MATHEMATICAL PREDICTIVE MODELS FOR COOLING PONDS AND LAKES

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

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PART B: USER'S MANUAL AND APPLICATIONS OF MITEMP

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PART C: A TRANSIENT ANALYTICAL MODEL FOR SHALLOW COOLING PONDS

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ABSTRACT

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

The 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.

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"Computer Optimization of the MIT Advanced Wet/Dry Cooling Tower Concept for Power Plants," by Choi, M., and Glicksman, L.R., MIT Energy Laboratory Report No. MIT-EL 79-035, September 1979.

"Operational Issues Involving Use of Supplementary Cooling Towers to Meet Stream Temperature Standards with Application to the Browns Ferry Nuclear Plant," by Stolzenbach, K.D., Freudberg, S.A., Ostrowski, P., and Rhodes, J.A., MIT Energy Laboratory Report No. MIT-EL 79-036, January 1979.

"An Environmental and Economic Comparison of Cooling System Designs for Steam-Electric Power Plants," by Najjar, K.F., Shaw, J.J., Adams, E.E., Jirka, G.H., and Harleman, D.R.F., MIT Energy Laboratory Report No. MIT-EL 79-037, January 1979.

"Economic Implications of Open versus Closed Cycle Cooling for New Steam-Electric Power Plants: A National and Regional Survey," by Shaw, J.J., Adams, E.E., Barbera, R.J., Arntzen, B.C., and Harleman, D.R.F., MIT Energy Laboratory Report No. MIT-EL 79-038, September 1979.

"Mathematical Predictive Models for Cooling Ponds and Lakes," Part B: User's Manual and Applications of MITEMP by Octavio, K.H. Watanabe, M., Adams, E.E., Jirka, G.H., Helfrich, K.R., and Harleman, D.R.F.; and Part C: A Transient Analytical Model for Shallow Cooling Ponds, by Adams, E.E., and Koussis, A., MIT Energy Laboratory Report No. MIT-EL 79-039, December 1979.

"Summary Report of Waste Heat Management in the Electric Power Industry: Issues of Energy Conservation and Station Operation under Environmental Constraints," by Adams, E.E., and Harleman, D.R.F., MIT Energy Laboratory Report No. MIT-EL 79-040, December 1979.

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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

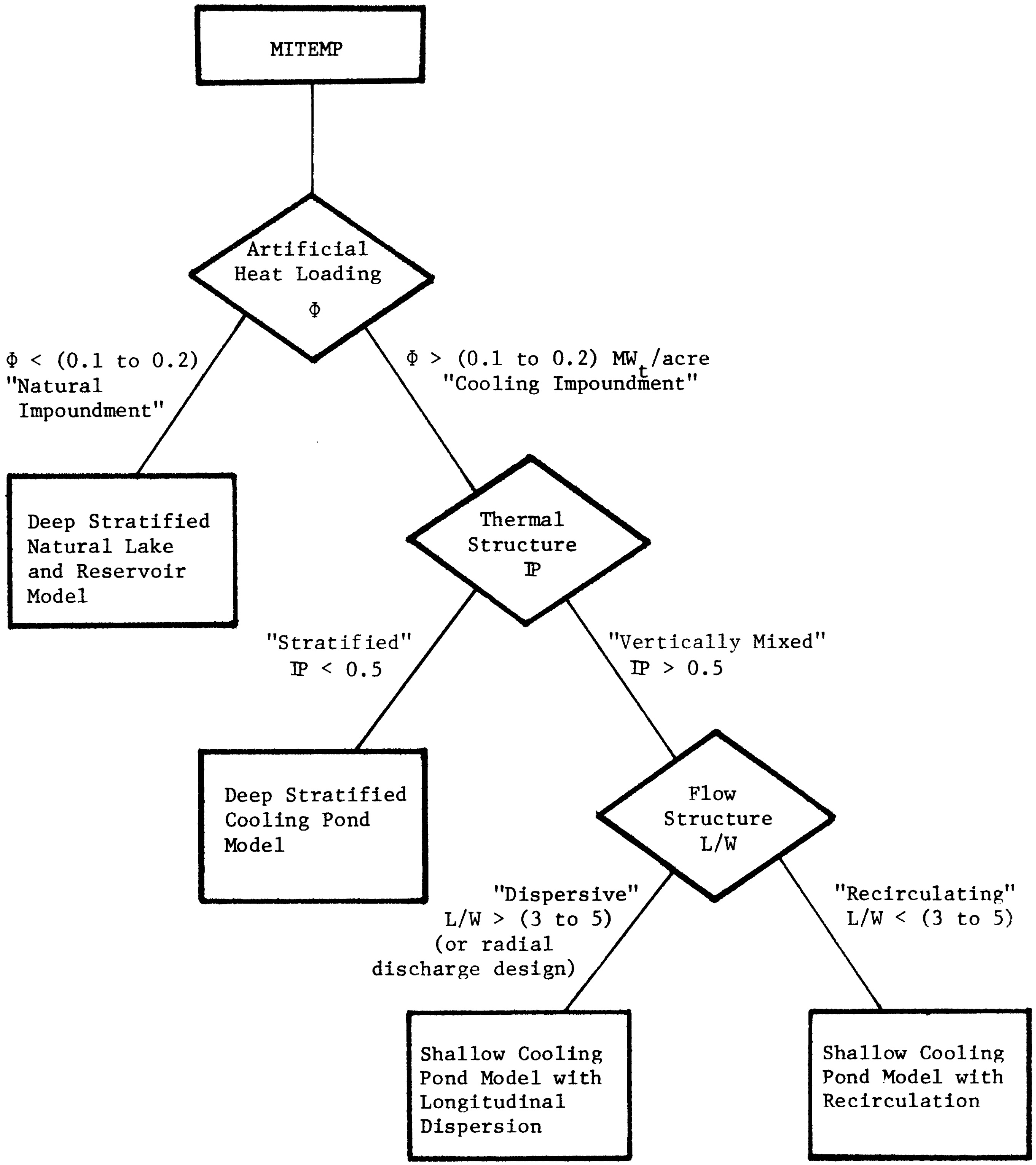


Figure 1-1: Hierarchical Structure of MITEMP and Decision Criteria

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

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

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_i = 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.

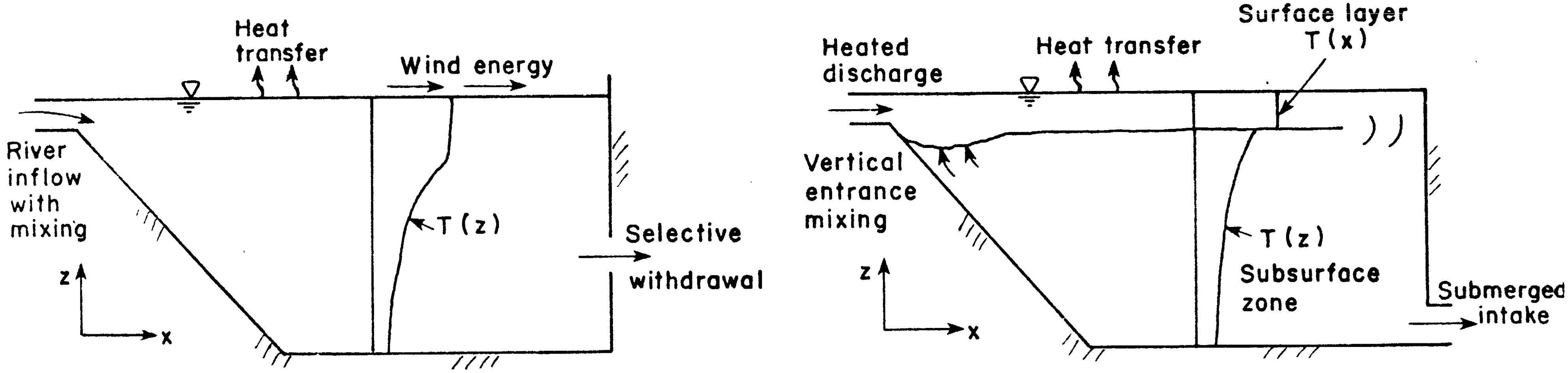
A criterion of $\mathbb{P} < 0.5$ is used to distinguish deep (vertically stratified) from shallow (vertically well-mixed) cooling ponds.

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).

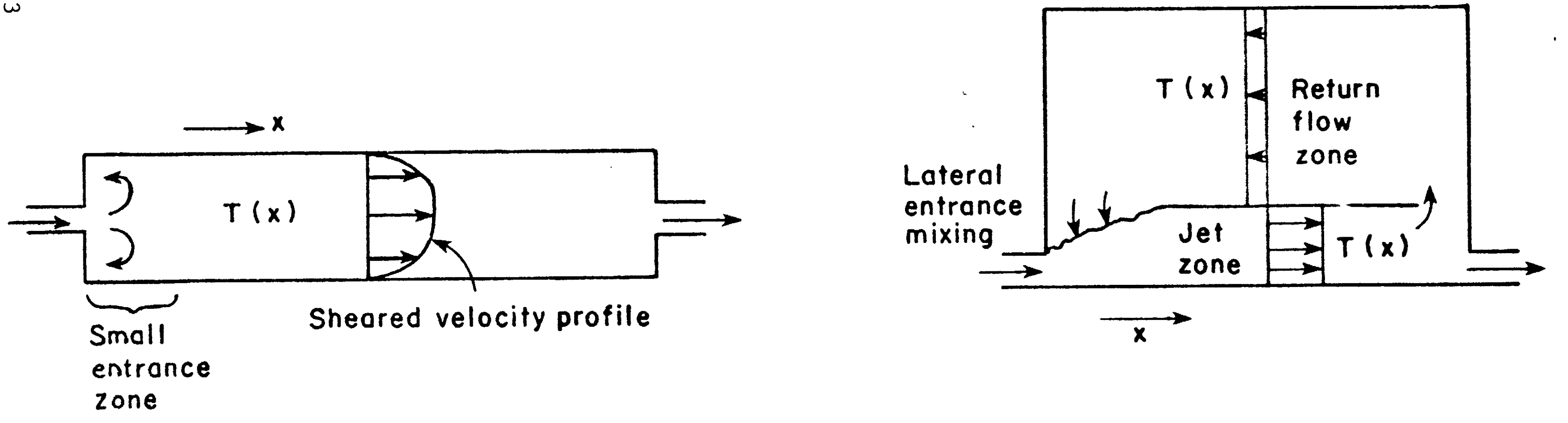
The temperature distribution in a natural deep lake or reservoir (Figure 1-2a) is assumed to be distributed vertically, i.e. T(z). The depth of the well-mixed surface layer is computed as a function of time in response to wind mixing and surface cooling using the algorithm described originally in Octavio 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)



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, $\mathbb{P}$ and L/W which place the pond in an inbetween classification, i.e. $\Phi \sim 0.1$ to 0.2, $\mathbb{P} \sim 0.5$ or L/W $\sim$ 3 to 5. In this case it may be prudent to perform simulations under both classifications and consider either average or worst case performance. It should also be clear that the classification systems can be used to guide initial pond design. For example, it is clear from linearized steady-state analysis (see Appendix B of Part A, Part C, or Jirka and Watanabe (1980b)) or from parametric sensitivity studies with the MITEMP model (Adams, et al., 1978), that shallow ponds with longitudinal dispersion are the most efficient; lateral entrance mixing associated with shallow recirculating ponds, or vertical entrance mixing associated with deep stratified ponds, may significantly decrease pond performance.

1.2 Use of MITEMP

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

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

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

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

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

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

(3) Time Variability: MITEMP can be run with a time scale of 3 hours to 1 day. This time step is short enough to adequately simulate weather fluctuations and plant transients, while filtering out events of a shorter duration which seem insignificant in view of the thermal inertia of water bodies. As coded, variable arrays allow a one year simulation of a deep stratified pond using one day time steps or a one year simulation of a vertically mixed pond using a 3 hour time step. Of course, variable dimensions can be changed to suit a user's need.

(4) Spatial Resolution: MITEMP allows one to differentiate the cooling (or natural)impoundment into major zones: namely the surface layer and the subsurface region. Within each zone, cumulative volume - temperature relationships are computed. Again, this procedure appears adequate in light of the governing requirements.

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

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

1.3 Report Outline

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

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

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

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

Numerical examples showing different input specifications and the resulting output are presented in Appendix B as a guideline and checkpoint for the prospective user.

II. STRUCTURE OF THE COMPUTER MODEL

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

2.1 Main Program

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

2.2 Data Input Subroutines

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

2.2.1 Subroutine MET

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

Meteorological requirements consist of:

(1) air temperature,

(2) relative humidity,

(3) wind speed,

(4) short wave solar radiation (If measured values are not available, maximum clear sky short wave solar radiation values can be used in conjunction with cloud cover data.),

(5) long wave atmospheric radiation - or cloud cover (Measured values of atmospheric radiation are generally not available. However, they can be computed from the air temperature and cloud cover.)

