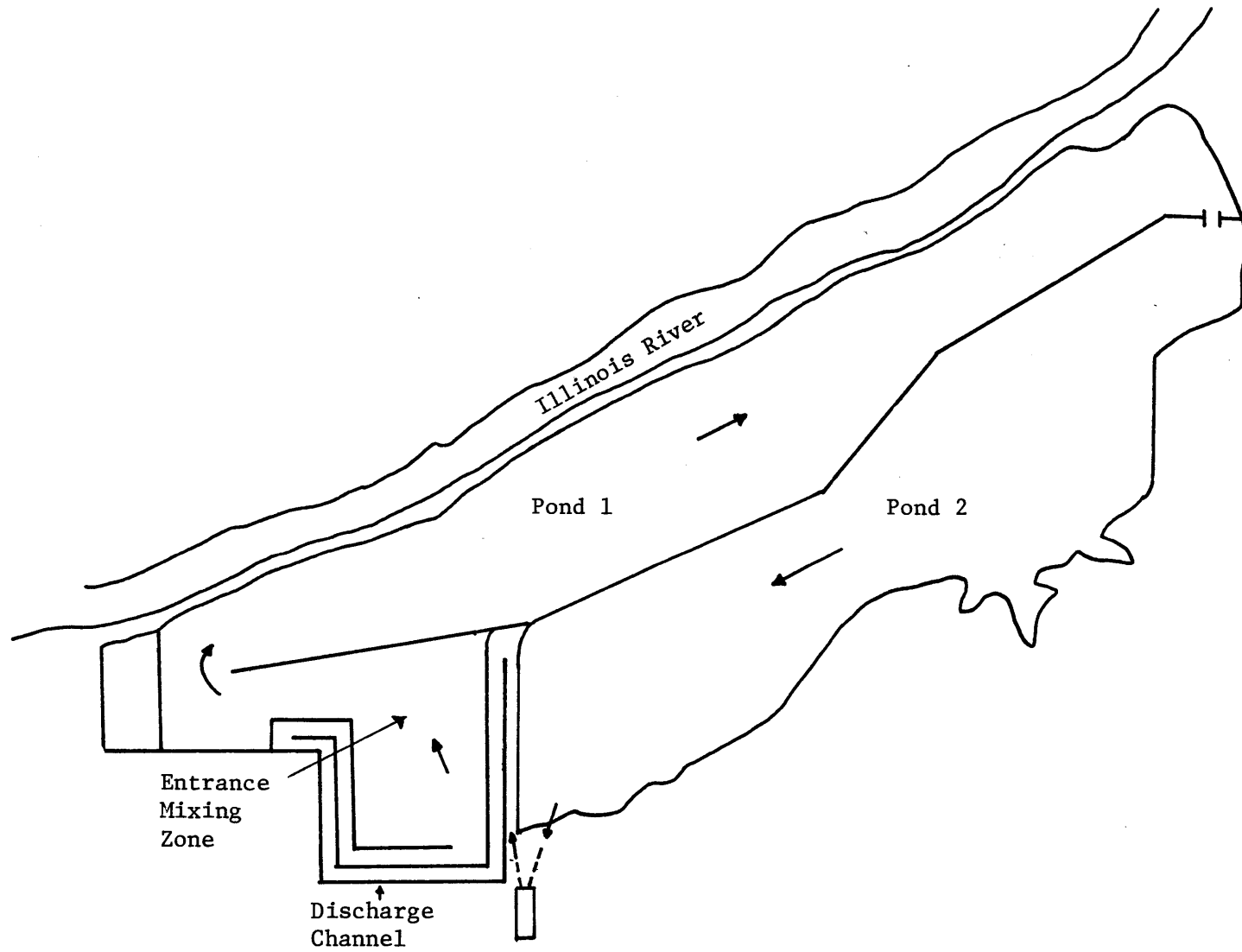


Figure 4-10: Plan View of Collins Cooling Lake.

completely mixed model has been applied:

$$\frac{dT_{out}}{dt} = \frac{Q_{in}}{V} (T_{in} - T_{out}) - \frac{\phi_n}{\rho c_p} \frac{A}{V}$$

where

T_{out} = outflow temperature from entrance mixing zone

T_{in} = inflow temperature

c_p = specific heat

ρ = density of water

Q_{in} = inflow

ϕ_n = net heat flux at surface

V = 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

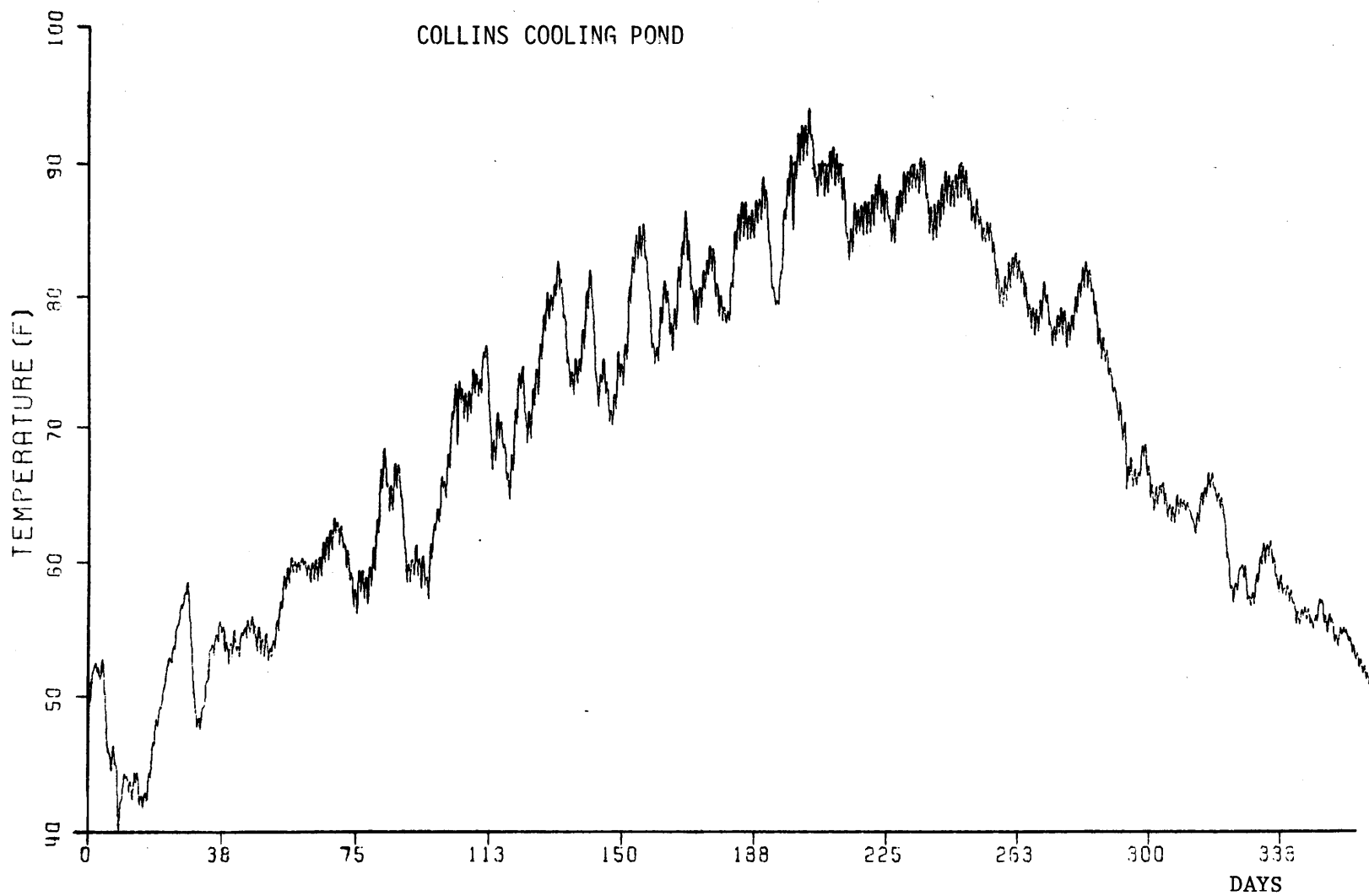


Figure 4-11: Simulated Intake Temperatures for Full Load Plant Operation at Collins Station, Illinois using 1969 Meteorological Data.

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 1.25×10^9 ft³. For two units operation, the power production is approximately 2150 MW_e. 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 $Q_o = 2673$ ft³/sec, temperature rise $\Delta T_o = 24^\circ\text{F}$ ($\beta \Delta T_o \approx 0.0024$) 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.

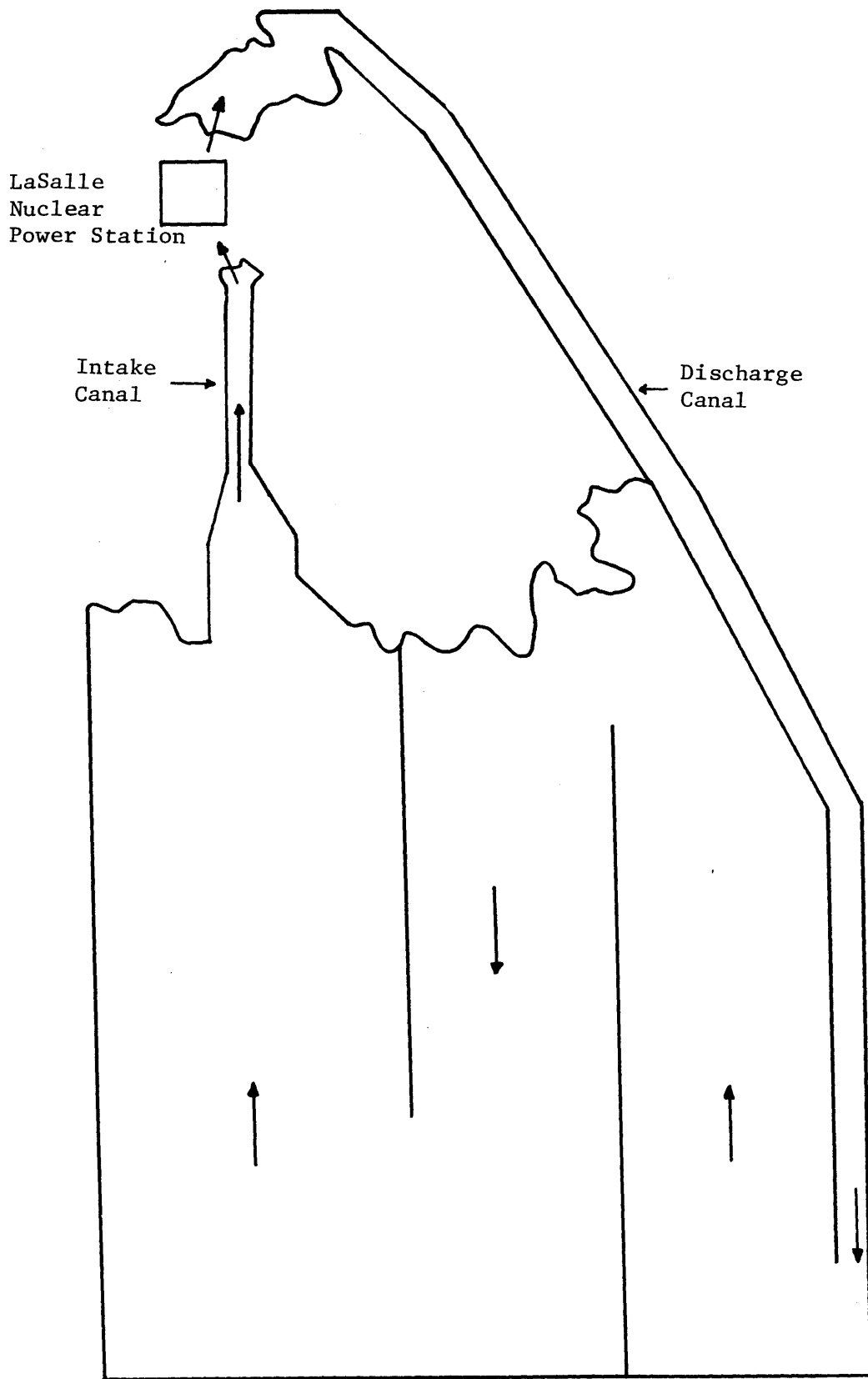


Figure 4-12: Plan View of LaSalle Cooling Pond

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 MW_e generating capacity. For two unit operation, the circulating flow is 3252 ft³/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