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

2.2.2 Subroutine GEOM1

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

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

2.2.3 Subroutine GEOM2

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

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

2.3 Subroutine WEATHR

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

2.4 Subroutine HEAT

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

2.5 Subroutine DISPER

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

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

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

$$\frac{\partial T}{\partial t} + \frac{1}{A}\frac{\partial}{\partial z}(Q_v T) = \frac{E}{A}\frac{\partial}{\partial z}[A \frac{\partial T}{\partial z}] + \frac{Bu_i T_i}{A} - \frac{Bu_o T}{A} - \frac{1}{\rho c A}\frac{\partial(A\phi_z)}{\partial z} \qquad (2.2)$$

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

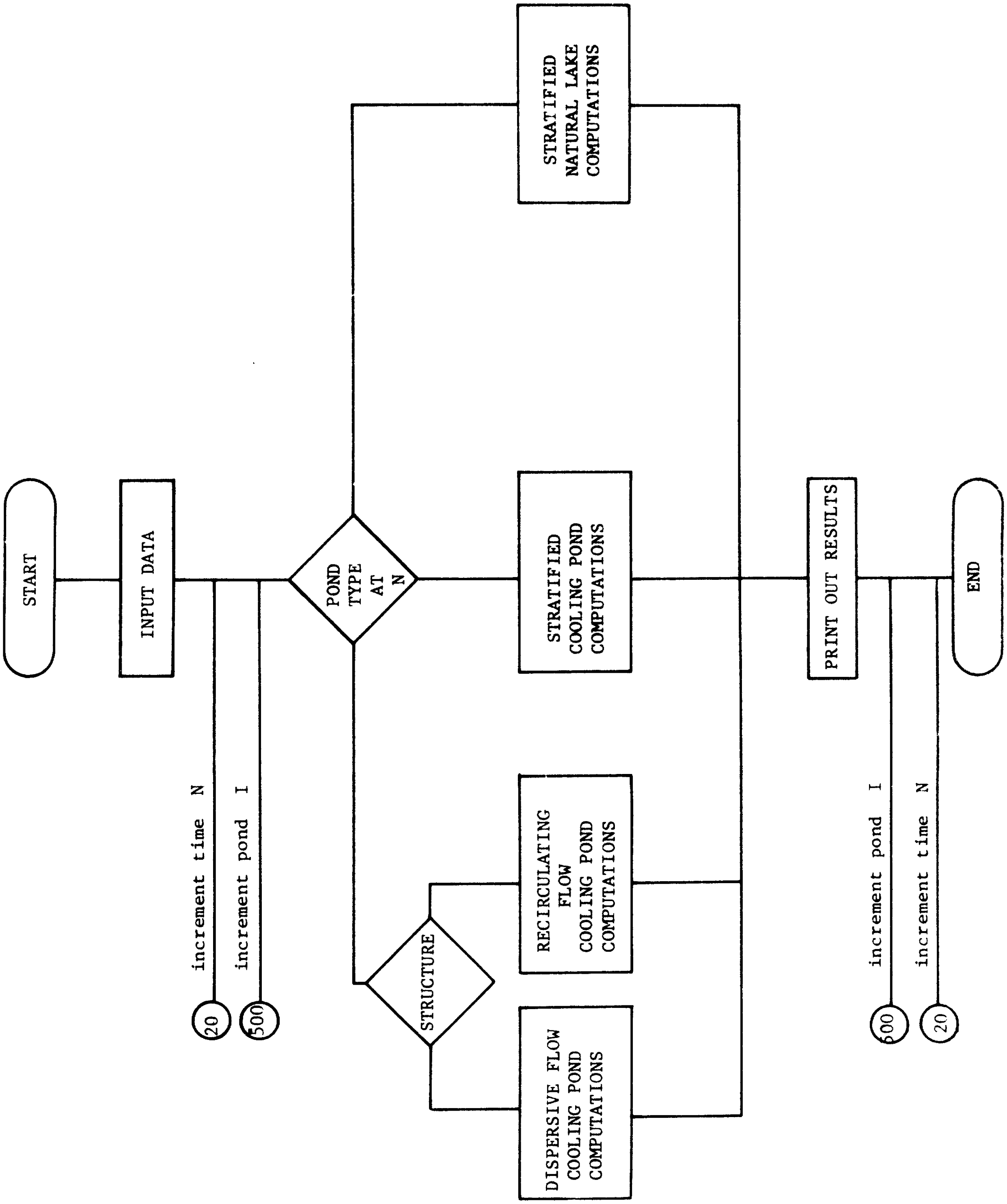


Figure 2-2: MAIN Program Flow Chart

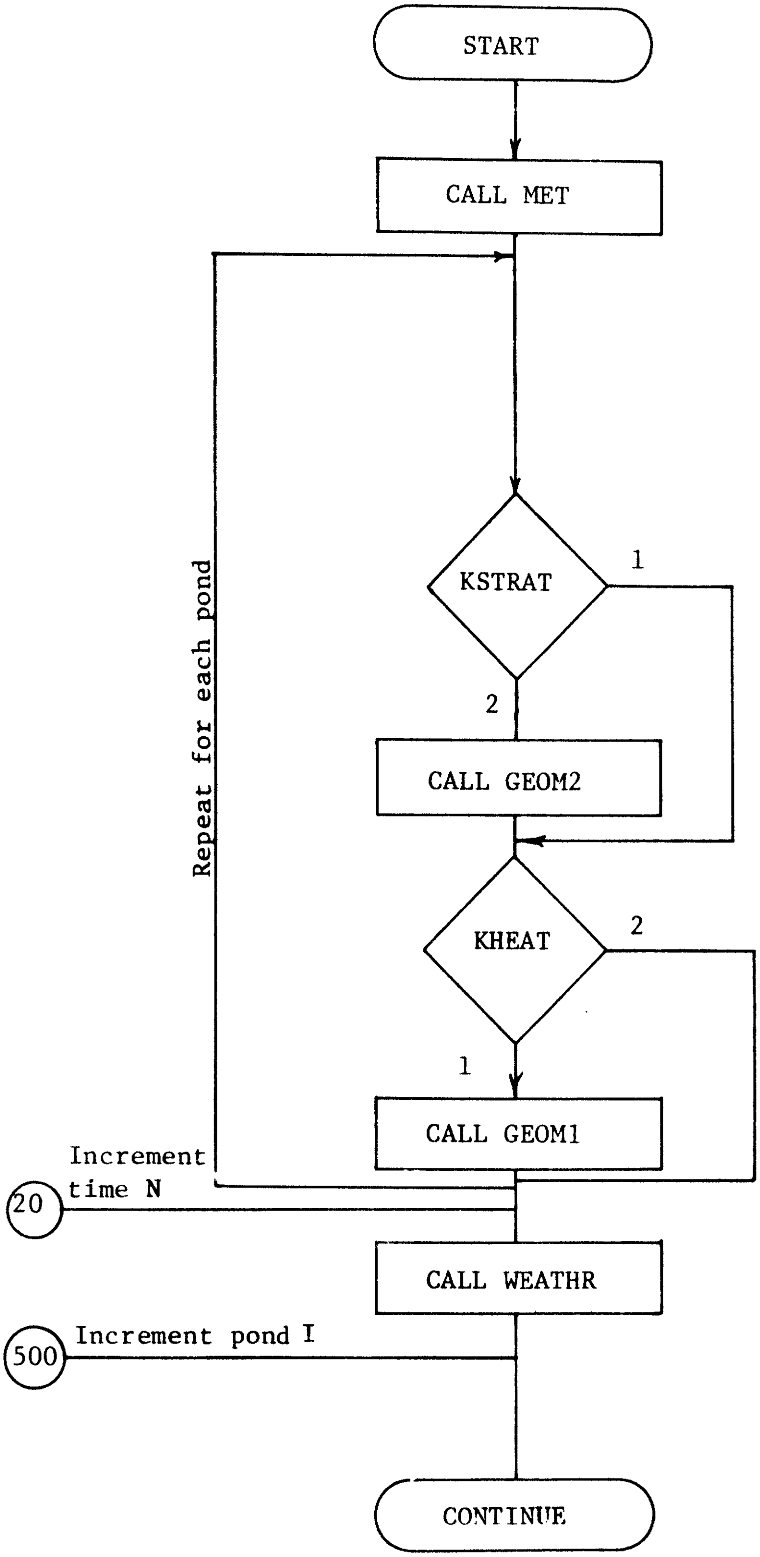


Figure 2-2 Cont'd

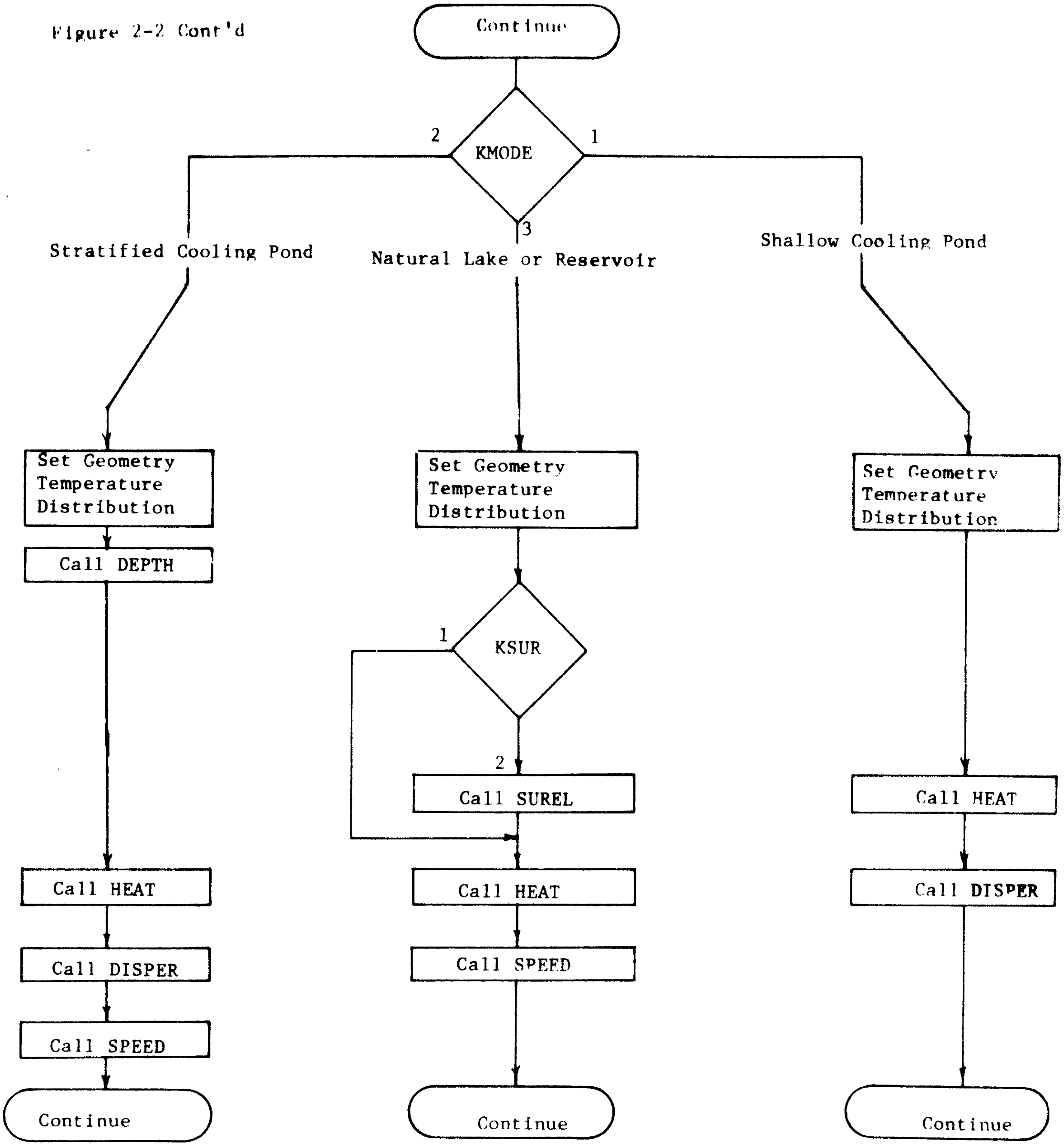


Figure 2-2 Cont'd

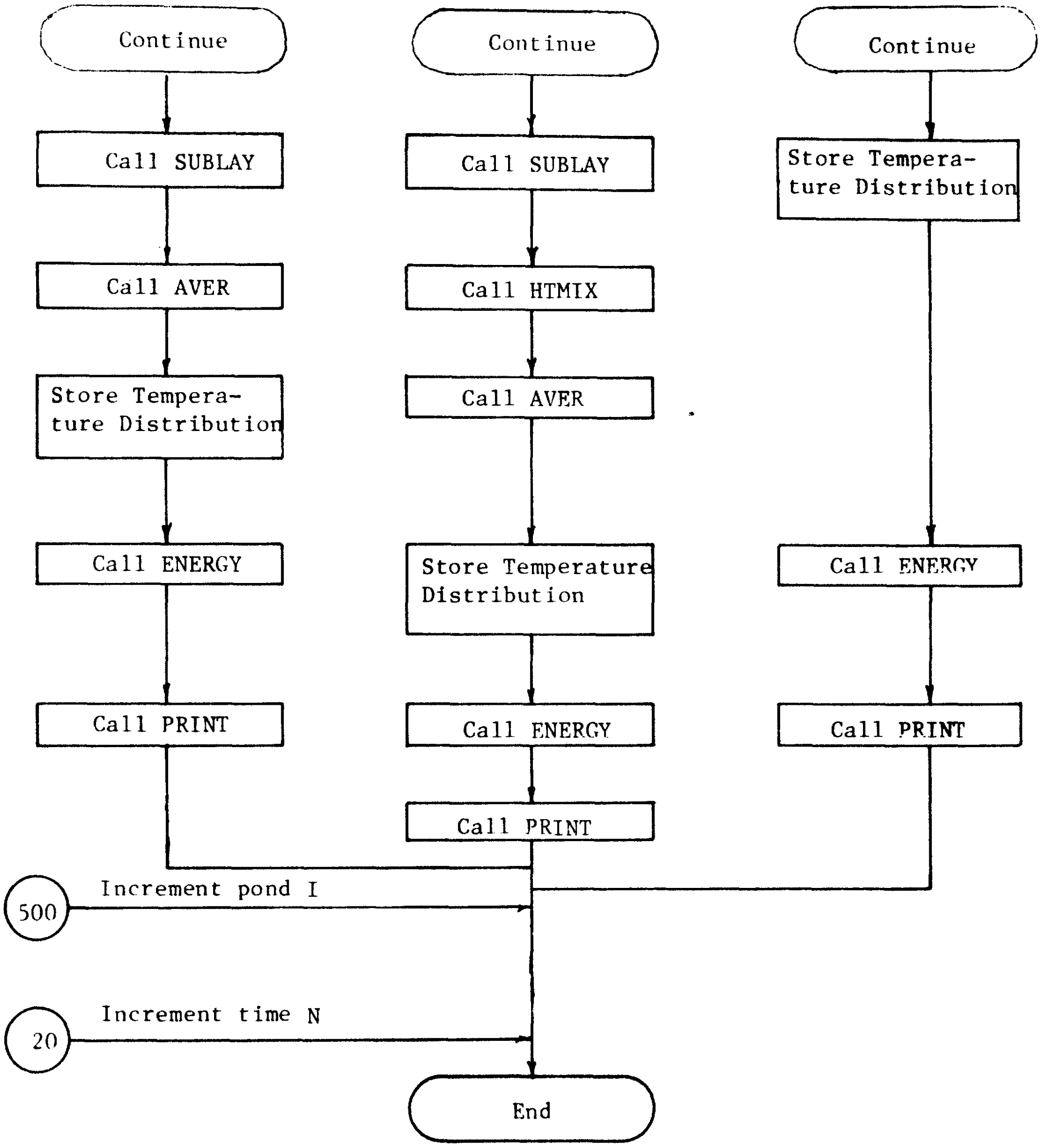


Figure 2-3: Subroutine MET Flow Chart

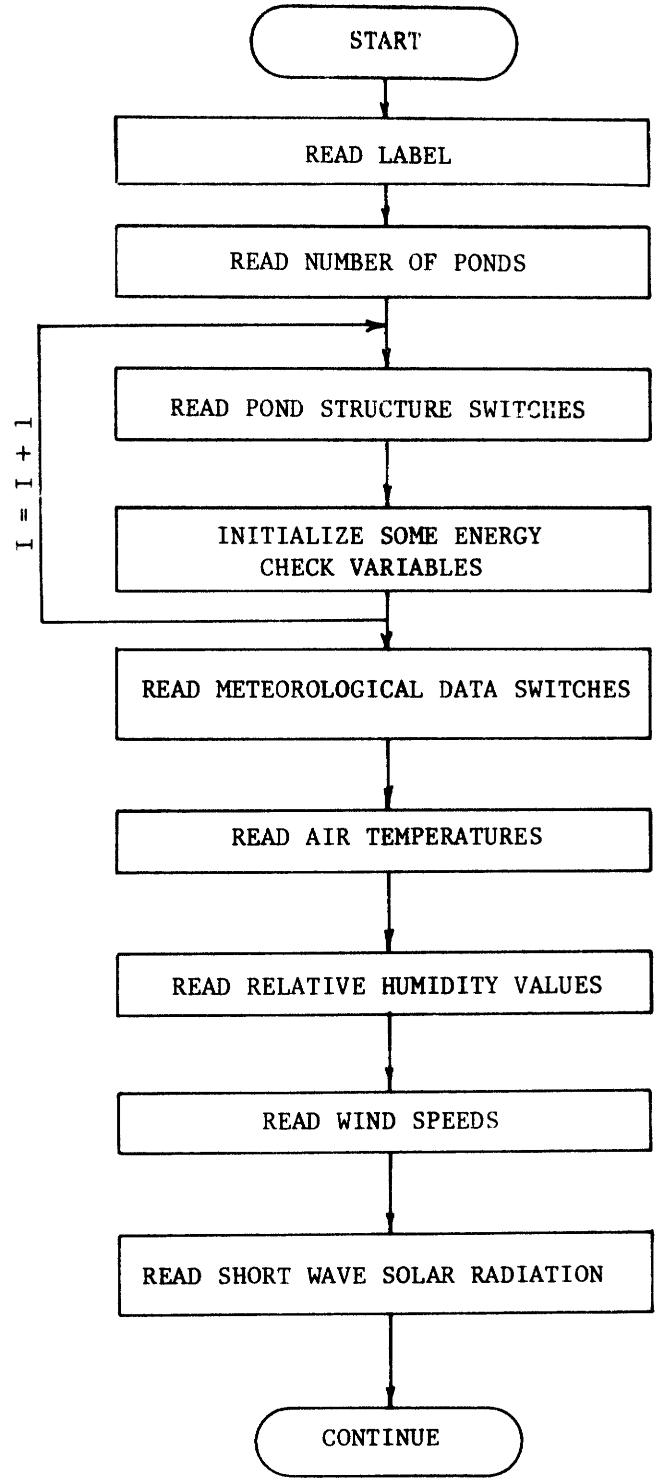


Figure 2-3 cont'd

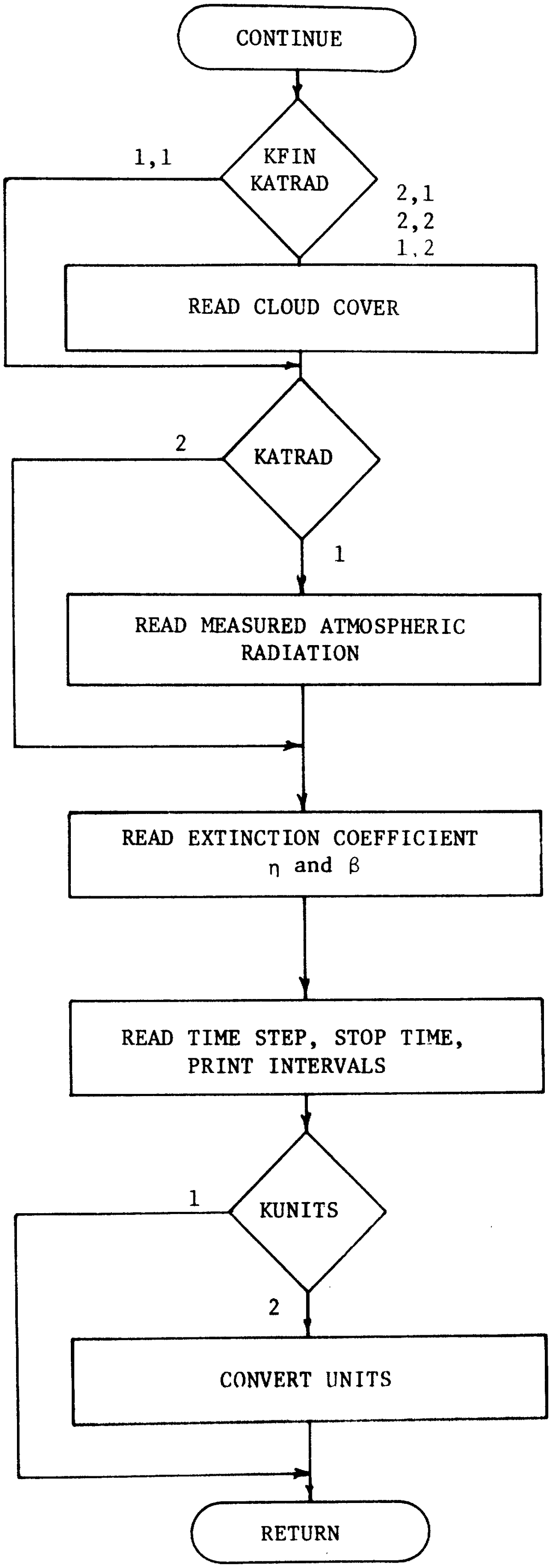


Figure 2-4: Subroutine GEOM1 Flow Chart

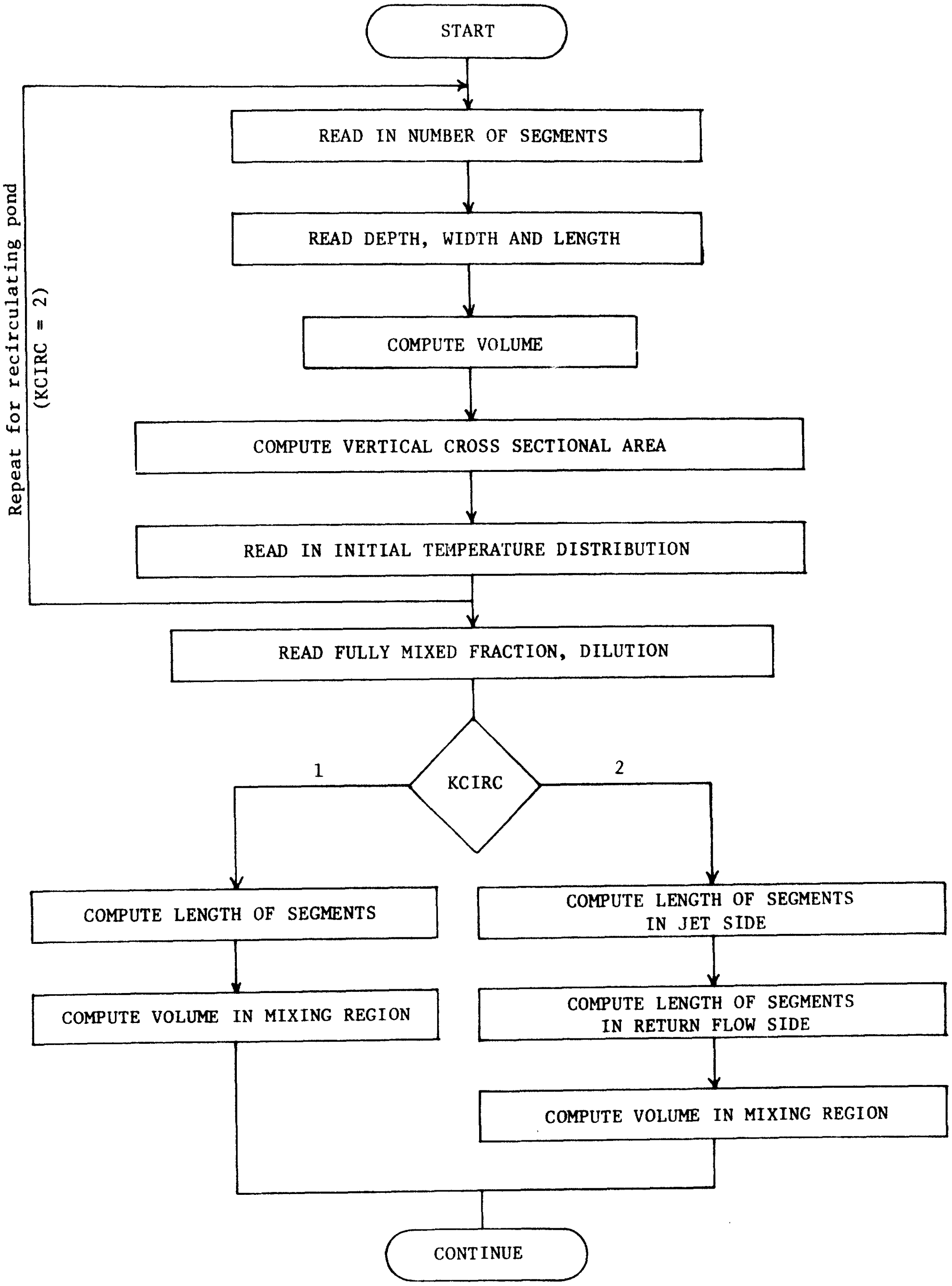


Figure 2-4 Cont'd

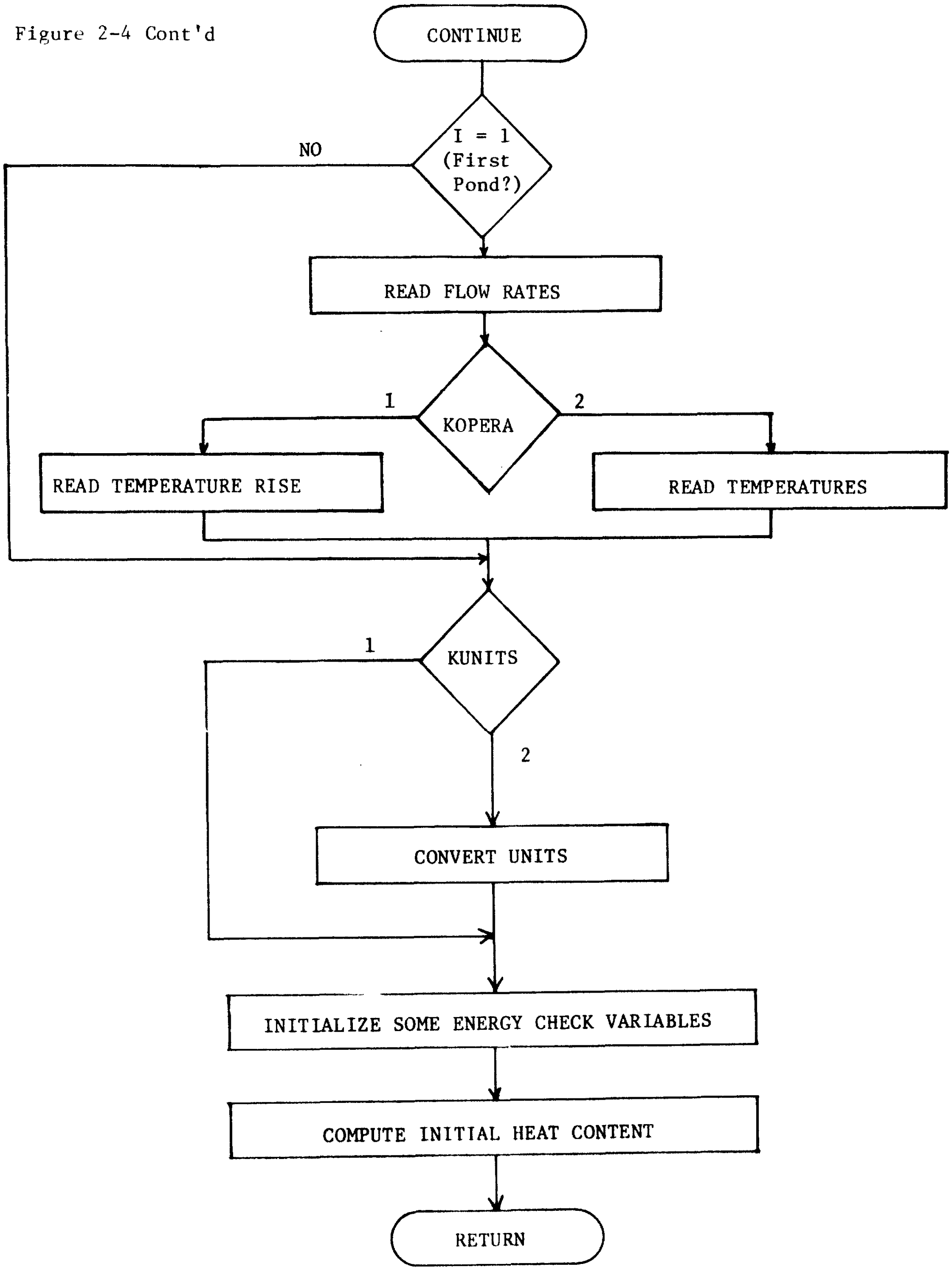


Figure 2-5: Subroutine GEOM2 Flow Chart

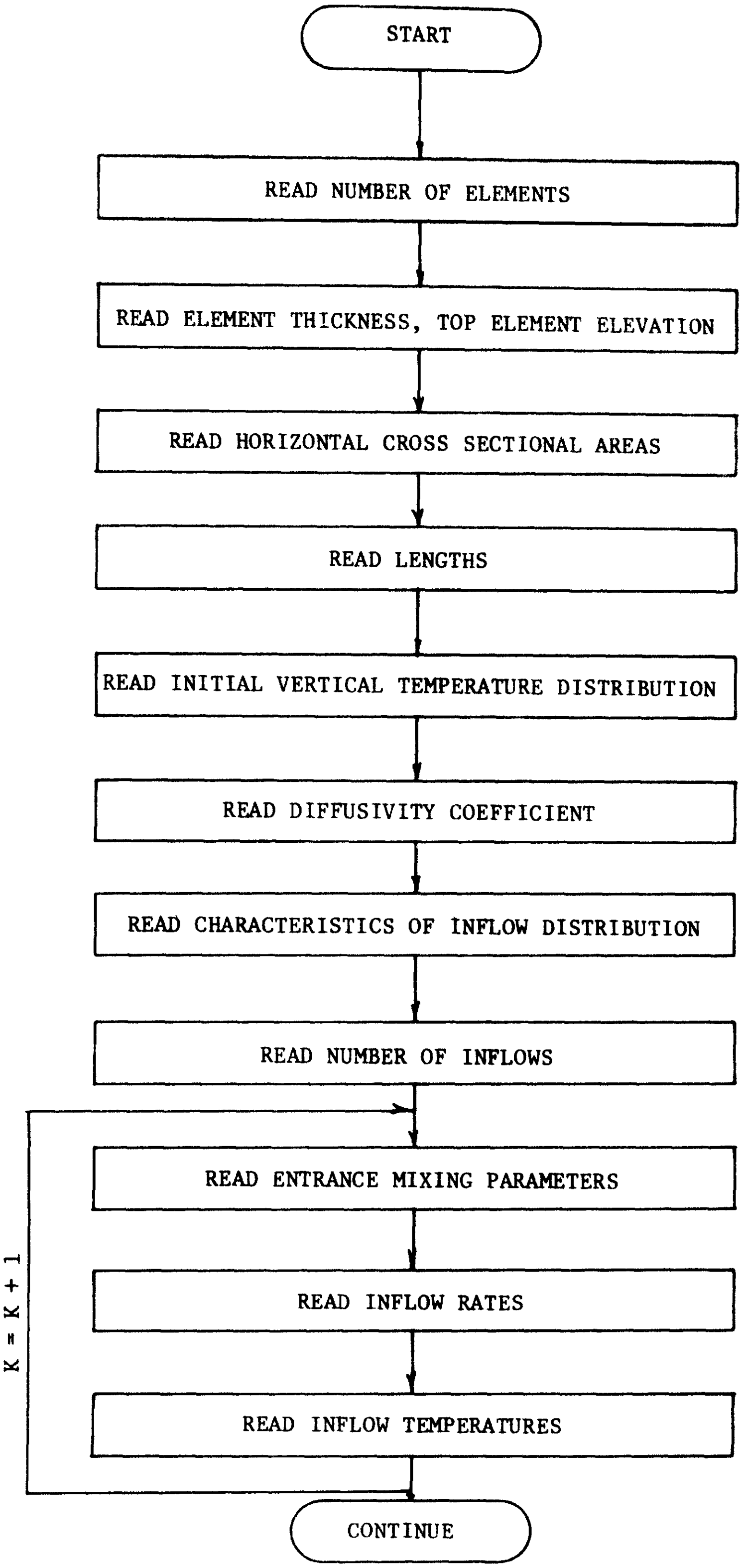


Figure 2-5 Cont'd

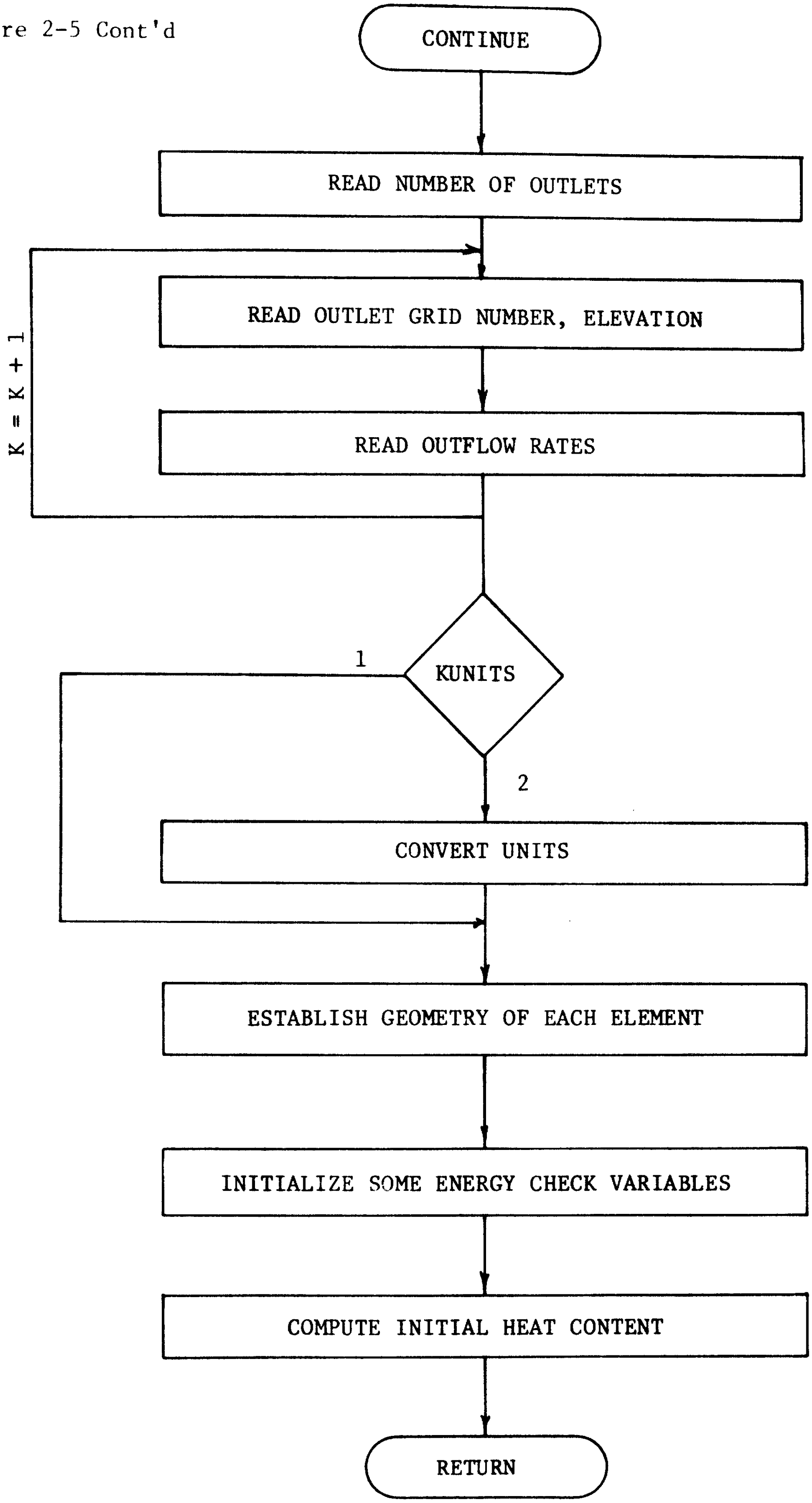


Figure 2-6: Subroutine WEATHR Flow Chart

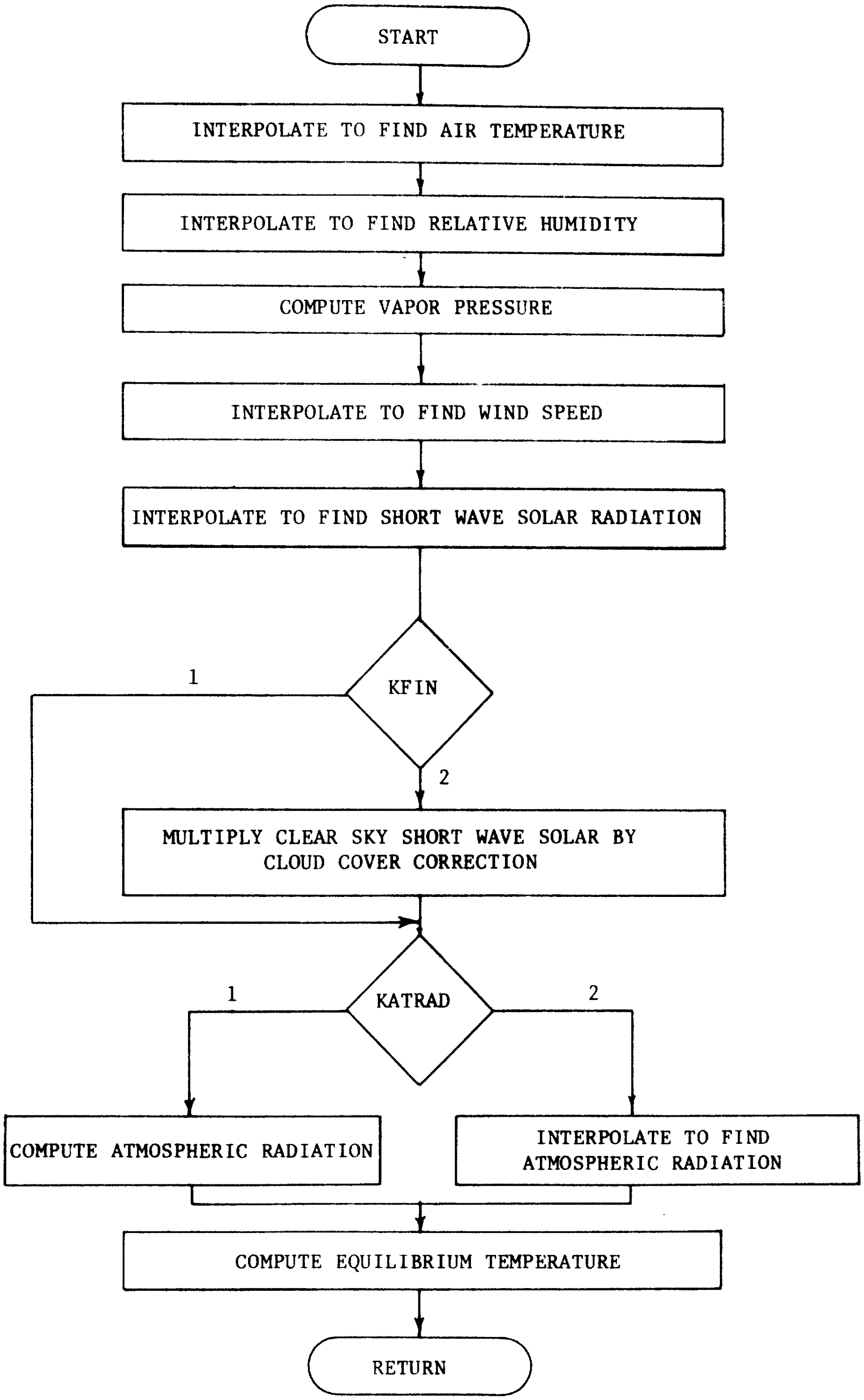


Figure 2-7: Subroutine HEAT Flow Chart

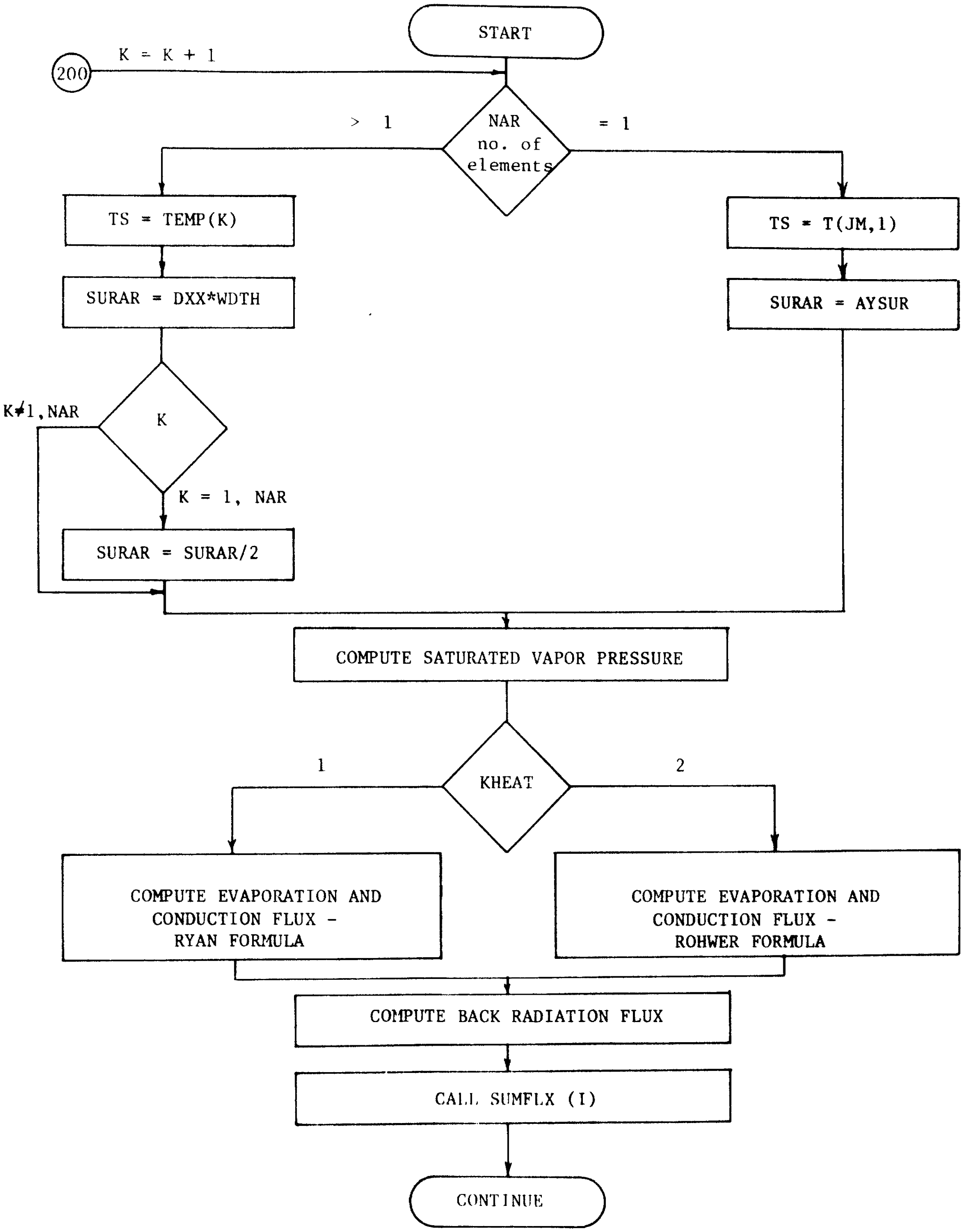


Figure 2-7 Cont'd

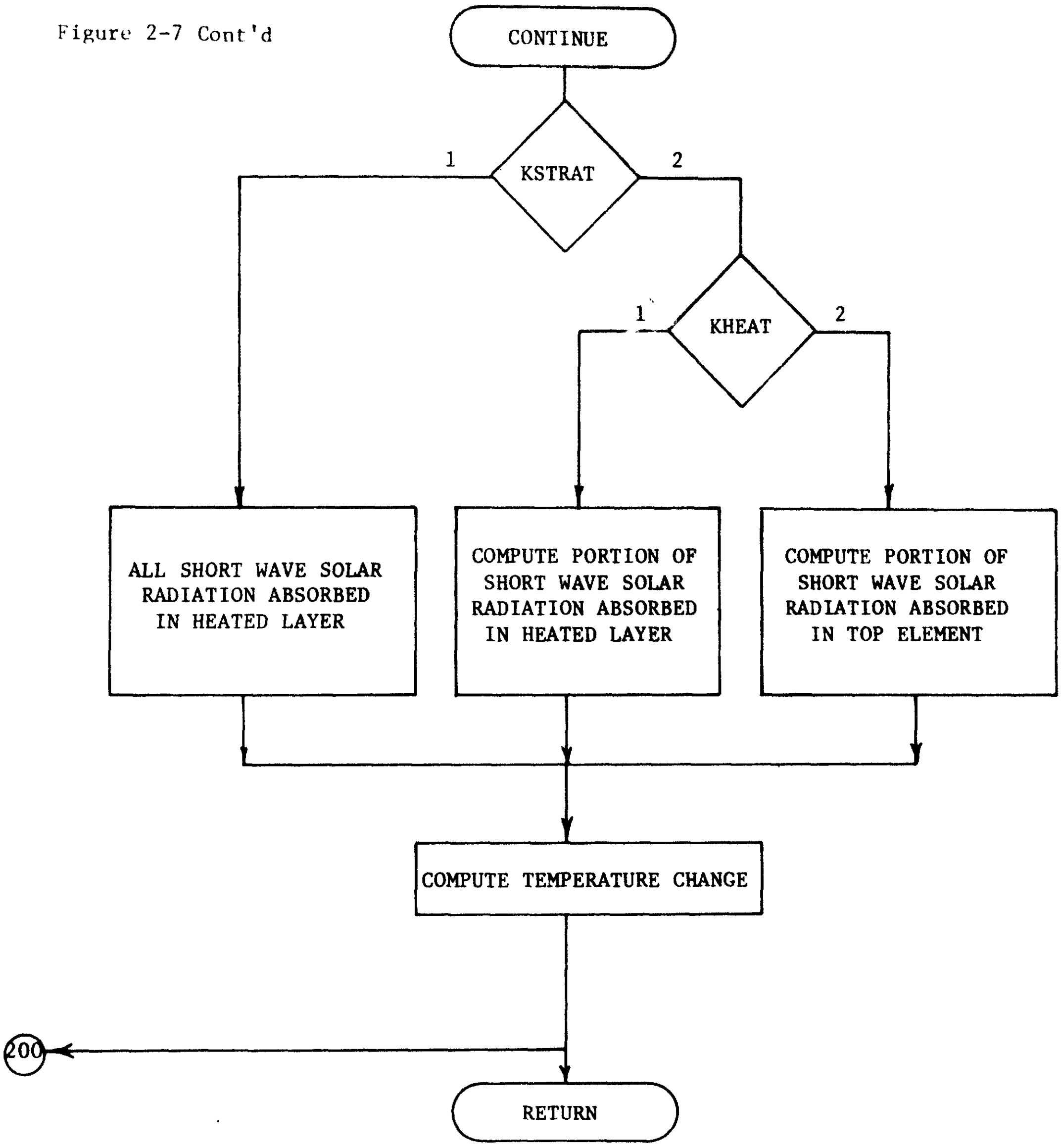


Figure 2-8 Subroutine DISPER Flow Chart

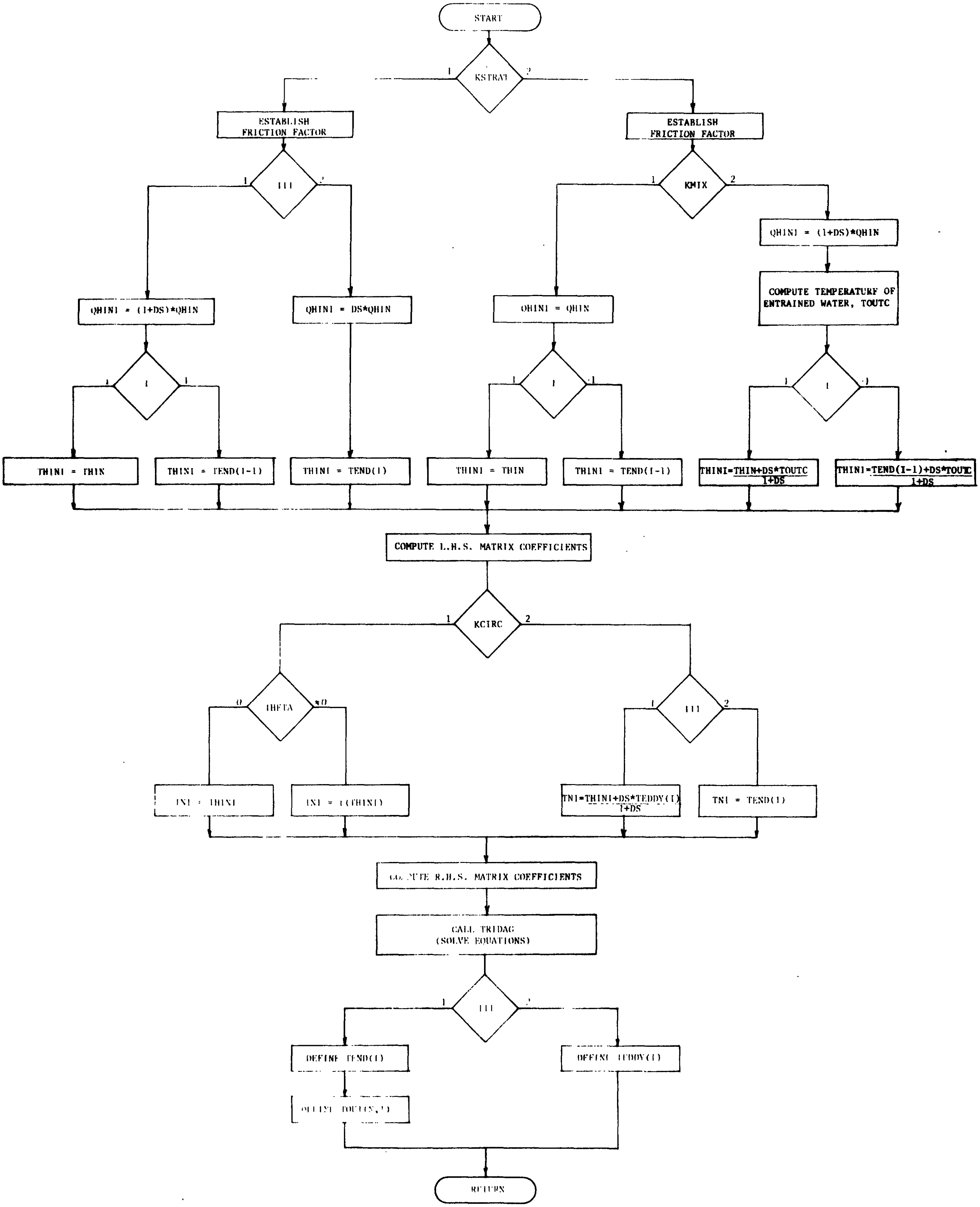


Figure 2-9: Subroutine SUREL Flow Chart

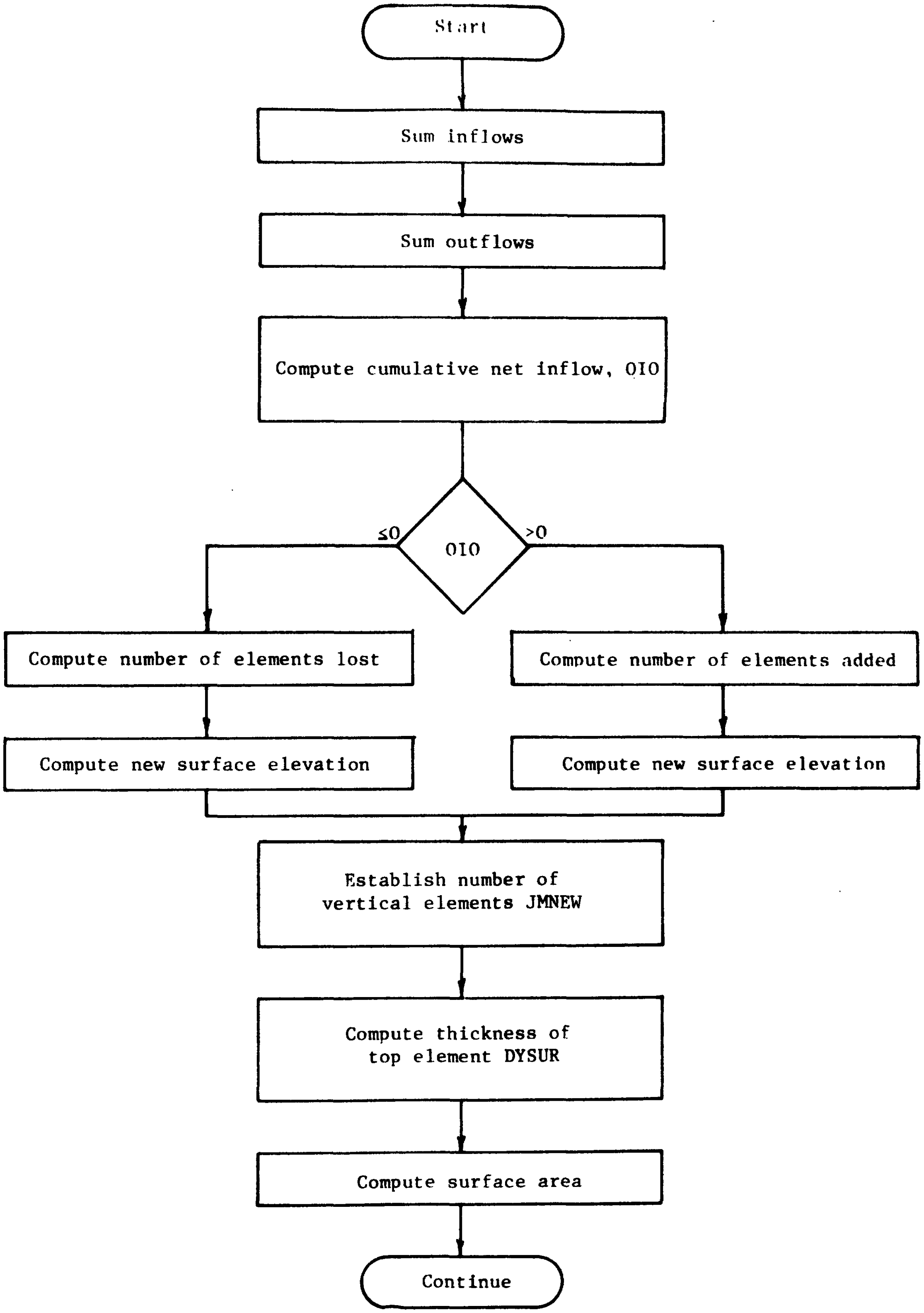


Figure 2-9 Cont'd

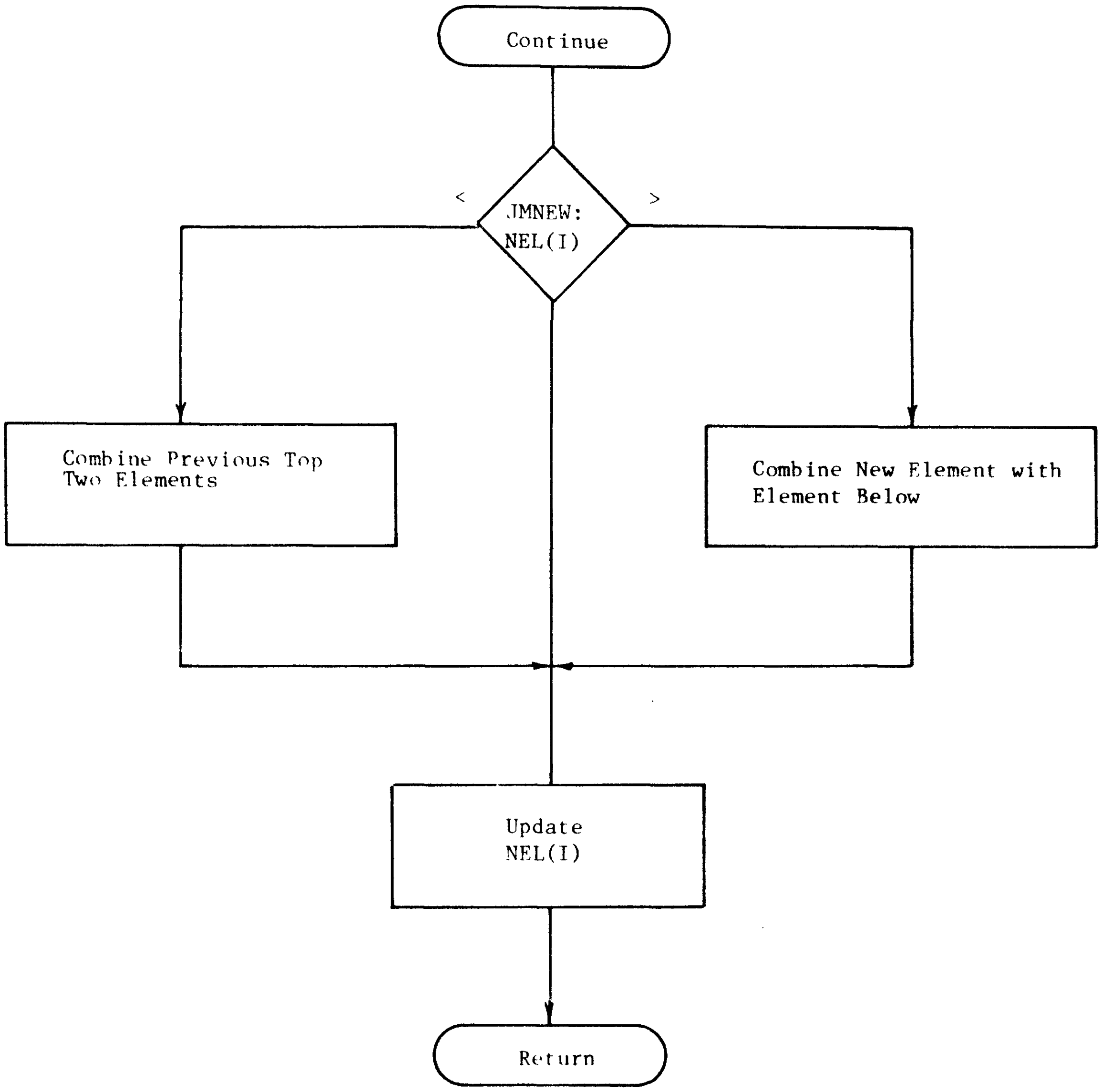


Figure 2-10: Subroutine SPEED Flow Chart

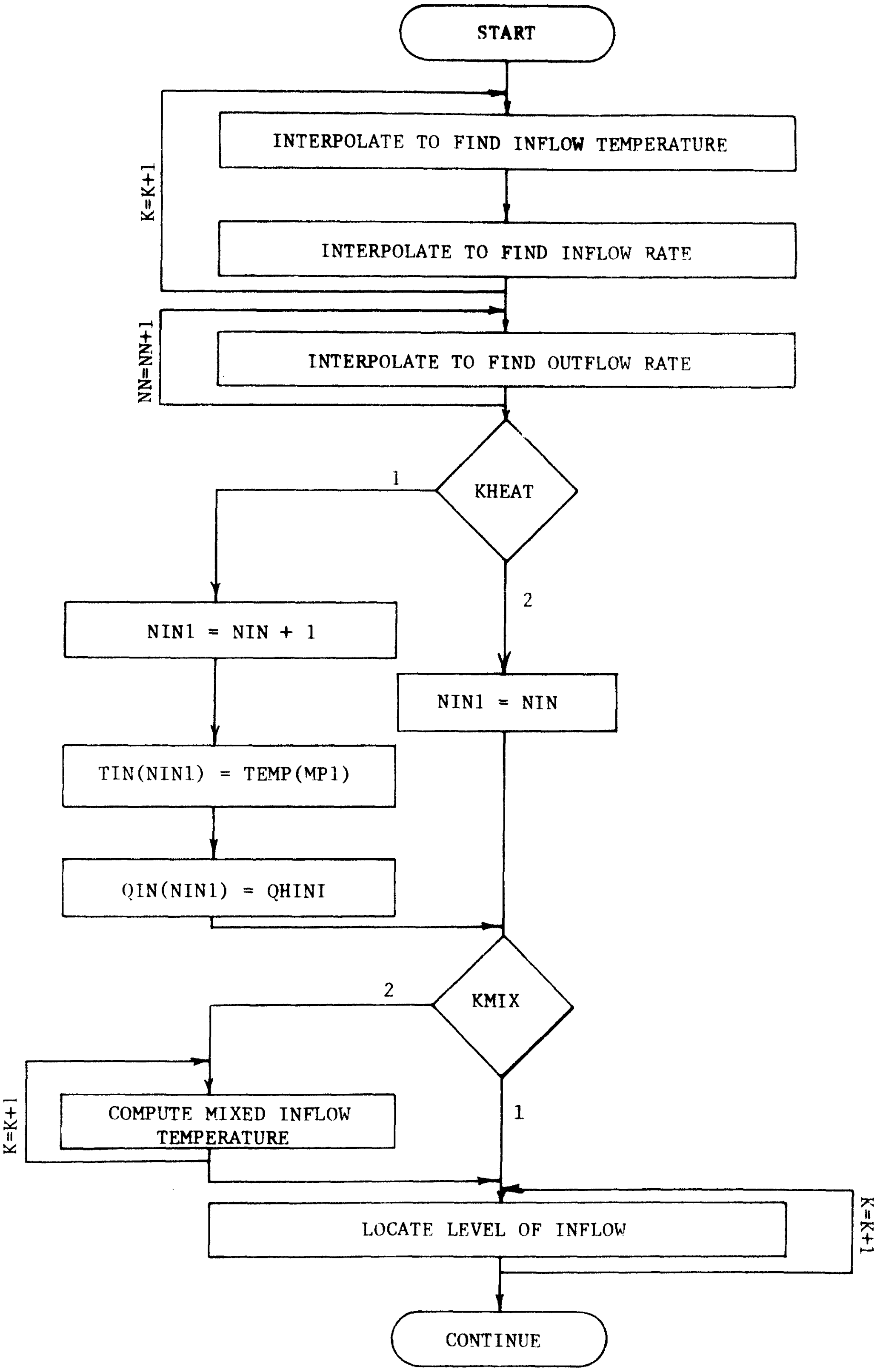


Figure 2-10 Cont'd

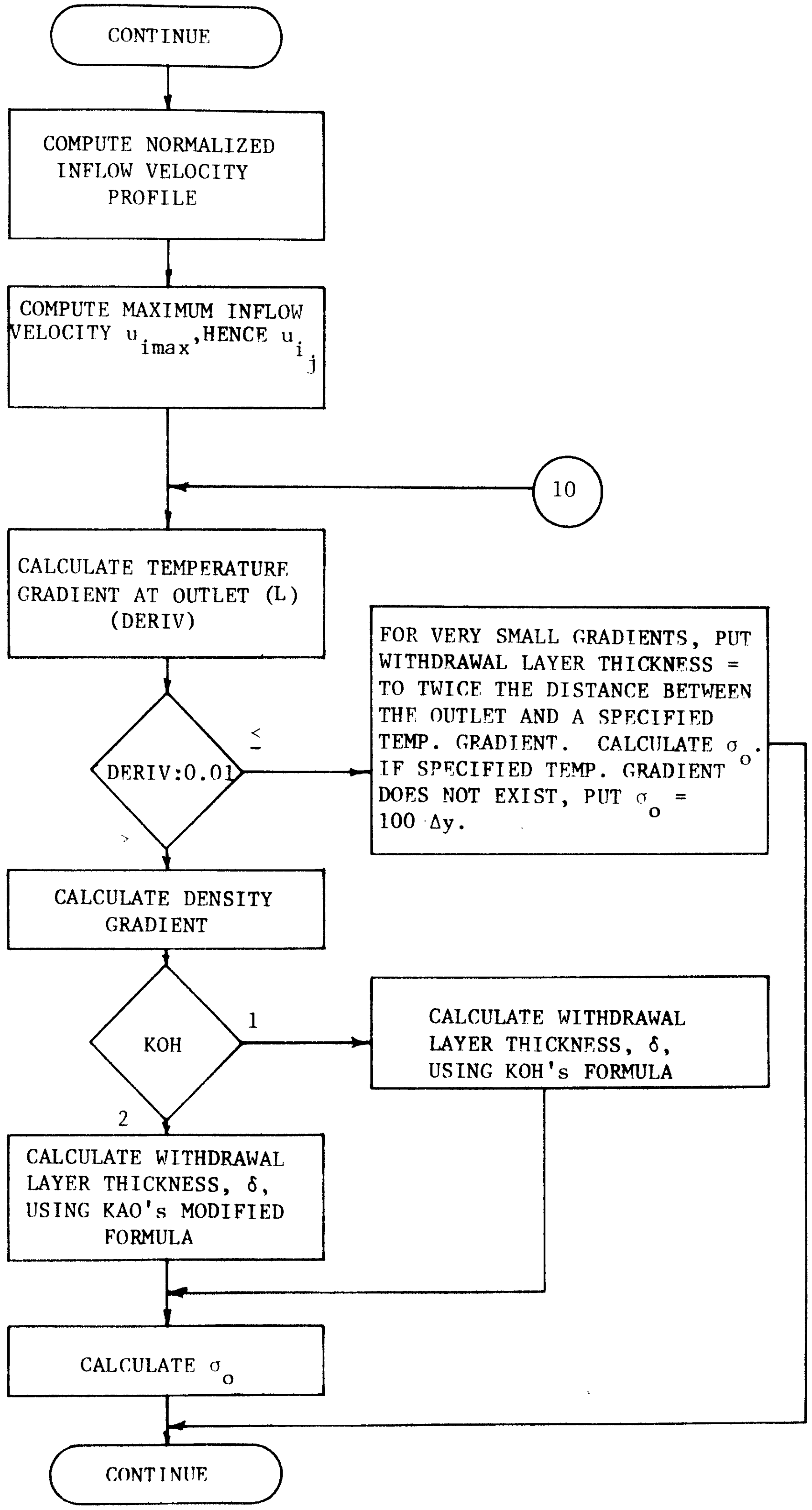


Figure 2-10 Cont'd

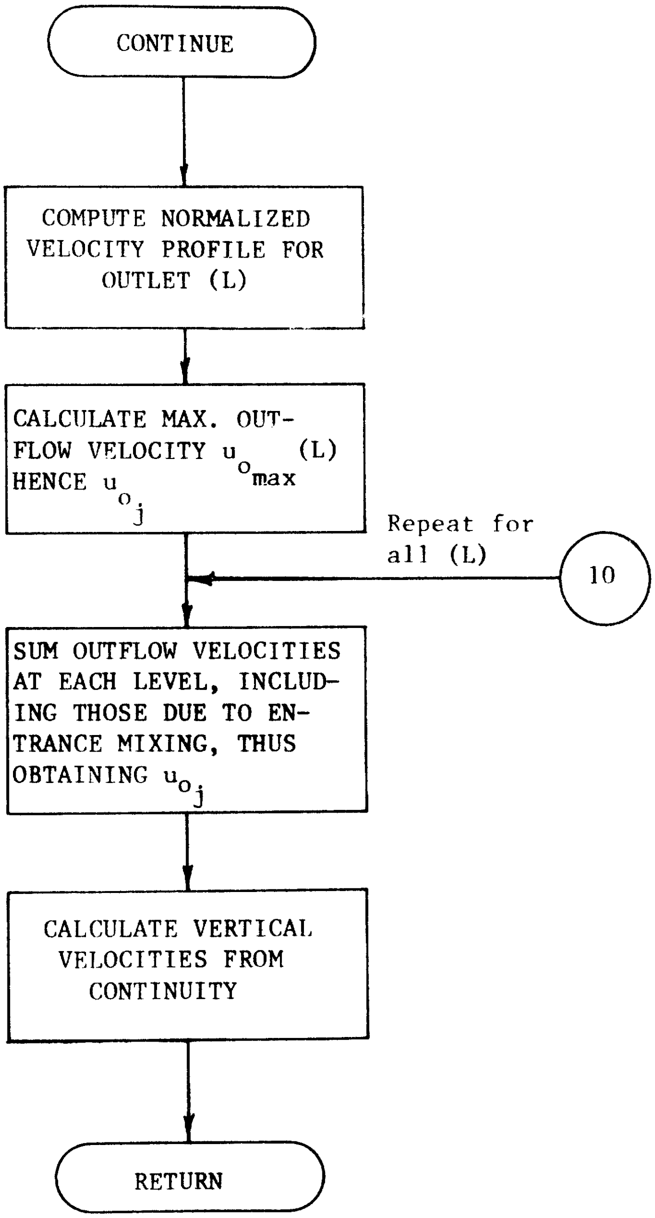


Figure 2-11: Subroutine SUBLAY Flow Chart

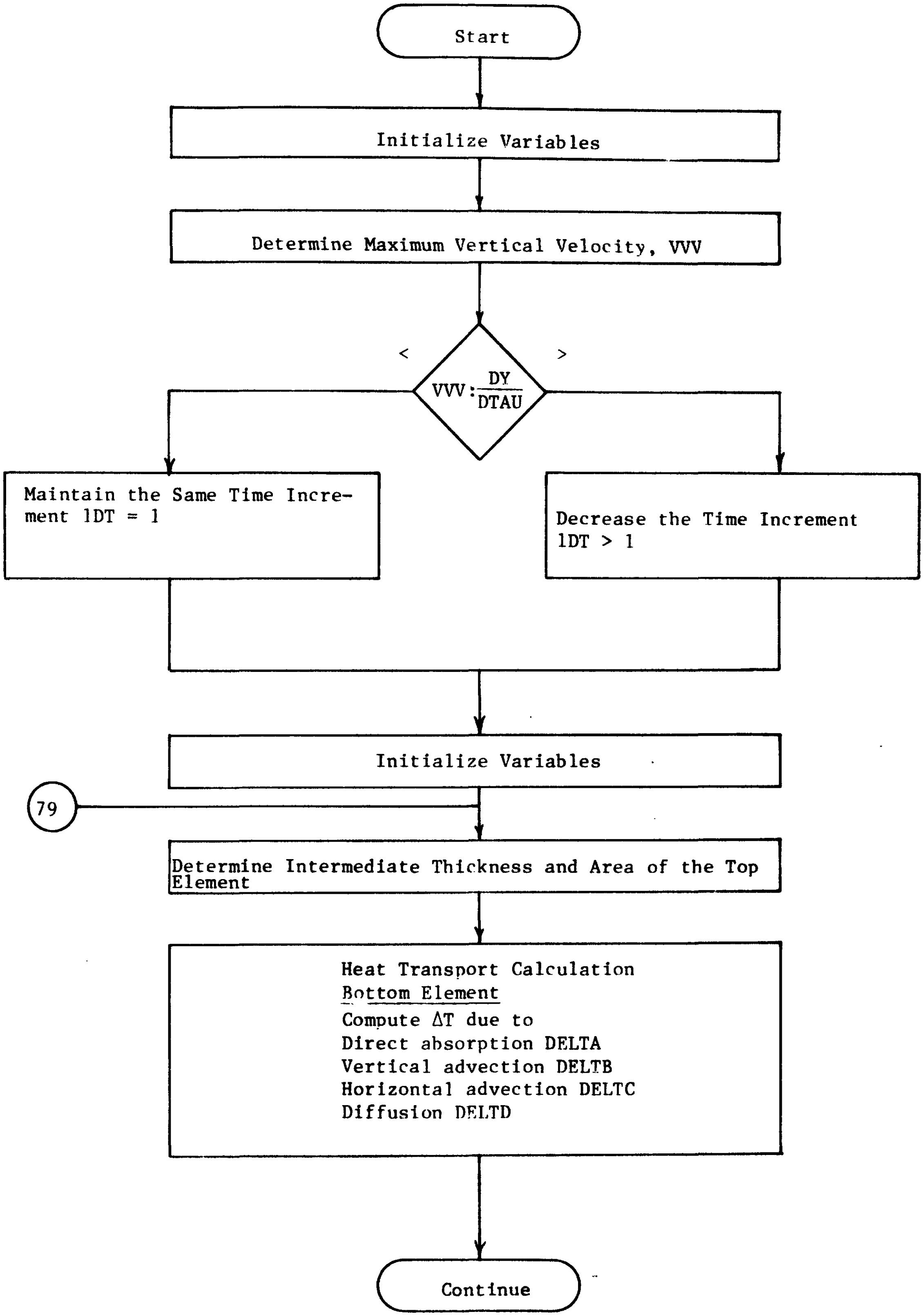


Figure 2-11 Cont'd

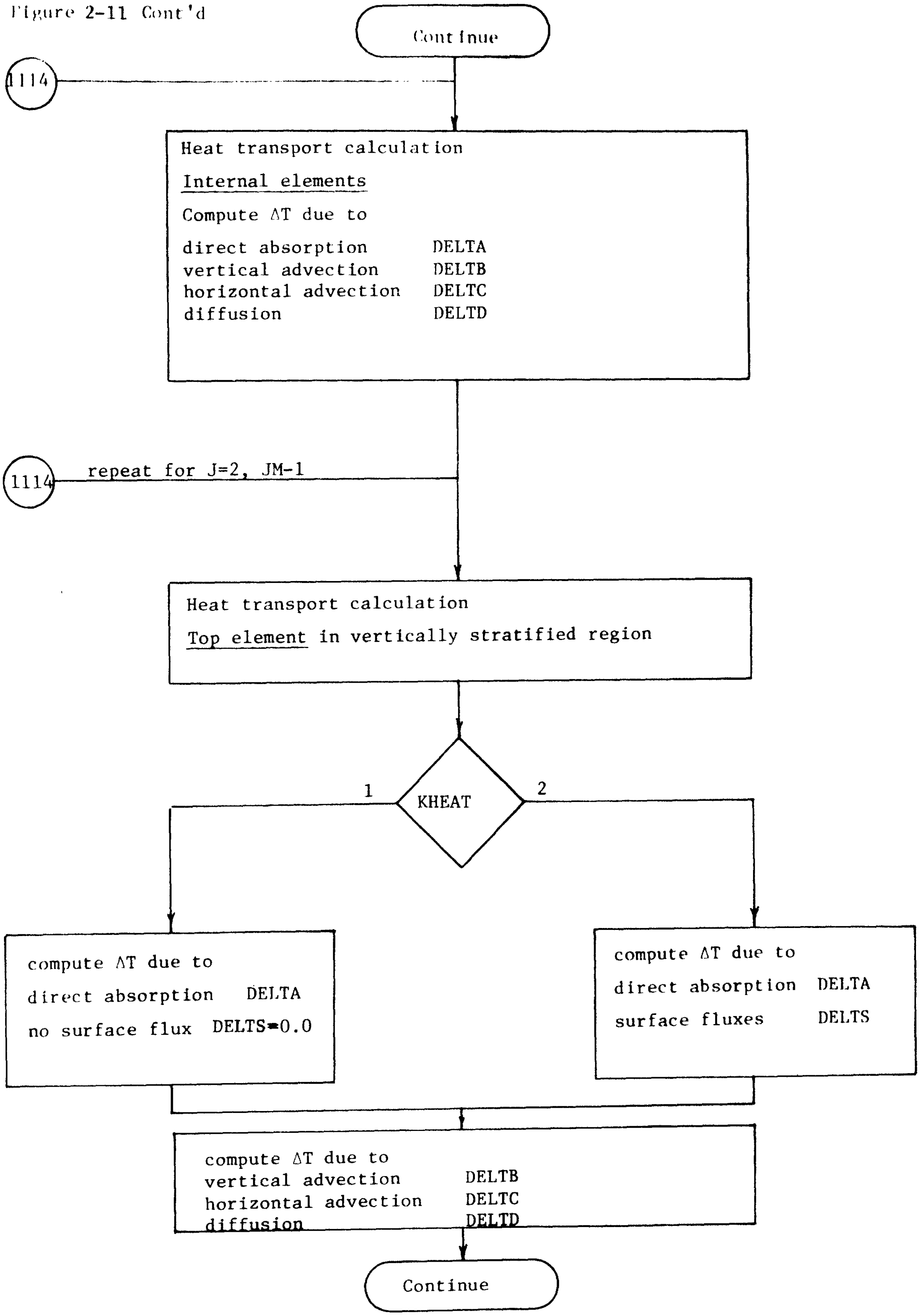


Figure 2-11 Cont'd

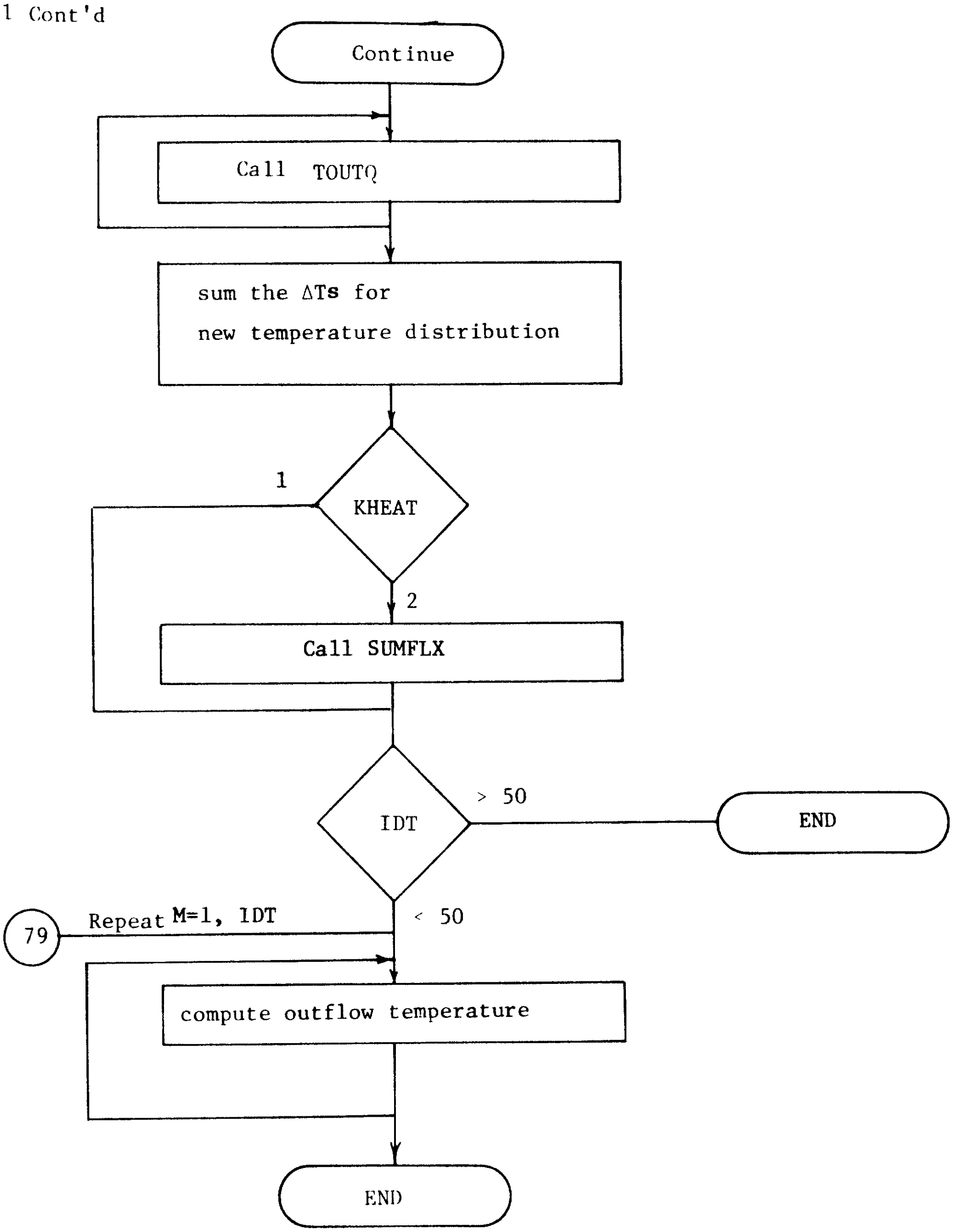


Figure 2-12: Subroutine HTMIX Flow Chart

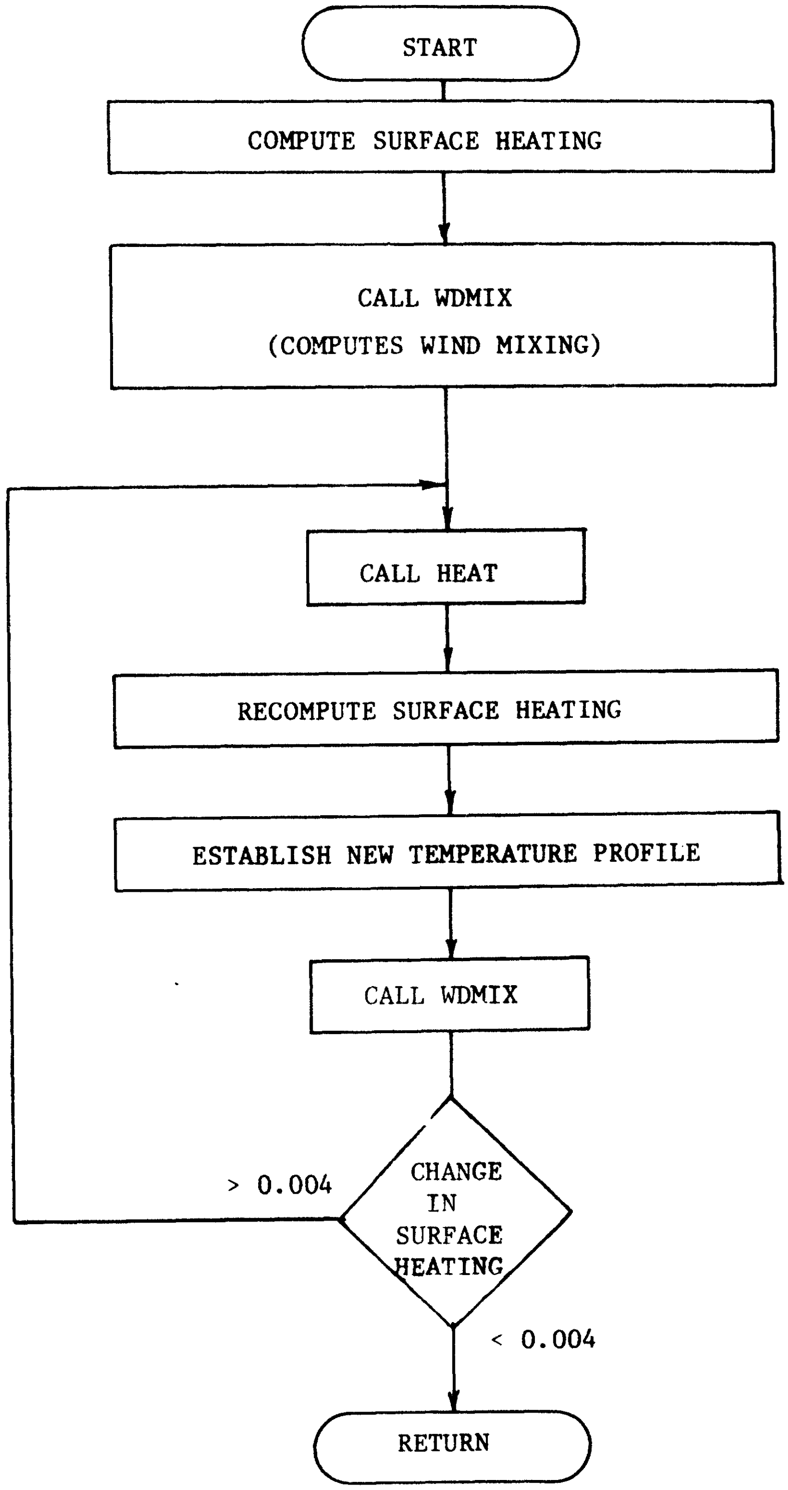


Figure 2-13: Subroutine WDMIX Flow Chart

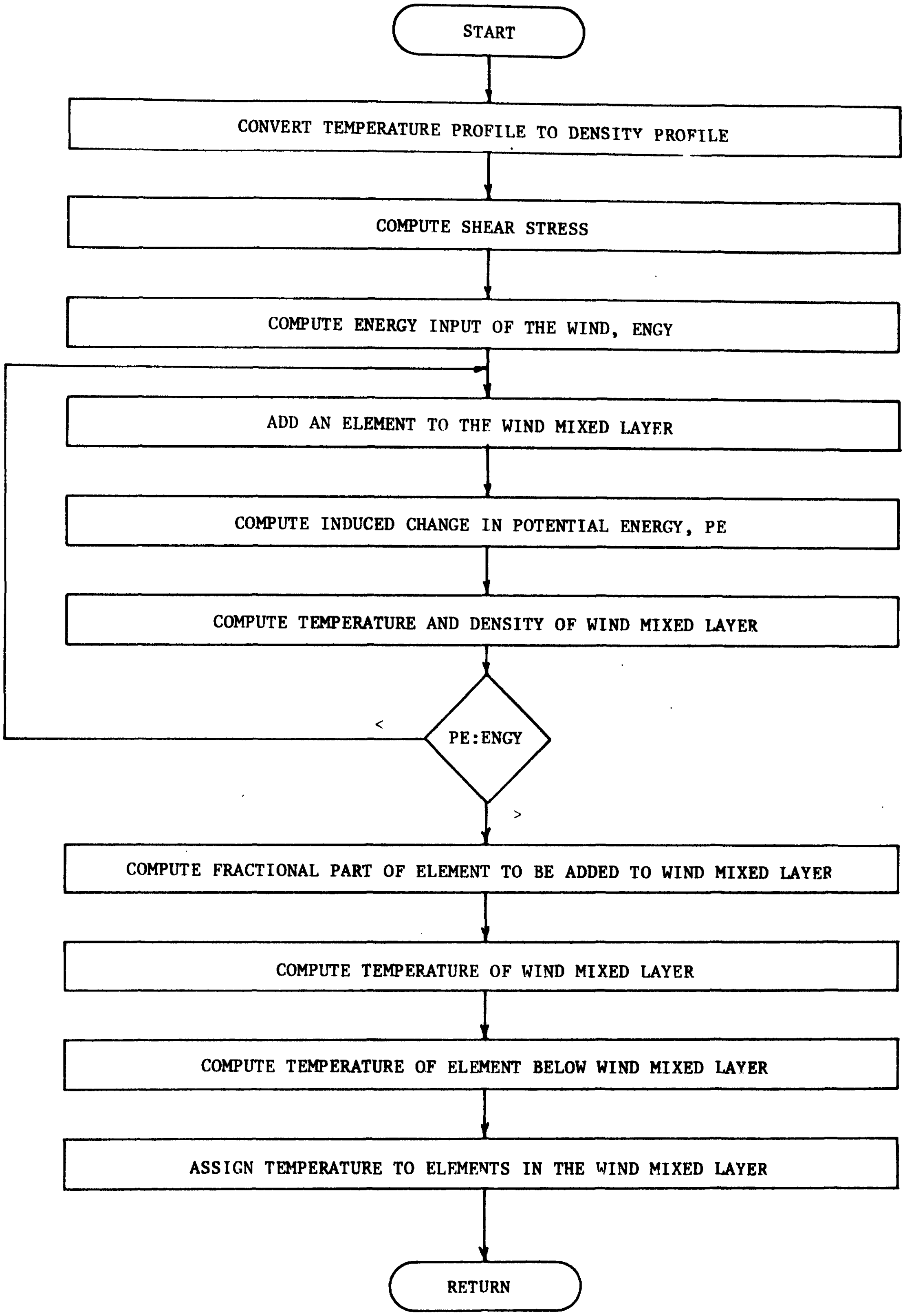


Figure 2-14: Subroutine AVER Flow Chart

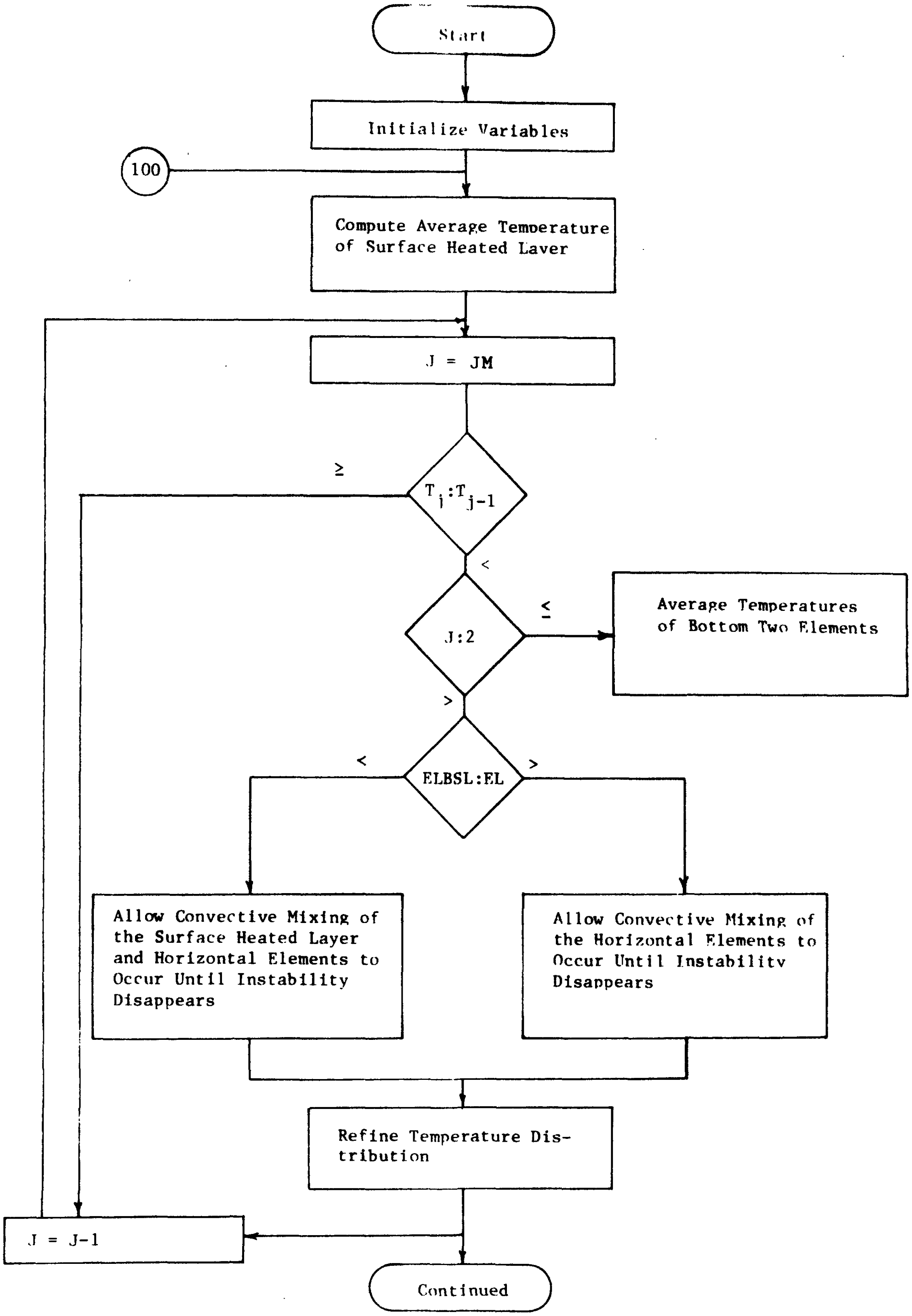


Figure 2-14 Cont'd

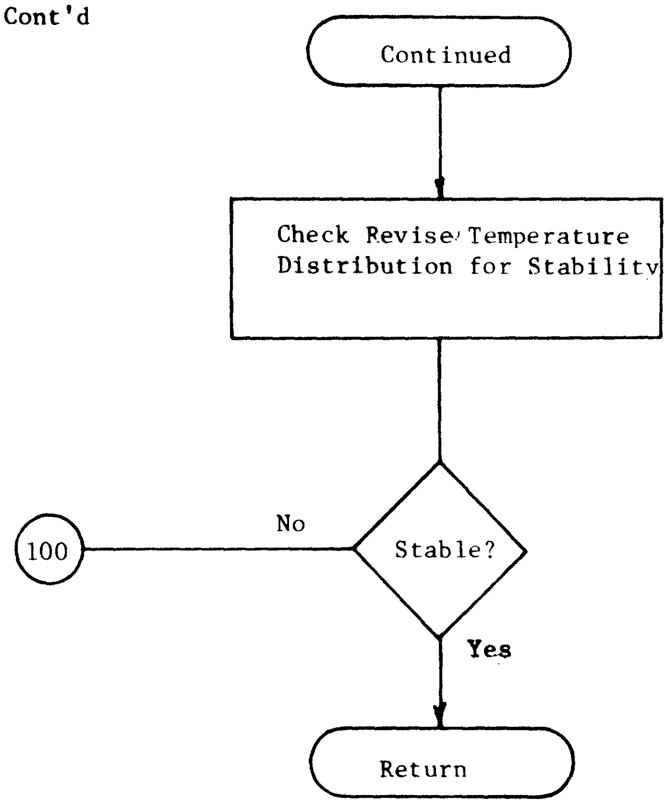
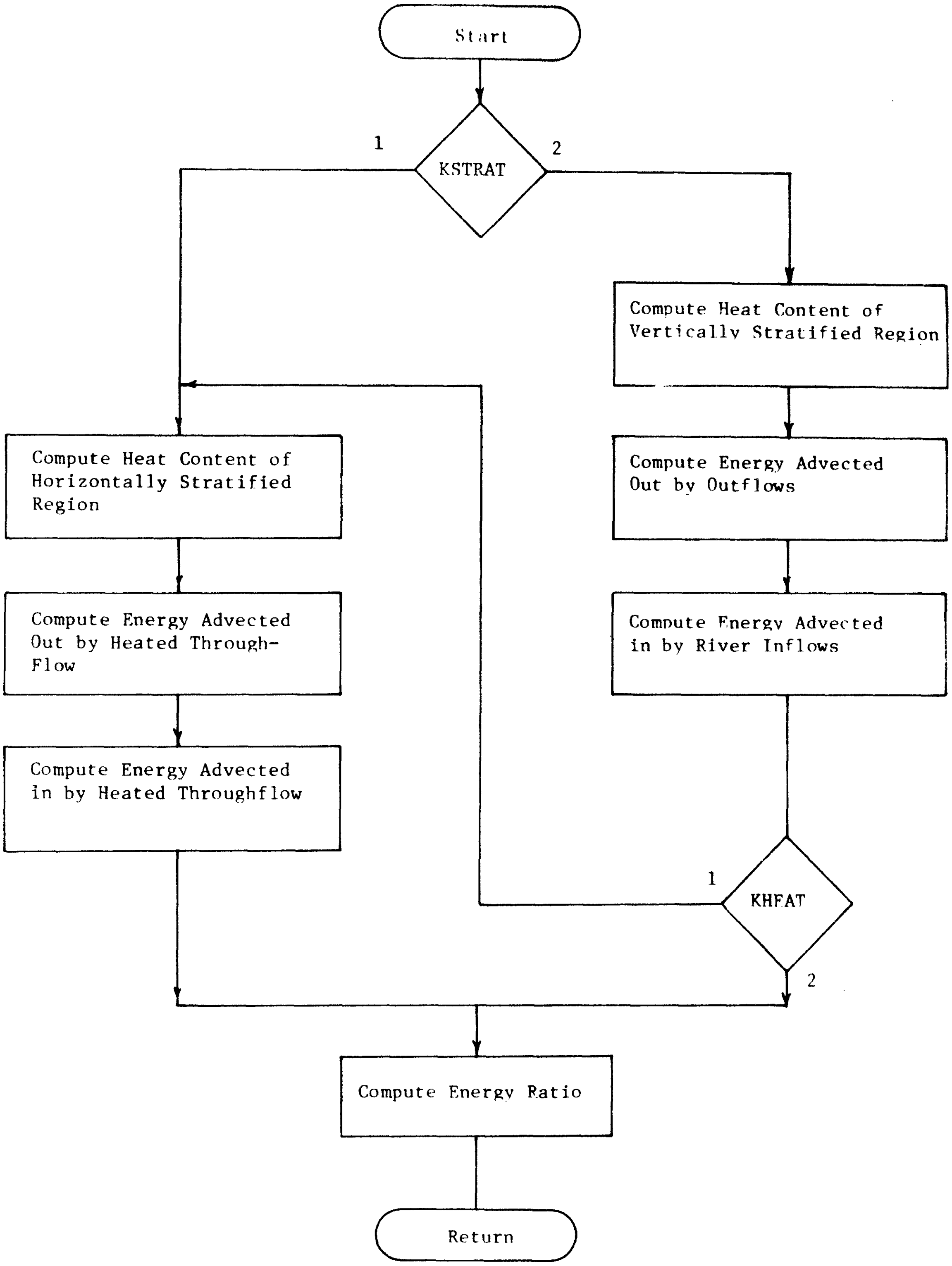


Figure 2-15: Subroutine ENERGY Flow Chart



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

NNNRUN = Number of runs

CARD
1

Table 3.1 Preparation of Input Data for Subroutine MET

System Structure and Meteorological Data

CARD	TYPE
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

WH(M) = Alphanumeric Heading

MET
1

MET
2

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

NPOND = number of ponds in series

POND STRUCTURE PARAMETERS
(Repeat the pond structure card for all ponds)