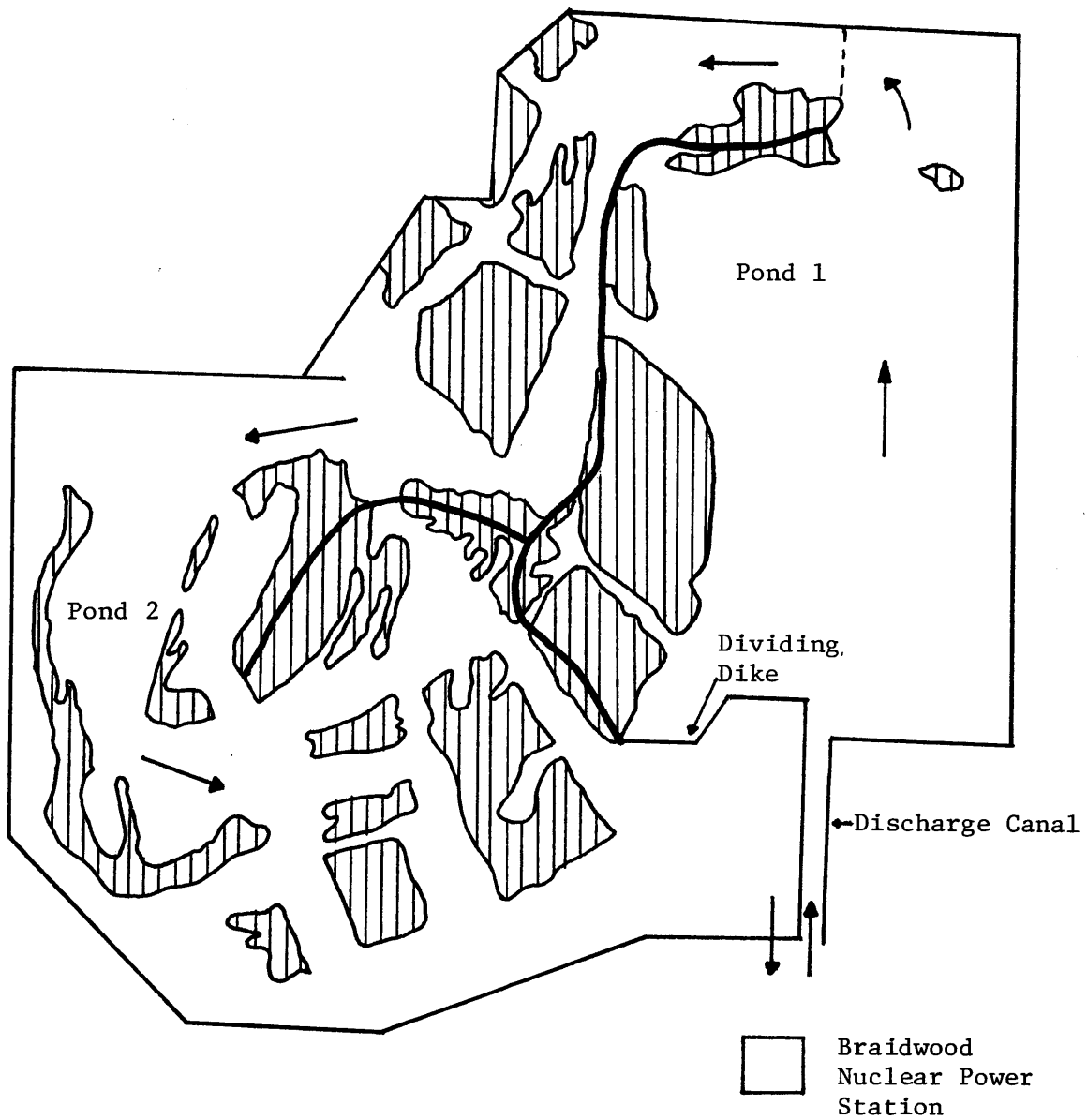


Figure 4-13: Plan View of Braidwood Cooling Pond

$\Delta T = 10^{\circ}\text{F}$ ($\beta\Delta T_0 \approx 0.001$) 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 ($L_{\text{jet}} = 8400 \text{ ft}$, $2b_0 = 375 \text{ ft}$) 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_e. With a design elevation of 470 ft above

* Application reported by R.W. Beck and Associates (1976).

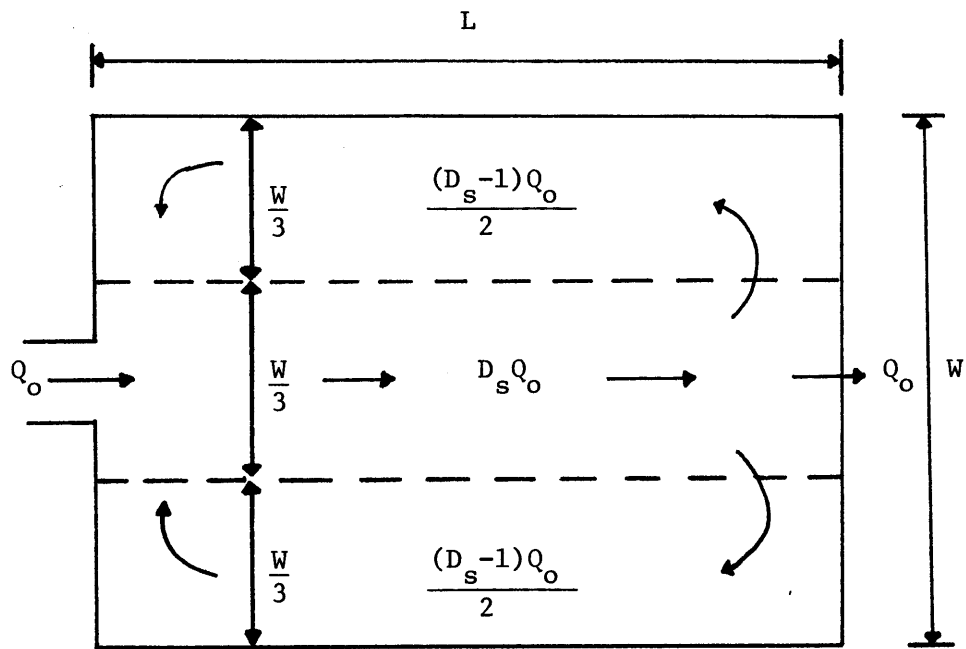


Figure 4-14: Schematic View of Pond 1
at Braidwood Cooling Pond

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 $\beta\Delta T_o = 0.0027$ 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 $h_s = IPH \approx 3.0$ 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

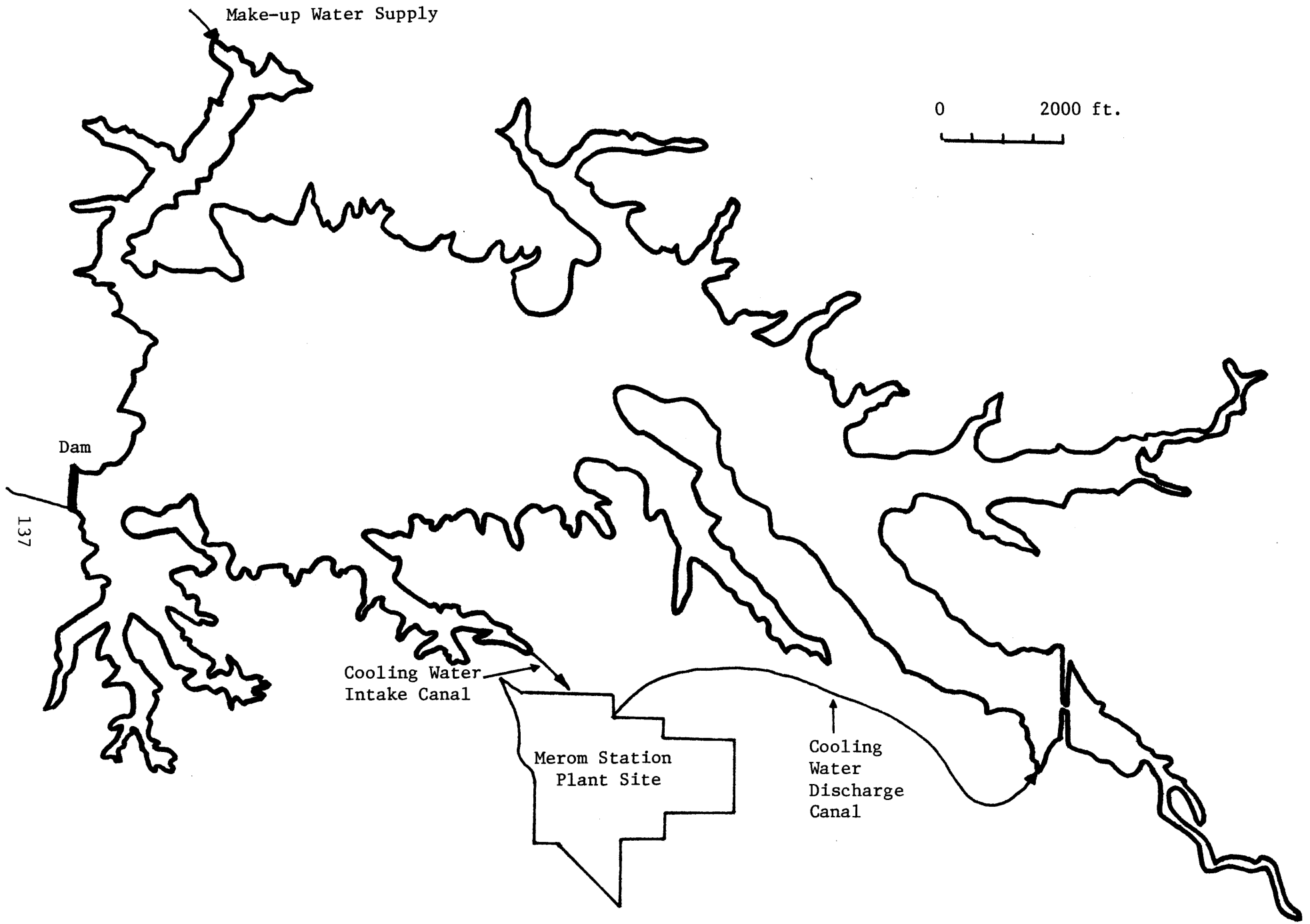


Figure 4-15: Plan View of Merom Lake

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 Flering 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.