KSTRT(I)	KCIRC(I)						
5x,I5	5x,I5						
10	20	30	40	50	60	70	80

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

KCIRC(I) = 1 Pond I has no recirculation
= 2 Pond I has recirculation (2 sides)

MET
3

DATA INPUT PARAMETERS							
KFIN	KATRAD	KUNITS	KSUR	KHEAT	KOPERA		
5x,I5	5x,I5	5x,I5	5x.I5	5x,I5	5x,I5		
10	20	30	40	50	60	70	80

KFIN = 1 Measured Solar Radiation
= 2 Computed Solar Radiation

KATRAD = 1 Measured Atmospheric Radiation
= 2 Compute Atmospheric Radiation

KUNITS = 1 Units for input and output are KCAL, METERS, °C, M/S, DAY
= 2 Units for input and output are BTU, FEET, °F, MPH, DAY

KSUR = 1 Constant Surface Elevation ($\Sigma Qin = \Sigma Qout$)
= 2 Variable Surface Elevation ($\Sigma Qin \neq \Sigma Qout$)

KHEAT = 1 Heat Loading
= 2 No Heat Loading

KOPERA = 1 Closed Cycle Operation
= 2 Open Cycle Operation

MET
4

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

NTA = Number of Air Temperature Values

DTTA = Time Interval Between Values of TA

MET
5

MET
6

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

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

MET
7

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

NSIGH = Number of Relative Humidity Values

DTSIGH = Time Intervals Between Values of SIGH

MET
8

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

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

MET
9

WIND SPEED INPUT PARAMETERS							
NWIND	DTWIND						
5x,I5	F10.5						
	days						
10	20	30	40	50	60	70	80

NWIND = Number of Wind Speed Values

DTWIND = Time Interval Between Values of WIND

MET
10

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

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

MET
11

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

WHGT = Measurement Height for Wind Speed

MET
12

SHORT WAVE SOLAR RADIATION INPUT PARAMETERS							
NFIN	DTFIN						
5x,I5	F10.5						
	days						
10	20	30	40	50	60	70	80

NFIN = Number of Short Wave Solar Radiation Values

DTFIN = Time Interval Between Values of FIN

MET
13

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

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)

NCLOUD	DCLOUD						
5x,I5	F10.5						
	days						
10	20	30	40	50	60	70	80

NCLOUD = Number of Cloud Cover Values

DCLOUD = 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

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

MET
15

MET
16

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

NATRAD = Number of Atmospheric Radiation Values

DATRAD = Time Interval Between Values of ATRAD

LONG WAVE ATMOSPHERIC RADIATION WITH TIME

(use this card group only if KATRAD = 1)

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

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

MET
18

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

ETA = Extinction Coefficient of Light in Water

BETA = Fraction of Solar Radiation Absorbed at the Surface

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

DTAU = Time Step in Computations

TAUMAX = Time at which Program Stops

IFREQ1 = Frequency of Printed Output of PRINT1, in Time Steps

IFREQ2 = Frequency of Printed Output of PRINT2, in Time Steps

IFREQA = Frequency of Printed Output of Met Data in Time Steps

MET
19

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

NDD = Number of Dates on which Output is Required

MET
20

MET
21

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