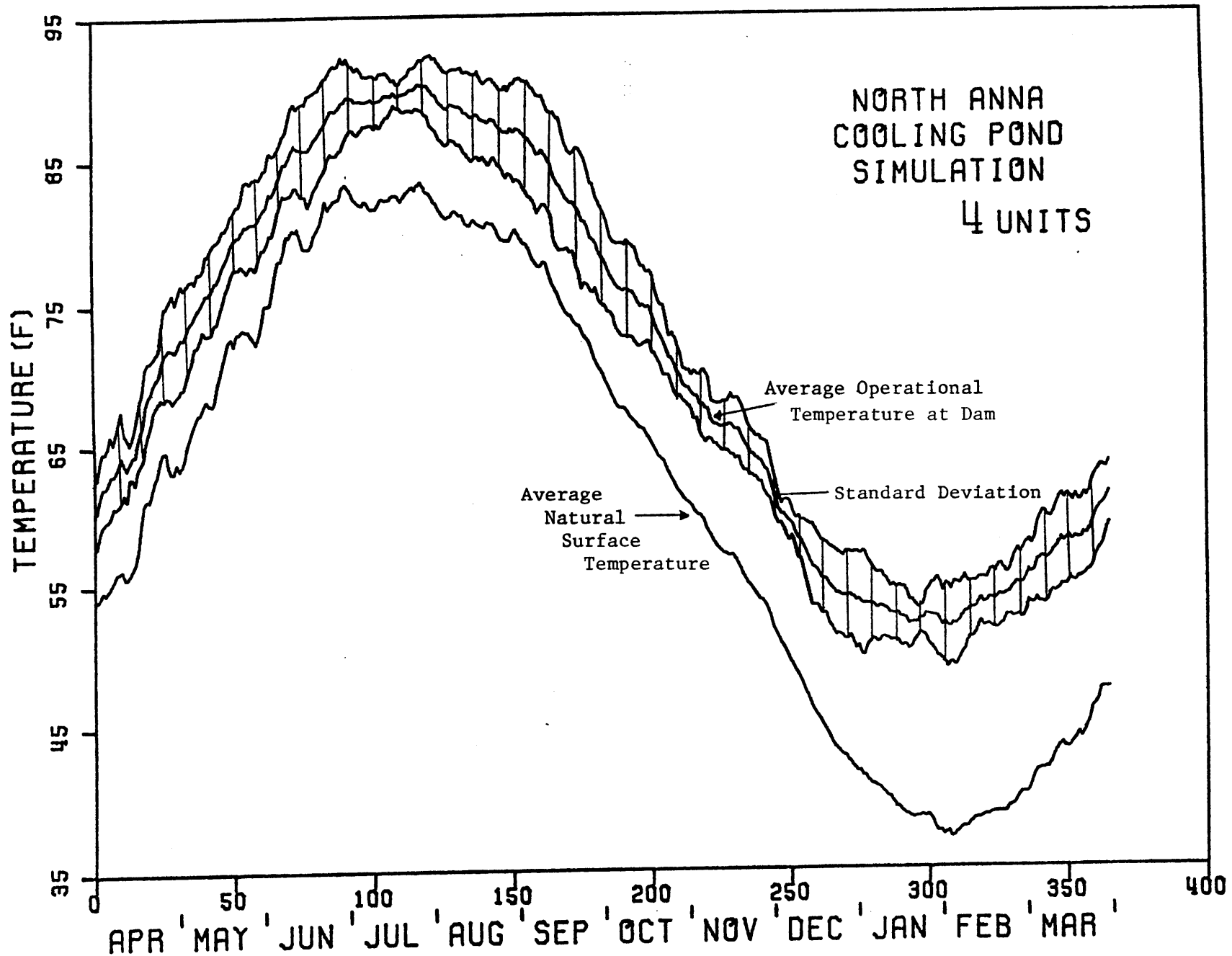


Figure 4-16: Average Yearly Temperature Cycle for Natural and Operational Conditions (Obtained from 10-year Simulation of the North Anna Cooling System)(After Jirka et al. 1977)

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)

	Natural	loaded with			
		1 unit	2 units	3 units	4 units
<u>10 year averaged data</u>					
a) Monthly means					
July mean temperature.....	82.4	83.2	85.3	87.5	89.4
January mean temperature	39.2	40.8	45.3	49.2	52.7
July mean temp. rise above natural	0.0	0.8	2.9	5.1	7.0
January mean temp. rise above natural	0.0	1.6	6.1	10.0	13.5
b) Single day					
Maximum temperature	83.4	84.0	86.1	88.3	90.2
Corresponding standard deviation*	2.1	1.9	1.8	1.6	1.7
<u>Non-averaged data</u>					
Maximum temperature	92.2	90.2	92.0	93.7	95.8
(in 10 years studied, occurred June 30, 1959)					

* For a process with Gaussian probability distribution, the region within the standard deviations represents 68% probability of occurrence.

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APPENDIX A

THE COMPUTER PROGRAM

C MAIN PROGRAM
 C
 C
 C THIS VERSION OF MITEMP COMPLETED 2/22/1980
 C
 C

REAL LENGTH

COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
 COMMON /SWTCHM/ KFIN,KATRAD
 COMMON /CUM/ CUMQIN,CUMQOT,SAREA1(5),DYSUR1(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,DCLOUD,DTFIN,DATRAD
 COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
 COMMON /HFLOW/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
 ,DTQHIN
 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 /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),
 ,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 /GEOMC/ YBOT(5),DYY(5),AI(100,5),XLI(100,5),BI(100,5),
 ,DYSURI(5),YSURI(5),ELL(100,5),SAREAI(5),AYSURI(5)
 COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),FF
 COMMON /METWD/ WHGT,TAU
 COMMON /ELB/ ELBSL
 COMMON /CONST/ RHO,HCAP,GRAV
 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,MIXH
 COMMON /FLXES/ SR,EVAP,RAD,CONDC,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/ EIN1(5),EPRES1(5),EQIN1(5),EQOUT1(5),ESTRT1(5)
 COMMON /ENGYB/ EIN2(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),EO(5),ENOW(5)
 COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
 COMMON /TENGY/ TENRAT(5)
 COMMON /TENTR/ TEDDY(5),THINI,TINP
 COMMON /DELTT/ DELSAV,DELTS,DELTT(10),TSAVE
 COMMON /SURFLR/ KSUR
 COMMON /DPTH/ THIN1,QHIN1
 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), KMODE
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=QQHIN(L+1)+RR*(QQHIN(L+2)-QQHIN(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(ICOOUNT, I, III)
CALL DISPER(ICOOUNT, I, III)
DO 120 J=1, NAR
120 THLM(J, I, III)=TEMP(J)
130 CONTINUE
CALL ENERGY(ICOOUNT, I)
CALL PRINT(ICOOUNT, 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(ICOOUNT.GT.1) GO TO 206
THIN=TLOW(LLL, NPOND)+DTEMP
GO TO 201
206 THIN=TOUTC(ICOOUNT-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)
      NAR=2

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    III=1
    DXX(I,III)=0.0
    WPTH(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 /SWTCHM/ KFIN,KATRAD
    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 /METIME/ DTTA,DTSIGH,DTWIND,DCLLOUD,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,MMO MDY,MYR,NDD
    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

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      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(WIND SPEED ONLY)
C   KHEAT  = 1  ARTIFICIAL HEAT LOADING
C         = 2  NATURAL RESERVOIR
C   KSTRT  = 1  FULLY MIXED POND
C         = 2  STRATIFIED POND
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
C   IS TO BE COMPUTED
      READ(5,920) NCLOUD,DCLOUD
      READ (5,980) (CLOUD(I),I=1,NCLOUD)
      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
C   READ STARTING DATE AND TEN OUTPUT DAYS
C
      READ(5,910)NDD

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      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
30   TA(I)=(TA(I)-32.)*5./9.
C   WIND SPEEDS CHANGED FROM MPH TO METERS/SEC
      DO 40 I=1,NWIND
40   WIND(I)=WIND(I)*.447
      WHGT=WHGT*0.3048
C   CONVERT INSOLATION FROM BTU/FT**2/DAY TO KCAL/M**2/DAY
      DO 50 I=1,NFIN
50   FIN(I) =FIN(I)*2.712
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
60   ATRAD(I) =ATRAD(I)*2.712
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
45   WIND(I)=FACTOR*WIND(I)
900  FORMAT(20A4)
905  FORMAT (20X,20A4/20X,80(' '*))
910  FORMAT(7(5X,I5))
920  FORMAT(5X,I5,F10.5)
930  FORMAT(16F5.1)
935  FORMAT (8(5X,F5.1))
940  FORMAT(8F10.1)
970  FORMAT (2F10.2,3I10)

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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 /GEOB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
      COMMON/GEOMC/ YYBOT(5),DYY(5),AI(100,5),XLI(100,5),BI(100,5),
      ,DYSURI(5),YSURI(5),ELL(100,5),SAREAI(5),AYSURI(5)
      COMMON /ETIME/ ET,NPOND
      COMMON /CUM/ CUMQIN,CUMQOT,SAREA1(5),DYSUR1(5),JM1,NELSV(5)
      COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(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 /GAUS/ SIGMAI,SPREAD,SIGMIN(3)
      COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
      COMMON /ENGYB/ EIN2(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),EO(5),ENOW(5)
      COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
      COMMON/METWD/ WHGT,TAU
      DIMENSION AA(100,5),XXL(100,5),NXXL(5),DXXL(5),XXLB(5),NAA(5),
      ,DAA(5),AAB(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  DYY       VERTICAL DISTANCE INCREMENT
C  YSURI     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  AA        HORIZONTAL CROSS-SECTIONAL AREAS
C  NXXL      NUMBER OF LENGTHS TO BE READ IN
C  DXXL      VERTICAL DISTANCE INTERVAL BETWEEN VALUES OF XXL
C  XXLB      ELEVATION OF FIRST (LOWEST) VALUE OF XXL
C  XXL       RESERVOIR LENGTHS
C  TLOW      INITIAL TEMPERATURE DISTRIBUTION
C  DD        VERTICAL DIFFUSION COEFFICIENT
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

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C   NOUT      NUMBER OF RESERVOIR OUTLETS
C   LOOUT     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)
150  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) NINI(I)
      NINI=NINI(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
      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)
      NQOO=NQO(K,I)
40   READ (5,951) (QO(J,K,I),J=1,NQOO)
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

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DAA(I)=DAA(I)*0.3048
DD(1,I)=DD(1,I)*0.3048*0.3048
NA=NAA(I)
DO 50 J=1,NA
50 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
55 XXL(J,I)=XXL(J,I)*0.3048
JM=NEL(I)
DO 65 J=1,JM
65 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
70 TTIN(II,K,I)=(TTIN(II,K,I)-32.)*5./9.
DO 80 K=1,NOUT1
ELOUT(K,I)=ELOUT(K,I)*0.3048
NQOO=NQO(K,I)
DO 80 J=1,NQOO
80 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

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16   AYSURI(I)=AI(JM,I)+(DYSURI(I)-DYY(I)/2.0)*(AI(JM+1,I)-AI(JM,I))/
    $DYY(I)
17   SAREAI(I)=(AYSURI(I)+(AI(JM,I)+AI(JM-1,I))/2.0)/2.0
    DYSUR1(I)=YSURI(I)-ELL(JMSV,I)+DYY(I)/2.0
    IF (YSURI(I)-ELL(JMSV,I)) 35,35,36
35   AYSURT=AI(JMSV,I)-(DYY(I)/2.0-DYSUR1(I))*
    *(AI(JMSV,I)-AI(JMSV-1,I))/DYY(I)
    GO TO 37
36   AYSURT=AI(JMSV,I)+(DYSUR1(I)-DYY(I)/2.0)*
    *(AI(JMSV+1,I)-AI(JMSV,I))/DYY(I)
37   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')
850  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
905  FORMAT(3(5X,I5),F5.2)
910  FORMAT (5(5X,I5))
920  FORMAT (5X,I5,F10.5)
925  FORMAT (5X,I5,F10.5,F10.5)
927  FORMAT(8F10.2)
930  FORMAT (16F5.1)
950  FORMAT (8F10.5)
951  FORMAT (6F12.1)