MMO = Starting Date Month

MDY = Starting Date Day

MYR = Starting Date Year

MMO/MDY/MYR

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

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

CARD		TYPE
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							
NELSV(I)	NELMAX(I)						
5x,I5	5x,I5						
10	20	30	40	50	60	70	80

NELSV(I) = Initial Number of Vertical Grid Points in Pond I

NELMAX(I) = Maximum Number of Vertical Grid Points in Pond I

GEOM2
1

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

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)

GEOM2
2

GEOM2
3

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

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)

GEOM2
4

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

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

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)

GEOM2
5

GEOM2
6

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

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

GEOM2
7

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

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	

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

GEOM2
8

GEOM2
9

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

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

SIGMAI = Inflow Standard Deviation

GEOM2
10

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

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

INFLOW MIXING PARAMETERS
(cards GEOM2-11, GEOM2-12, GEOM2-13 and GEOM2-14 form a package and must be repeated NIN times.)

KOH	KMIX	MIXED(K,I)	RMIX(K,I)				
5x,I5	5x,I5	5x,I5	F5.1				
10	20	30	40	50	60	70	80

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

KMIX = 1 No Entrance Mixing
= 2 Entrance Mixing

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

RMIX(K,I) = Mixing Ratio for Inflow K in Pond I

GEOM2
11

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

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)

GEOM2
12

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

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

GEOM2
13

GEOM2
14

INFLOW TEMPERATURE WITH TIME							
TTIN(M,K,I) TTIN(M+1,K,I)	TTIN(M+2,K,I) TTIN(M+3,K,I)	TTIN(M+4,K,I) TTIN(M+5,K,I)	TTIN(M+6,K,I) TTIN(M+7,K,I)	TTIN(M+8,K,I) TTIN(M+9,K,I)	TTIN(M+10,K,I) TTIN(M+11,K,I)	TTIN(M+12,K,I) TTIN(M+13,K,I)	TTIN(M+14,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

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

GEOM2
15

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

NOUT(I) = Number of Outlets in Pond I

GEOM2
16

OUTLET PARAMETERS
(cards GEOM2-16, GEOM2-17 and GEOM2-18 form a package and must be repeated NOUT times)

LOUT(K,I)	ELOUT(K,T)						
5x,I5	F10.5						
10	20	30	40	50	60	70	80

LOUT(K,I) = Number of Grid Point Corresponding to Outlet K Elevation in Pond I

ELOUT(K,I) = Outlet K Elevation in Pond I

GEOM2
17

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

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)

GEOM2
18

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

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

CARD	TYPE
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

GEOM1
1

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

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

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