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RETURN
END
SUBROUTINE GEOM1(I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
COMMON /DISP/ DCOEF(5),DBETA(5),TEND(5),FF
COMMON /HFLWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
,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),NSEG(5,2),NAR,MP1
COMMON /ENTRN/ DSS(5),DS
COMMON /TENTR/ TEDDY(5),THINI,TINP
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),EEVAP(5),EBRAD(5),EATRAD(5)
COMMON /CIRCL/ REDDY(5)
COMMON /DISCH/ DTEMP
DIMENSION NTO(5,2)
C DEFINITION OF VARIABLES IN THE ORDER IN WHICH THEY ARE READ
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 (NSEG+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) NSEG(I,III)
      READ (5,960) DZ(I,III),WDTH(I,III),LENGTH(I,III)
      VTOTAL(I)=VTOTAL(I)+DZ(I,III)*WDTH(I,III)*LENGTH(I,III)
      AREA(I,III)=DZ(I,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

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DXX(I,1)=(1.-THETA(I))*LENGTH(I,1)/FLOAT(NSEG(I,1))
VFM(I)=THETA(I)*VTOTAL(I)
VDF(I)=(1.0-THETA(I))*VTOTAL(I)
GO TO 115
110 DXX(I,1)=LENGTH(I,1)/FLOAT(NSEG(I,1))
DXX(I,2)=(1.-THETA(I))*LENGTH(I,1)/FLOAT(NSEG(I,2))
VFM(I)=THETA(I)*LENGTH(I,2)*WIDTH(I,2)*DZ(I,2)
VDF(I)=VTOTAL(I)-VFM(I)
115 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 III=1,KK
NM=NTO(I,III)
2 WRITE (6,865) (THLM(J,I,III),J=1,NM)
865 FORMAT (10(/10X,10(F6.2,5X)))
C CONVERT UNITS IF NECESSARY
GO TO (160,150), KUNITS
150 VTOTAL(I)=VTOTAL(I)*0.02832
KK=KCIRC(I)
DO 90 III=1,KK
AREA(I,III)=AREA(I,III)*0.0929
DZ(I,III)=DZ(I,III)*0.3048
WIDTH(I,III)=WIDTH(I,III)*0.3048
LENGTH(I,III)=LENGTH(I,III)*0.3048
DXX(I,III)=DXX(I,III)*0.3048
NM=NTO(I,III)
DO 80 J=1,NM
80 THLM(J,I,III)=(THLM(J,I,III)-32.)*5./9.
90 CONTINUE
95 VFM(I)=VFM(I)*0.02832
VDF(I)=VDF(I)*0.02832
IF (I.GT.1) GO TO 160
DO 60 J=1,NQHIN
60 QQHIN(J)=QQHIN(J)*0.02832
IF(KOPERA.NE.1) GO TO 61
DTEMP=DTEMP*5./9.
61 IF(KOPERA.EQ.1) GO TO 75
DO 70 J=1,NQHIN
70 TTHIN(J)=(TTHIN(J)-32.)*5./9.
75 CONTINUE
160 CONTINUE
IF (KK.EQ.2) TEDDY(I)=THLM(NM,I,2)

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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)*
    *DXX(I, III)/2.*RHO*HCAP
    ESTRT1(I)=THLM(NM, I, III)*DZ(I, III)*WDTH(I, III)*DXX(I, III)/2.0*
    *RHO*HCAP+ESTRT1(I)
    NMM=NTO(I, III)-1
    DO 200 J=2, NMM
200   ESTRT1(I)=THLM(J, I, III)*DZ(I, III)*WDTH(I, III)*DXX(I, III)*RHO*HCAP+
    ,ESTRT1(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), KOPEA, KCIRC(5)
  COMMON /SWTCHM/ KFIN, KATRAD
  COMMON /METEOA/ TA(3000), SIGH(3000), WIND(3000), CLOUD(3000)
  COMMON /METEOB/ FIN(3000), ATRAD(3000)
  COMMON /METIME/ 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.)))

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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
10  R=ET/DCLOUD
    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/DCLOUD
    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

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FW=22.4*DTV**.333+14.*W/.447
FW=0.85*FW
EVAPE=FW*DE*2.712
CONDCE=EVAPE*(T1-TAIR)/DE*.46
IF (EVAPE.LE.0.0) EVAPE=0.0
GO TO 270
C EVAPORATION ROHWER EQN FOR UNHEATED LAKE
235 FW=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
250 EVAPE=0.0
260 CONDCE=RHO*0.01*269.1*(T1-TAIR)*FW
270 CONTINUE
SHS=EVAPE+CONDCE+RADE
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 /METIME/ DTTA,DTSIGH,DTWIND,DCLLOUD,DTFIN,DA TRAD
COMMON /EXTIN/ DTAU,DT,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,MP1
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,CONDC,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=WDTH(I,III)*DXX(I,III)
IF ((K.EQ.1).OR.(K.EQ.NAR)) SURAR=SURAR/2.0

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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*HCAP*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*0.01
IF(EVAP)85,85,86
85 EVAP=0.0
C CONDUCTION
86 CONDC=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.-.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
CONDC=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)

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      AAV=(ABOT+AREADX)/2.0
      ARATIO=AREADX/AAV
      R=1.0-EXP(-ETA*DHL)*ABOT/AREADX
      GO TO 150
C   NATURAL RESERVOIR
140  ARATIO=AYSUR/SAREA
      R=1.0-EXP(-ETA*DYSUR)*(A(JM)+A(JM-1))/2.0/AYSUR
150  TLOSS(K)=(EVAP+CONDOC+RAD-AR-BETA*SR-(1.-BETA)*SR*R)
      $*ARATIO/RHO/HCAP/DY1*DTAU
200  CONTINUE
350  RETURN
      END
      SUBROUTINE SUMFLX(I)
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
      COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
      COMMON /FLXES/ SR,EVAP,RAD,CONDOC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
      COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),EO(5),ENOW(5)
      EFXIN(I)=EFXIN(I)+(SR+AR)*DT*SURAR
      EFXOT(I)=EFXOT(I)+(EVAP+CONDOC+RAD)*DT*SURAR
C   CUMMULATIVE EVAPORATIVE MASS LOSS IS IN CUBIC METERS
      EEMASS(I)=EEMASS(I)+EVAP*DT*SURAR/H/1000.
C   CUMMULATIVE HEAT FLUXES ARE IN KCALS
      EEVAP(I)=EEVAP(I)+EVAP*DT*SURAR
      EBRAD(I)=EBRAD(I)+RAD*DT*SURAR
      EATRAD(I)=EATRAD(I)+AR*DT*SURAR
      RETURN
      END
      SUBROUTINE ENERGY(ICOUNT,I)
      REAL LENGTH
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
      COMMON /HFLWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
,DTQHIN
      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 /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),
,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 /GEOMC/ YYBOT(5),DYY(5),AI(100,5),XLI(100,5),BI(100,5),
,DYSURI(5),YSURI(5),ELL(100,5),SAREAI(5),AYSURI(5)
      COMMON /CONST/ RHO,HCAP,GRAV
      COMMON /TENTR/ TEDDY(5),THINI,TINP
      COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
      COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
      COMMON /ENGYA/ EIN1(5),EPRES1(5),EQIN1(5),EQOUT1(5),ESTRT1(5)
      COMMON /ENGYB/ EIN2(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),EO(5),ENOW(5)
      COMMON /TENGY/ TENRAT(5)

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        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)+EQOUT2(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.*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=NSEG(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)

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      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.*RHO*HCAP
      DO 110 J=2, NMP
110  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)=EQOUT1(I)+QHIN*DTAU*THLM(MP1, I, 1)*RHO*HCAP
30   EOUT(I)=EOUT(I)+EQOUT1(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 /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 /HFLWS/ QQHIN(3000), TTHIN(3000), THIN, QHIN, QHINI, NQHIN,
      , DTQHIN
      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, IFREQA
      COMMON /ENFLW/ TININ(3), QININ(3), NOUT1
      COMMON /TENTR/ TEDDY(5), THINI, TINP
      COMMON /TOUTT/ 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/ THIN1, QHIN1
      DIMENSION X(101), Y(101), Z(101), D(101)
      DIMENSION VEL(5)
C   FF=FRICION FACTOR
C   VKRMN=VON KARMAN CONSTANT
      VKRMN=0.4
      GO TO (50,60), KSTRAT
60   F=0.01

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        GO TO (61,62), KMIX
62     NIN1=NIN(I)+1
        MIXED(NIN1,I)=MIXED(1,I)
        MXX=MIXED(NIN1,I)+1
        JMIXB=JM-MIXED(NIN1,I)
        IF (JMIXB.GT.0) GO TO 88
        JMIXB=1
        MXX=JM
88     CONTINUE
        NOUT1=NOUT(I)+1
        QOUT(NOUT1)=DS*QHIN
        TOUTC(ICOUNT,NOUT1)=0.0
        DO70 J=JMIXB,JM
70     TOUTC(ICOUNT,NOUT1)=TOUTC(ICOUNT,NOUT1)+T(J,1)/FLOAT(MXX)
        IF (I.GT.1) GO TO 75
        THINI=(THIN+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
        GO TO 78
75     THINI=(TEND(I-1)+DS*TOUTC(ICOUNT,NOUT1))/(1.+DS)
78     QHINI=(1.+DS)*QHIN
        GOTO 22
61     CONTINUE
        QHINI=QHIN
        IF (I.GT.1) GO TO 20
        THINI=THIN
        GO TO 22
20     THINI=TEND(I-1)
22     CONTINUE
        TINP=THINI
        GO TO 65
50     FF=0.02
        IF (III.GT.1) GO TO 10
        QHINI=(1.+DS)*QHIN
        IF (I.GT.1) GO TO 30
        THINI=THIN
        GO TO 32
30     THINI=TEND(I-1)
32     CONTINUE
        TINP=THINI
        GO TO 65
C     RECIRCULATION
10     QHINI=DS*QHIN
        THINI=TEND(I)
65     DCOEF(I)=0.3*(SQRT(FF/8.)*QHINI/AREA(I,III))*(WDTH(I,III)**2.)/4.
        ./DZ(I,III)/VKRMN**2
C     MINIMUM VALUE IN CASE OF NO THROUGHFLOW
        IF (QHINI .EQ. 0.) DCOEF(I) =100000000000.
        VEL(I)=QHINI/AREA(I,III)
        SIGMA=DTAU*VEL(I)/DXX(I,III)
        LAMBDA=DTAU*DCOEF(I)/(DXX(I,III)*DXX(I,III))
C     CHECK INPUT PARAMETERS AND SET ARRAYS A, B, C
        DO 2 J=2,MP1
4&     X(J)=- (LAMBDA+SIGMA)
        Y(J)=2.0+2.0*LAMBDA+SIGMA
2     Z(J)=-LAMBDA

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      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.-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.-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

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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 /HFLWS/ 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),
      , 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 /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/ SAREAP, DYSURP, DYSUR, AYSUR, SAREA, SURAR
      COMMON /GEOMA/ VTOTAL(5), VFM(5), VDF(5), LENGTH(5,2), DX(5,2),
      , DZ(5,2), WIDTH(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 /TOUTT/ 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

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QIN(K)=QQIN(L+1,K,I)+RR*(QQIN(L+2,K,I)-QQIN(L+1,K,I))
QININ(K)=QIN(K)
TIN(K)=TTIN(L+1,K,I)+RR*(TTIN(L+2,K,I)-TTIN(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
83  TP=TP+T(J,1)/FLOAT(MXX)
    TIN(K)=(TIN(K)+TP*RMIX(K,I))/(1.+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
    ARG1=S(J)/2.0/SIGMIN(K)/SIGMIN(K)
    IF(ARG1-20.0)4,4,5

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4 EX(J)= EXP(-ARGI)
  GO TO 1
5 EX(J)=0.0
1 CONTINUE
  DO 2 J=1,JM
  II=IABS(J-JIN(K))+1
2 EXI(J)=EX(II)
C COMPUTE MAX INFLOW VEL.
  VOLIN=EXI(1)*B(1)*DY/2.0+EXI(JM)*B(JM)*DYSUR
  JMM=JM-1
  DO 3 J=2,JMM
3 VOLIN=VOLIN+EXI(J)*B(J)*DY
  UIMAX(1)=QIN(K)/VOLIN
  GO TO (8,7),KMIX
7 UIMAX(1)=UIMAX(1)*(1.0+RMIX(K,I))
8 DO 6 J=1,JM
  UI(J,K)=UIMAX(1)*EXI(J)
6 CONTINUE
9 CONTINUE
C COMPUTE OUTFLOW VELOCITIES
  DO 10 LT=1,NOUTI
  JOUT=LOUT(LT,I)
C COMPUTE WITHDRAWAL THICKNESS.
C NOTE THAT ONLY HALF THE WITHDRAWAL THICKNESS IS COMPUTED.
  IF (JOUT.EQ.1) GO TO 40
  IF (JOUT.EQ.JM) GO TO 45
  DERIV = (T(JOUT+1,1)-T(JOUT-1,1))/2.0/DY
  GO TO 49
40 DERIV=(T(JOUT+1,1)-T(JOUT,1))/DY
  GO TO 49
45 DERIV=(T(JOUT,1)-T(JOUT-1,1))/DY
49 IF (DERIV-0.010) 11,11,15
11 JOUT1=JOUT+2
C CUTOFF DUE TO SHARP CHANGE IN DENSITY GRADIENT
  IF (JOUT1-JMM) 50,51,51
50 DO 12 J=JOUT1,JMM
  IF((T(J+1,1)-T(J,1))/DY-.05)12,13,13
12 CONTINUE
51 SIGMAO=100.0*DY
  GO TO 19
13 HAFDEL=FLOAT(J-JOUT)*DY
  SIGMAO=HAFDEL/SPREAD
19 JOUT2=JOUT-2
  IF (JOUT2) 14,14,53
53 DO 21 JJ=1,JOUT2
  J=JOUT2+2-JJ
  IF((T(J,1)-T(J-1,1))/DY-0.05) 21,21,22
21 CONTINUE
  GO TO 14
22 HAFD1=FLOAT(JOUT-J)*DY
  SIGM1=HAFD1/SPREAD
  IF(SIGM1.LT.SIGMAO) SIGMAO=SIGM1
  GO TO 14
C APPROXIMATING FORMULA USED DENSITY IS RHO=1.0-0.00000663*(T-4.0)**2

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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.
    VOLOUT=EXO(1)*B(1)*DY/2.0+EXO(JM)*B(JM)*DYSUR
    JMM=JM-1
    DO 120 J=2,JMM
120 VOLOUT=VOLOUT+EXO(J)*B(J)*DY
    UOMAX(LT)=QOUT(LT)/VOLOUT
    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)=QOUT(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
    JMIXB=JM-MIXED(K,I)

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    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
47  UIN=UIN+UI(1,K)
    V(2,1)=(UIN-UO(1,1))*B(1)*DY/(A(1)+A(2))
    JMX=JM+1
    DO 500 J=3,JMX
    UIN=0.0
    DO 38 K=1,NIN1
38  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 /SWTCHM/ KFIN,KATRAD
    COMMON /METIME/ DTTA,DTSIGH,DTWIND,DCLLOUD,DTFIN,DATRAD
    COMMON /METEOA/ TA(3000),SIGH(3000),WIND(3000),CLOUD(3000)
    COMMON /METEOB/ FIN(3000),ATRAD(3000)
    COMMON /FLXES/ SR,EVAP,RAD,CONDC,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),NELMAX(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,IFREQA
    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 /DELTT/ DELSAV,DELTS,DELTT(10),TSAVE

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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=0.0
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(2,1)) 1166,1167,1167
1167 DELTB=-V(2,1)*T(1,1)*(A(1)+A(2))/2./A(1)/(DY/2.)
GO TO 1168
1166 DELTB=-V(2,1)*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.)
DELTD=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
509 ARJ1=(A(J)+A(J+1))/2.
ARJ2=(A(J)+A(J-1))/2.0
C DIRECT ABSORPTION TERM

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      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)*(A(J+1)+
      1A(J))/2.0)/A(J)/DY
      GO TO 1162
1161 IF(V(J+1,1))1172,1172,1173
1173 DELTB=(V(J,1)*T(J-1,1)*(A(J)+A(J-1))/2.0-V(J+1,1)*T(J,1)*(A(J+1)+
      1A(J))/2.0)/A(J)/DY
      GO TO 1162
1172 DELTB=(V(J,1)*T(J-1,1)*(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-CONDUCT-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./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./SARNEW/DYNEW
      DELTC=-UO(JM,1)*T(JM,1)*B(JM)*DYSUR/(DYNEW*SARNEW)
      DO 1190 K=1,NIN1
1190 DELTC=DELTC+UI(JM,K)*TIN(K)*B(JM)*DYSUR/(DYNEW*SARNEW)
C DIFFUSION TERM

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1165 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)*SAROLD*DYSOLD/(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
   IF (FLOWOT(LT).LE.0.0) FLOWOT(LT)=0.0
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
   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),NSEG(5,2),NAR,MP1
   COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
   COMMON /EXTIN/ DTAU,DT,ETA,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,CONDUCT,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
   COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
   COMMON /METWD/ WHGT,TAU
   COMMON /DELTT/ DELSAV,DELTS,DELTT(10),TSAVE
   DIMENSION FLX(10)
   FLX(1)=EVAP+CONDUCT+RAD-AR-BETA*SR
   DELTT(1)=-FLX(1)*AYSUR/RHO/HCAP/DYSUR/SAREA
   JMM=JM-1
   MM=1
   CALL WDMIX(N,I)
   DO 2000 MM=2,10
   CALL HEAT(N,I,III)
   FLX(MM)=EVAP+CONDUCT+RAD-AR-BETA*SR
   DELTT(MM)=-FLX(MM)*AYSUR/RHO/HCAP/DYSUR/SAREA
   DELTS=(DELTT(1)+DELTT(MM))/2.
   T(JM,1)=TSAVE+DELSAV+DELTS*DTAU

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DO 2001 J=1,JMM
2001 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
88 T(J,1)=T(JM,1)
JM=NEL(I)
87 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 /GEOB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
COMMON /CONST/ RHO,HCAP,GRAV
COMMON /METWD/ WHGT,TAU
COMMON /FLXES/ SR,EVAP,RAD,CONDC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
DIMENSION D(100)
GRAV=7315000000.
DO 100 J=1,JM
100 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.
120 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=C1+(OS-RHS)/20000.
KT=KT+1
IF (KT.GT.10) GO TO 180
GO TO 140
170 C1=0.0005
180 C0=C1
TAU=C0*W*W*PAIR
VSTR=(TAU/1000.)**.5
C ENTRAINMENT VELOCITY APPROACH
TMIX=T(JM,1)

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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-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
SUBROUTINE SUREL(N,I)
REAL LENGTH
COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
COMMON /ETIME/ ET,NPOND
COMMON /SURFLR/ KSUR
COMMON /MIX/ KMIX,MIXED(3,5),RMIX(3,5),KOH
COMMON/CUM/CUMQIN,CUMQOT,SAREA1(5),DYSUR1(5),JM1,NELSV(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 /GEOMC/ YYBOT(5),DYY(5),AI(100,5),XLI(100,5),BI(100,5),

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,DYSURI(5),YSURI(5),ELL(100,5),SAREAI(5),AYSURI(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),NOUTI,
,LOUT(5,5),ELOUT(5,5),NIN(5),QO(366,3,5),NINI,NIN1
COMMON /HFLows/ QQHIN(3000),TTHIN(3000),THIN,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=QQHIN(L+1)+RR*(QQHIN(L+2)-QQHIN(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=-SAREA1(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)

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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 VOLM=VOLM+A(JM-KL)*DY
   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)

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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),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 /CONMIX/ DMIX,MIXH
COMMON /ELB/ ELBSL
INTEGER COLD
III=1
DAHL=DXX(I,III)*WDTH(I,III)
NH=NSEG(I,III)
DMIX=DY
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 J=1,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
AREAA1=DAHL*DHL/DY/2.
TAREA1=AREAA1*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 AREAA1=AREAA1+DAHL*DHL/DY
TAREA1=TAREA1+DAHL/DY*DHL*TEMP(K22)
K33=K22
888 CONTINUE
800 AREAA1=AREAA1+A(JM)
TAREA1=TAREA1+A(JM)*T(JM,1)
TAV1=TAREA1/AREAA1
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

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      J=JM-IJ+1
      JJ=J-1
      GO TO (13,12),COLD
12  CALL COLDCK(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   AREAA=DAHL*DHL/DY/2.
      TAREA=AREAA*TEMP(NAR)
      NAR1=NAR-1
      DO 37 K1=1,NAR1
      K2=NAR-K1
      TAR=TEMP(K2)
      GO TO (15,14),COLD
14  CALL COLDCK(TAR,T(JJ,1),IFLG,LOOP)
      GO TO (4,35),IFLG
15  IF(TAR-T(JJ,1))35,4,4
35  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 COLDCK(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.
      KX=KJ
      TAVX=TAV
      AVX=AV2
      AVY=AV1
      K4=K3
      DO 60 L=J,JM
60  T(L,1)=TAV
      DO 70 L=K3,NAR

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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 TO91
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.OF
      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 /TEMP/ 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

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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/ 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
COMMON /EQUIL/ TE,IDT
COMMON /ETIME/ ET,NPOND
COMMON /TENGY/ TENRAT(5)
COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
COMMON /PRNTKT/ KT1,KT2,KTA
COMMON /FLXES/ SR,EVAP,RAD,CONDUCT,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
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(5,5),ELOUT(5,5),NIN(5),QO(366,3,5),NINI,NIN1
COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
COMMON /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/ NDAY(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)*IFREQT.NE.ICOUNT)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 ',
,'STEPS= ',I4,8X,'DATE ',I2,'/',I2,'/',I4)
    IF((ICOUNT/IFREQA)*IFREQA.NE.ICOUNT) GO TO 150
    CALL PRINTA(ICOUNT)
150 GO TO (160,160,180),KMODE
160 IF((ICOUNT/IFREQ1)*IFREQ1.NE.ICOUNT) GO TO 170
    CALL PRINT1(ICOUNT,I)
170 IF(KMODE.EQ.1) RETURN
180 IF((ICOUNT/IFREQ2)*IFREQ2.NE.ICOUNT) 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

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```

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,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),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',
,I4)
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,KSTRT(5),KOPERA,KCIRC(5)
COMMON /HFLOW/ 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

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```

COMMON /EQUIL/ TE, IDT
COMMON /ETIME/ ET, NPOND
COMMON /TENGY/ TENRAT(5)
COMMON /CWU/ H, EEMASS(5), EEVAP(5), EBRAD(5), EATRAD(5)
COMMON /PRNKT/ KT1, KT2, KTA
DIMENSION THLMF(101,5)
DIMENSION DTVDF(5), DTVTTL(5)
C DEFINITION OF VARIABLES LISTED IN ALPHABETICAL ORDER
C DTVDF = THEORETICAL DETENTION TIME IN THE DIFFUSIVE FLOW 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 DISPERSIVE FLOW REGION
C MP1 = NSEG+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)

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```

IF (QHIN .NE. 0.) GO TO 26
DTVTTL(I)=999.
DTVDF(I)=999.
GO TO 27
26 CONTINUE
DTVTTL(I)=VTOTAL(I)/QHIN
DTVDF(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 THLMF(J, I)=THLM(J, I, III)*9./5.+32.
WRITE (6,240) (THLMF(J, I), J=1, NM)
40 CONTINUE
RETURN
END
SUBROUTINE PRINTA(ICOUNT)
COMMON /SWITCH/KUNITS, KSTRAT, KHEAT, KSTRT(5), KOPERA, KCIRC(5)
COMMON /TEMPA/ TEMP(100), THLM(100,5,2), TLOSS(100), TOUT(3000,5)
COMMON /HFLWS/ QQHIN(3000), TTHIN(3000), THIN, QHIN, QHINI, NQHIN,
,DTQHIN
COMMON /FLXES/ SR, EVAP, RAD, CONDOC, 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+CONDOC+RAD
WRITE (6,949)
949 FORMAT (///5X, 'METEOROLOGICAL 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
60 DO 65 I=1, NPOND
65 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

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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 RADIATION',
,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 /HFLWS/ 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),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 /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),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 /ETIME/ ET,NPOND
COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
COMMON /FLXES/ SR,EVAP,RAD,CONDC,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 TLOWF(100,5),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

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280 WRITE(6,803)K,JIN(K),TININ(K),QIN(K),TIN(K)
803 FORMAT(13X,I2,7X,I3,3X,F9.2,4X,F12.2,4X,F9.2)
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 LEAPYEAR 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

```

2
1      1
1      2
1      2      2      1      1      2
32      1.0
57.2 58.9 59.1 64.9 63.8 53.9 59.6 65.6 70.1 70.4 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.
32      1.0
.51 .40 .47 .62 .89 .57 .67 .63 .74 .77 .82 .82 .90 .94 .84 .70
.53 .48 .68 .89 .80 .89 .79 .87 .92 .72 .59 .57 .80 .69 .58 .89
32      1.0
4.04 5.29 4.34 6.25 5.85 6.33 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 .90 .00 .30 .10 .38 .40 .50 .40 .90 1.00 1.00 .30
.00 .00 .60 1.00 .50 .90 .70 .90 1.00 .70 .40 .80 .70 .30 .60 1.00
0.3      0.5
.125      8.00      64      64      64
1
5/16/1979
5/24/1979
9
8.0      1200.0      24000.0
10
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 155692800.0 155692800.0
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155692800.0 155692800.0 155692800.0 155692800.0 155692800.0 155692800.0
92.0 92.5 93.0 93.5 93.0 90.0 91.0 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 89.0 90.0 90.0 90.0 91.7 89.8 88.0 87.0
86.5 86.0 85.5 88.0 88.6 88.9 90.1 94.0 94.0
6
10.0      2250.0      9000.0
7
91.1 89.5 89.0 88.5 88.0 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

	2																
	1		1														
	1		2														
	1		2		2		1		1		1						
	32		1.0														
57.2	58.9	59.1	64.9	63.8	53.9	59.6	65.6	70.1	70.4	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.		
	32		1.0														
.51	.40	.47	.62	.89	.57	.67	.63	.74	.77	.82	.82	.90	.94	.84	.70		
.53	.48	.68	.89	.80	.89	.79	.87	.92	.72	.59	.57	.80	.69	.58	.89		
	32		1.0														
4.04	5.29	4.34	6.25	5.85	6.33	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	.90	.90	.00	.30	.10	.38	.40	.50	.40	.90	1.00	1.00	.30		
.00	.00	.60	1.00	.50	.90	.70	.90	1.00	.70	.40	.80	.70	.30	.60	1.00		
	0.3		0.5														
.125		8.00		64		64		64									
	1																
5/16/1979																	
5/24/1979																	
	9																
8.0		1200.0		24000.0													
	10																
92.0	91.9	91.8	91.7	91.6	91.5	91.4	91.3	91.2	91.1								
0.0		0.0															
	2		20.0														
155692800.0		155692800.															
20.0																	
	6																
10.0		2250.0		9000.0													
	7																
91.1	89.5	89.0	88.5	88.0	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															

195

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 POND 1
 TOTAL VOLUME 230400000.
 HORIZONTALLY MIXED FRACTION 0.0
 VOLUME DFR 230400000.
 VOLUME FM 0.
 CROSS SECTIONAL AREA 9600.00
 DEPTH 8.00
 WIDTH 1200.00
 LENGTH 24000.00
 ELEMENTS IN DFR 9
 DISTANCE INCREMENT 2666.67
 ENTRAINMENT 0.0

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

VERTICALLY MIXED REGION GEOMETRY POND 2
 TOTAL VOLUME 404999936.
 HORIZONTALLY MIXED FRACTION 0.05
 VOLUME DFR 394874880.

	JET SIDE	RETURN SIDE
VOLUME FM		10125000.
CROSS SECTIONAL AREA	22500.00	22500.00
DEPTH	10.00	10.00
WIDTH	2250.00	2250.00
LENGTH	9000.00	9000.00
ELEMENTS IN DFR	6	6

DISTANCE INCREMENT 1500.00 1425.00
 ENTRAINMENT 1.00

INITIAL TEMPERATURE DISTRIBUTION IN POND 2

91.10	89.50	89.00	88.50	88.00	87.50	87.00
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.	AIR TEMPERATURE	69.54		
REL HUMIDITY	0.73	WIND SPEED	4.58	CLOUD COVER	0.34		
HEAT LOSS=	5753.						

POND	CUMULATIVE EVAP MASS LOSS
1	10374404.0
2	9782652.0

197

VERTICALLY MIXED REGION

INFLOW TEMPERATURE	86.75	FLOW RATE	155692784.						
FOR POND 1	ENERGY RATIO= 1.0031								
TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:									
86.75	86.51	86.41	86.26	86.08	85.86	85.61	85.35	85.12	84.96

VERTICALLY MIXED REGION

FOR POND 2	ENERGY RATIO= 1.0020					
TEMPERATURE DISTRIBUTION IN THE DIRECTION OF FLOW:						
81.50	80.59	80.49	80.42	80.36	80.31	80.29
80.29	78.73	78.59	78.47	78.37	78.30	78.27

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 POND 1
 TOTAL VOLUME 230400000.
 HORIZONTALLY MIXED FRACTION 0.0
 VOLUME DFR 230400000.
 VOLUME FM 0.
 CROSS SECTIONAL AREA 9600.00
 DEPTH 8.00
 WIDTH 1200.00
 LENGTH 24000.00
 ELEMENTS IN DFR 9
 DISTANCE INCREMENT 2666.67
 ENTRAINMENT 0.0

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

VERTICALLY MIXED REGION GEOMETRY POND 2
 TOTAL VOLUME 404999936.
 HORIZONTALLY MIXED FRACTION 0.05
 VOLUME DFR 394874880.

	JET SIDE	RETURN SIDE
VOLUME FM		10125000.
CROSS SECTIONAL AREA	22500.00	22500.00
DEPTH	10.00	10.00
WIDTH	2250.00	2250.00
LENGTH	9000.00	9000.00
ELEMENTS IN DFR	6	6
DISTANCE INCREMENT	1500.00	1425.00
ENTRAINMENT	1.00	

INITIAL TEMPERATURE DISTRIBUTION IN POND 2

91.10	89.50	89.00	88.50	88.00	87.50	87.00
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	ATMOS RADIATION	2586.	AIR TEMPERATURE	69.54
SOLAR RADIATION	2161.	WIND SPEED	4.58	CLOUD COVER	0.34
REL HUMIDITY	0.73				
HEAT LOSS=	6986.				

POND	CUMULATIVE EVAP MASS LOSS
1	14648437.0
2	11045575.0

199

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

1
EXAMPLE: VERTICALLY STRATIFIED COOLING POND

```

1
2      1
1      2      2      1      1      1
32     1.0
57.2 58.9 59.1 64.9 63.8 53.9 59.6 65.6 70.1 70.4 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.
32     1.0
.51  .40  .47  .62  .89  .57  .67  .63  .74  .77  .82  .82  .90  .94  .84  .70
.53  .48  .68  .89  .80  .89  .79  .87  .92  .72  .59  .57  .80  .69  .58  .89
32     1.0
4.04 5.29 4.34 6.25 5.85 6.33 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 .90 .90 .00 .30 .10 .38 .40 .50 .40 .90 1.00 1.00 .30
.00 .00 .60 1.00 .50 .90 .70 .90 1.00 .70 .40 .80 .70 .30 .60 1.00
0.3 0.5
1.00 8.00 8 8 8

```

200

```

1
5/16/1979
5/24/1979
20      24
5.0     96.0
4       50.0      0.0
60000000.102000000.144000000.144000000.
4       50.0      0.0
15000. 19500. 24000. 24000.
55.0 55.0 55.0 55.0 55.0 57.0 57.0 57.0 57.0 57.0 60.0 60.0 60.0 60.0 60.0 63.0
63.0 63.0 63.0 63.0
1.2900
1.96   5.0
1
2      2      4 2.0
7      5.0
8640000. 8640000. 8640000. 8640000. 8640000. 8640000.
8640000.
58.0 58.0 58.0 58.0 58.0 58.0 58.0
2
17     80.0
2      32.0
8640000. 8640000.
5      20.0
2      32.0
172800000. 172800000.
12
4.0      6000.0      24000.0
13
75.0 74.5 74.0 72.5 71.0 70.0 69.0 68.0 67.0 66.0 65.0 64.0 63.0

```

0.1	0.3
2	32.0
172800000.	172800000.
25.0	

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 5/16/1979

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

ELEMENT	AREA	LENGTH	WIDTH	TEMPERATURE
1	0.60000E+08	15000.	4000.	55.00
2	0.64200E+08	15450.	4155.	55.00
3	0.68400E+08	15900.	4302.	55.00
4	0.72600E+08	16350.	4440.	55.00
5	0.76800E+08	16800.	4571.	55.00
6	0.81000E+08	17250.	4696.	57.00
7	0.85200E+08	17700.	4813.	57.00
8	0.89400E+08	18150.	4925.	57.00
9	0.93600E+08	18600.	5032.	57.00
10	0.97800E+08	19050.	5134.	57.00
11	0.10200E+09	19500.	5231.	60.00
12	0.10620E+09	19950.	5323.	60.00
13	0.11040E+09	20400.	5412.	60.00
14	0.11460E+09	20850.	5496.	60.00
15	0.11880E+09	21300.	5577.	60.00
16	0.12300E+09	21750.	5655.	63.00
17	0.12720E+09	22200.	5730.	63.00
18	0.13140E+09	22650.	5801.	63.00
19	0.13560E+09	23100.	5870.	63.00
20	0.13980E+09	23550.	5936.	63.00

VERTICALLY MIXED REGION GEOMETRY
 TOTAL VOLUME
 HORIZONTALLY MIXED FRACTION

POND 1
 576000000.
 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

203

METEOROLOGICAL DATA

EQUILIBRIUM TEMPERATURE 75.0
 SOLAR RADIATION 2331. ATMOS RADIATION 2428. AIR TEMPERATURE 65.60
 REL HUMIDITY 0.63 WIND SPEED 4.95 CLOUD COVER 0.10
 HEAT LOSS= 3981.

POND 1 CUMULATIVE EVAP MASS LOSS 18150400.0

VERTICALLY MIXED REGION

INFLOW TEMPERATURE 81.55 FLOW RATE 172799952.
 FOR POND 1 ENERGY RATIO= 0.9875
 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= 0.9875

INFLOW LEVEL INFLOW TEMP INFLOW RATE MIXED TEMP
 1 17 58.00 8639998.00 63.91

2 20 71.59 224639792. 71.59

OUTFLOW	LEVEL	OUTFLOW TEMP	OUTFLOW RATE
1	17	65.25	8639998.00
2	5	56.70	172799952.

J	ELEV	TEMP	J	ELEV	TEMP	J	ELEV	TEMP	J	ELEV	TEMP	J	ELEV	TEMP	J	ELEV	TEMP
1	0.0	55.00	11	50.0	60.27												
2	5.0	55.03	12	55.0	60.76												
3	10.0	55.28	13	60.0	61.43												
4	15.0	56.11	14	65.0	62.19												
5	20.0	56.91	15	70.0	63.02												
6	25.0	57.51	16	75.0	64.17												
7	30.0	58.18	17	80.0	65.90												
8	35.0	58.87	18	85.0	67.74												
9	40.0	59.46	19	90.0	69.23												
10	45.0	59.89	20	95.0	71.32												

Run 3 Input Data

1
EXAMPLE: NATURAL LAKE

1																			
2	1																		
1	2			2		2		2		1									
32	1.0																		
57.2	58.9	59.1	64.9	63.8	53.9	59.6	65.6	70.1	70.4	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.				
32	1.0																		
.51	.40	.47	.62	.89	.57	.67	.63	.74	.77	.82	.82	.90	.94	.84	.70				
.53	.48	.68	.89	.80	.89	.79	.87	.92	.72	.59	.57	.80	.69	.58	.89				
32	1.0																		
4.04	5.29	4.34	6.25	5.85	6.33	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	.90	.90	.00	.30	.10	.38	.40	.50	.40	.90	1.00	1.00	.30				
.00	.00	.60	1.00	.50	.90	.70	.90	1.00	.70	.40	.80	.70	.30	.60	1.00				
0.3	0.5																		
1.00	8.00			8		8		8											
1																			
5/ 1/1979																			
5/ 9/1979																			
21	24																		
5.0	100.0																		
4	50.0			0.0															
60000000.10	2000000.14	4000000.14	4000000.14	4000000.14															
4	50.0			0.0															
15000.	19500.			24000.		24000.													
48.0	48.0	48.0	48.0	48.1	48.3	48.5	49.0	50.0	51.0	53.5	55.0	58.0	60.0	61.0	61.8				
62.1	62.5	63.0	63.0	64.0															
1.2900																			
1.96	5.0																		
1																			
2	2			4	2.0														
7	5.0																		
17280000.	17280000.			17280000.		17280000.		17280000.		17280000.		17280000.		17280000.					
17280000.																			
48.0	50.0	53.0	50.0	48.0	47.0	47.0													
1																			
11	50.0																		
2	32.0																		
17280000.	17280000.																		

205

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

KQH 2 KMIX 2 MIXED(1) 4 RMIX(1) 2.00

STRATIFIED PORTION GEOMETRY

ELEMENT	AREA	LENGTH	WIDTH	TEMPERATURE
1	0.60000E+08	15000.	4000.	48.00
2	0.64200E+08	15450.	4155.	48.00
3	0.68400E+08	15900.	4302.	48.00
4	0.72600E+08	16350.	4440.	48.00
5	0.76800E+08	16800.	4571.	48.10
6	0.81000E+08	17250.	4695.	48.30
7	0.85200E+08	17700.	4813.	48.50
8	0.89400E+08	18150.	4925.	49.00
9	0.93600E+08	18600.	5032.	50.00
10	0.97800E+08	19050.	5134.	51.00
11	0.10200E+09	19500.	5231.	53.50
12	0.10620E+09	19950.	5323.	55.00
13	0.11040E+09	20400.	5412.	58.00
14	0.11460E+09	20850.	5496.	60.00
15	0.11880E+09	21300.	5577.	61.00
16	0.12300E+09	21750.	5655.	61.80
17	0.12720E+09	22200.	5730.	62.10
18	0.13140E+09	22650.	5801.	62.50
19	0.13560E+09	23100.	5870.	63.00
20	0.13980E+09	23550.	5936.	63.00
21	0.14400E+09	24000.	6000.	64.00

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" \mathbb{P} , and a horizontal aspect ratio L/W . The former is defined as

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

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

(1) deep stratified cooling ponds ($\mathbb{P} \leq 0.5$), (2) shallow cooling ponds with longitudinal dispersion ($\mathbb{P} \geq 0.5$; $L/W \geq 4$) and (3) shallow cooling ponds with lateral recirculation ($\mathbb{P} \geq 0.5$; $L/W \leq 4$). 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

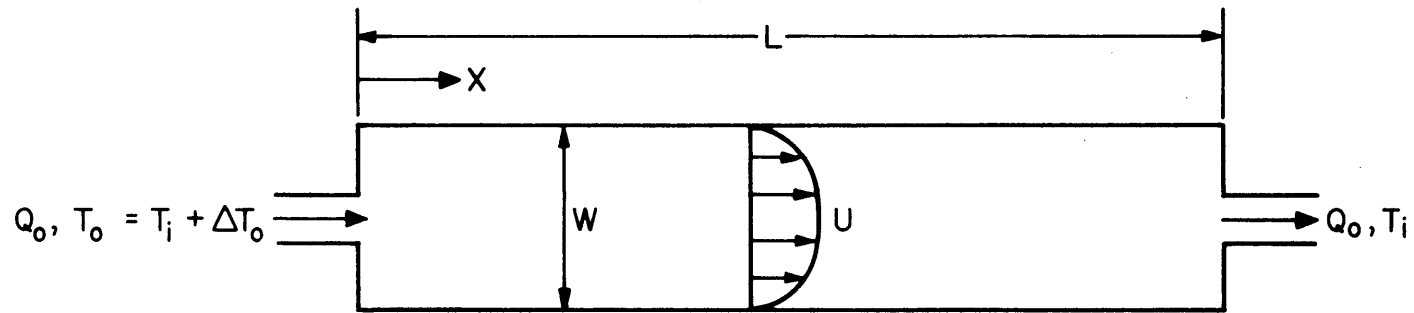


Figure 1 Plan View of Shallow Cooling Pond with Longitudinal Dispersion (Depth = H)

4

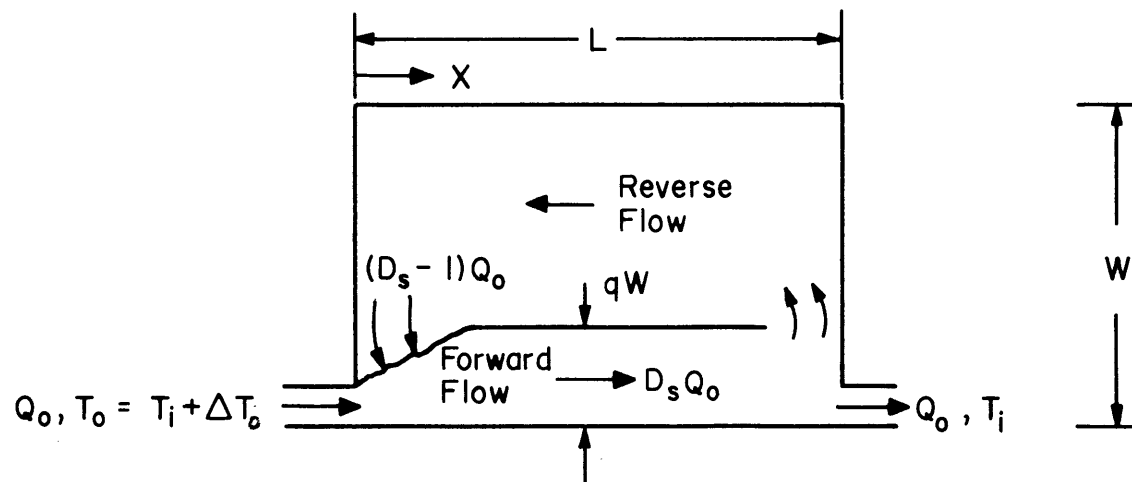


Figure 2 Plan View of Shallow Cooling Pond with Lateral Recirculation (Depth = H)

long pond or a series of three shorter ponds.

The pond is represented by the variables L, W, H, Q_o 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:

$$\frac{\partial T(x,t)}{\partial t} + U \frac{\partial T(x,t)}{\partial x} = E_L \frac{\partial^2 T(x,t)}{\partial x^2} - \frac{\phi_n}{\rho c H} \quad (2)$$

with boundary conditions

$$UT(0,t) - E_L \frac{\partial T(0,t)}{\partial x} = U[T(L,t) + \Delta T_o] \quad \text{at } x = 0 \quad (3)$$

$$\frac{\partial T(L,t)}{\partial x} = 0 \quad \text{at } x = L \quad (4)$$

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, ϕ_n = net surface heat flux to the atmosphere, ρ = density and c = the specific heat of water. E_L is based on Fischer's dispersion analysis (1967) and is given by

$$E_L = \frac{0.3 \sqrt{f_o/8} U \left(\frac{W}{2}\right)^2}{\kappa^2 H} \quad (5)$$

where κ 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

$$\phi_n = K(T - T_E) \quad (6)$$

and Eq. 2 is rewritten

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

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 ΔT_O (appearing in Eq. 3), U , or both ΔT_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-

ificantly. 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 ΔT_o with a frequency ω . 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

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

Similarly the equilibrium temperature is written

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

The steady state solution is found by setting $\partial/\partial t$ and $\Delta T_{E_t} = 0$ in Eq. 7 leaving

$$U \frac{\partial T_{ss}(x)}{\partial x} - E_L \frac{\partial^2 T_{ss}(x)}{\partial x^2} + \frac{K}{\rho c H} T_{ss}(x) = \frac{K T_{E_{ss}}}{\rho c H} \quad (10)$$

$$U T_{ss}(0) - E_L \frac{\partial T_{ss}(0)}{\partial x} = U [T_{ss}(L) + \Delta T_o] \quad \text{at } x = 0 \quad (11)$$

$$\frac{\partial T_{ss}(L)}{\partial x} = 0 \quad \text{at } x = L \quad (12)$$

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

$$\frac{T_{ss}(x) - T_{E_{ss}}}{T_o} = \frac{r_1 e^{r_1 x/L} - r_2 e^{r_2 x/L}}{r_1 e^{r_1}(1 - E_L r_2/UL - e^{r_2}) - r_2 e^{r_2}(1 - E_L r_1/UL - e^{r_1})} \quad (13)$$

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

$a = \sqrt{1 + 4KA E_L/\rho c Q UL}$. The solution for the steady state intake temperature

$T_{i_{ss}}$ is found by setting $x/L = 1$, yielding the solution reported in

Appendix B to Part A of this report

$$\frac{T_{i_{ss}} - T_{E_{ss}}}{\Delta T_o} = \frac{UL/2E_L}{(1+a)^2 e^{aUL/2E_L} - (1-a)^2 e^{-aUL/2E_L} - 4a e^{UL/2E_L} - 4a e^{-UL/2E_L}} \quad (14)$$

The transient solution, ΔT_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 ΔT_t can be shown to vanish (after any transient adjustment following station start-up) resulting in the equivalent equation:

$$\frac{\partial \Delta T_t(t)}{\partial t} = - \frac{K}{\rho c H} [\Delta T_t(t) - \Delta T_{E_t}] \quad (15)$$

The solution to Eq. 15 for an arbitrary input $\Delta T_{E_t}(t)$ 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 $[1 - \exp(-Kn\Delta t/\rho cH)]$. 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

$$\Delta T_t(t) = [1 - \exp(-K\Delta t/\rho cH)] \sum_{n=0}^{\infty} T_E(t-n\Delta t) \exp(-nK\Delta t/\rho cH) \quad (16)$$

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 ΔT_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/UL . In this regard the often-used plug flow and well-mixed models are seen to result from the limits of $E_L = 0$ and ∞ 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 $\rho cH/K$; in other words, the pond's thermal inertia is governed solely by its water depth. For typical values of $K = 100 - 300 \text{ BTU-ft}^{-2} \text{-}^\circ\text{F}^{-1}\text{-day}^{-1}$ ($25\text{-}75 \text{ W-m}^{-2}\text{-}^\circ\text{C}^{-1}$) 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 ΔT_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

$$\langle y(t) \rangle = (1-\alpha) \sum_{n=0}^{\infty} y(t-n\Delta t) \alpha^n \quad (17)$$

where $y(t)$ is the input series with time interval Δt , $\langle y(t) \rangle$ is the output series and α 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

$$T(x,t) = T_{ss}(x, T_{E_{ss}}) + \langle \Delta T_{E_t}(t) \rangle \quad (18a)$$

and

$$T(x,t) = \langle T_{ss}(x, T_E(t)) \rangle \quad (18b)$$

where the term $\langle T_{ss}(x, T_E(t)) \rangle$ 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 α (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 ϕ_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

$$T = T_E + \frac{\rho c Q_o}{KA} \Delta T_o \quad (19)$$

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 α . 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

$$\langle y(t) \rangle = \frac{1}{N} \sum_{n=0}^{N-1} y(t-n\Delta t) \quad (20)$$

and is used implicitly whenever averaged input data are used. In the case study example, meteorological variables used to compute ϕ_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 χ represents the meteorological variables used to compute T_E , this means

$$T(x,t) = T_{ss}(x, T_E(\langle \chi(t) \rangle)) \quad (21)$$

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

$$\frac{\partial T_f(x,t)}{\partial t} + U_f \frac{\partial T_f(x,t)}{\partial x} = - \frac{K}{\rho c H} [T_f(x,t) - T_E] \quad (22)$$

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

$$\frac{\partial T_r(x,t)}{\partial t} + U_r \frac{\partial T_r(x,t)}{\partial x} = - \frac{K}{\rho c H} [T_r(x,t) - T_E(t)] \quad (23)$$

with

$$U_f = \frac{D_s Q_o}{qWH} \quad (24)$$

$$U_r = \frac{-(D_s - 1)Q_o}{(1-q)WH} \quad (25)$$

Boundary conditions for the two zones are

$$D_s Q_o T_f(0,t) = Q_o [T_f(L,t) + \Delta T_o] + (D_s - 1) Q_o T_r(0,t) \quad (26)$$

$$\text{and} \quad T_f(L,t) = T_r(L,t) \quad (27)$$

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

$$U_f \frac{\partial T_{f_{ss}}(x)}{\partial x} + \frac{K}{\rho c H} T_{f_{ss}}(x) = \frac{K T_E}{\rho c H} \quad (28)$$

and

$$U_r \frac{\partial T_{r_{ss}}(x)}{\partial x} + \frac{K}{\rho c H} T_{r_{ss}}(x) = \frac{K T_E}{\rho c H} \quad (29)$$

with

$$D_s Q_o T_{f_{ss}}(0) = Q_o [T_{f_{ss}}(L) + \Delta T_o] + (D_s - 1) Q_o T_{r_{ss}}(0) \quad (30)$$

and

$$T_{f_{ss}}(L) = T_{r_{ss}}(L) \quad (31)$$

The solution to this set of equations is

$$\frac{T_{f_{ss}}(x) - T_E}{\Delta T_o} = \frac{e^{-r q x / D_s L}}{D_s - e^{-r q / D_s} - (D_s - 1) e^{-r [(1 - q / D_s) / (D_s - 1)]}} \quad (32)$$

$$\frac{T_{f_{ss}}(x) - T_E}{\Delta T_o} = \frac{e^{-\frac{r}{(D_s - 1)} [(1 - q / D_s) - (1 - q) x / L]}}{D_s - e^{-r q / D_s} - (D_s - 1) e^{-r [(1 - q / D_s) / (D_s - 1)]}} \quad (33)$$

The steady state intake temperature, $T_{i_{ss}} = T_{f_{ss}}(x=L) = T_{r_{ss}}(x=L)$, as reported in Appendix B of Part A, is given by

$$\frac{T_{i_{ss}} - T_{E_{ss}}}{\Delta T_o} = \frac{e^{-rq/D_s}}{D_s - e^{-rq/D_s} - (D_s - 1)e^{-r[(1-q/D_s)/(D_s - 1)]}} \quad (34)$$

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. ($51 \text{ m}^3/\text{s}$) and $\Delta T_o = 20^\circ\text{F}$ (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

Run No. (1)	Designation (2)	Maximum Intake Temperature in Degrees Fahrenheit (Celsius) (3)	Minimum Intake Temperature in Degrees Fahrenheit (Celsius) (4)	Maximum minus Minimum in Degrees Fahrenheit (Celsius) (5)
1	Transient	97.8(36.6)	78.3(25.7)	19.5(10.9)
2	Q-S, filtered T _E	99.7(37.6)	76.7(24.8)	23.0(12.8)
3	Q-S, filtered K, T _E	97.1(36.2)	77.4(25.2)	19.7(11.0)
4	Q-S, 1-day data average	102.1(38.9)	73.7(23.2)	28.4(15.7)
5	Q-S, 3-day data average	99.2(37.3)	76.7(24.8)	22.5(12.5)
6	Q-S, 5-day data average	96.7(35.9)	80.3(26.8)	16.4(9.1)
7	Q-S, 10-day data average	95.8(35.4)	83.9(28.8)	11.9(6.6)
8	Q-S, 30-day data average	92.6(33.7)	86.4(30.2)	6.2(3.5)

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 , $234 \text{ BTU-ft}^{-2}\text{-}^\circ\text{F}^{-1}\text{-day}^{-1}$ ($55 \text{ W-m}^{-2}\text{-}^\circ\text{C}^{-1}$), 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

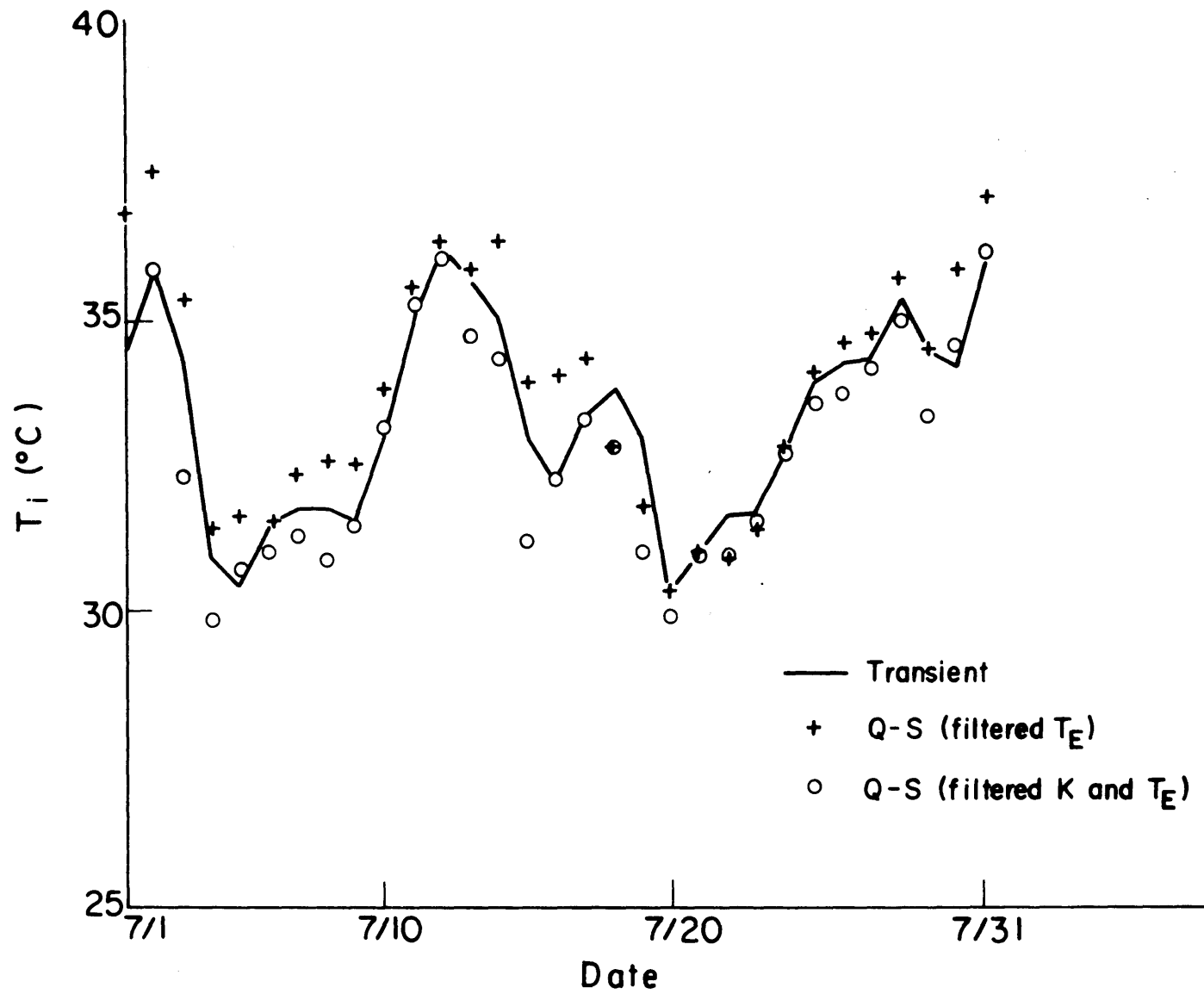


Fig. 3 Comparison of Transient and Quasi-Steady Models for July 1970

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 $\rho cH/K = 2.4$ days computed with the seasonal average value of $K = 234 \text{ BTU} \cdot \text{ft}^{-2} \cdot \text{day}^{-1} (55 \text{ W} \cdot \text{m}^{-2} \cdot \text{C}^{-1})$.

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 ($E_L \rightarrow 0$ in Eq. 14) and a steady state well-mixed model ($E_L \rightarrow \infty$ in Eq. 14). Based on seasonal average meteorology, $T_E = 77^\circ\text{F}(25^\circ\text{C})$ and $K = 234 \text{ BTU} \cdot \text{ft}^{-2} \cdot \text{day}^{-1} (55 \text{ W} \cdot \text{m}^{-2} \cdot \text{F}^{-1})$, 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

E_L/UL (1)	Designation (2)	$T_{i_{ss}} - T_{E_{ss}}$ in degrees Fahrenheit (Celsius) (3)
0	Plug-flow	10.8 (6.0)
0.41	Dispersive	14.8 (8.2)
∞	Well-mixed	19.1 (10.6)

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 then 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).

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