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

GEOM1
2

GEOM1
3

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

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+1,I,III)	THLM(J+2,I,III) THLM(J+3,I,III)	THLM(J+4,I,III) THLM(J+5,I,III)	THLM(J+6,I,III) THLM(J+7,I,III)	THLM(J+8,I,III) THLM(J+9,I,III)	THLM(J+10,I,III) THLM(J+11,I,III)	THLM(J+12,I,III) THLM(J+13,I,III)	THLM(J+14,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
^{o}C or ^{o}F							
10	20	30	40	50	60	70	80

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

GEOM1
4

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

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

NQHIN = Number of Heated Inflow Rate Values

DTQHIN = Time Interval Between Values of QQHIN

GEOM1
6

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

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

DTEMP = Temp rise across condenser

GEOM1
8

GEOM1
9

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

TTHIN(M) TTHIN(M+1)	TTHIN(M+2) TTHIN(M+3)	TTHIN(M+4) TTHIN(M+5)	TTHIN(M+6) TTHIN(M+7)	TTHIN(M+8) TTHIN(M+9)	TTHIN(M+10) TTHIN(M+11)	TTHIN(M+12) TTHIN(M+13)	TTHIN(M+14) 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

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 virture of its molecular structure, such changes are easily incorporated into MITEMP. The seven impoundments are:

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

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

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*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	$\mathbb{P}$	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

[1] Main 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

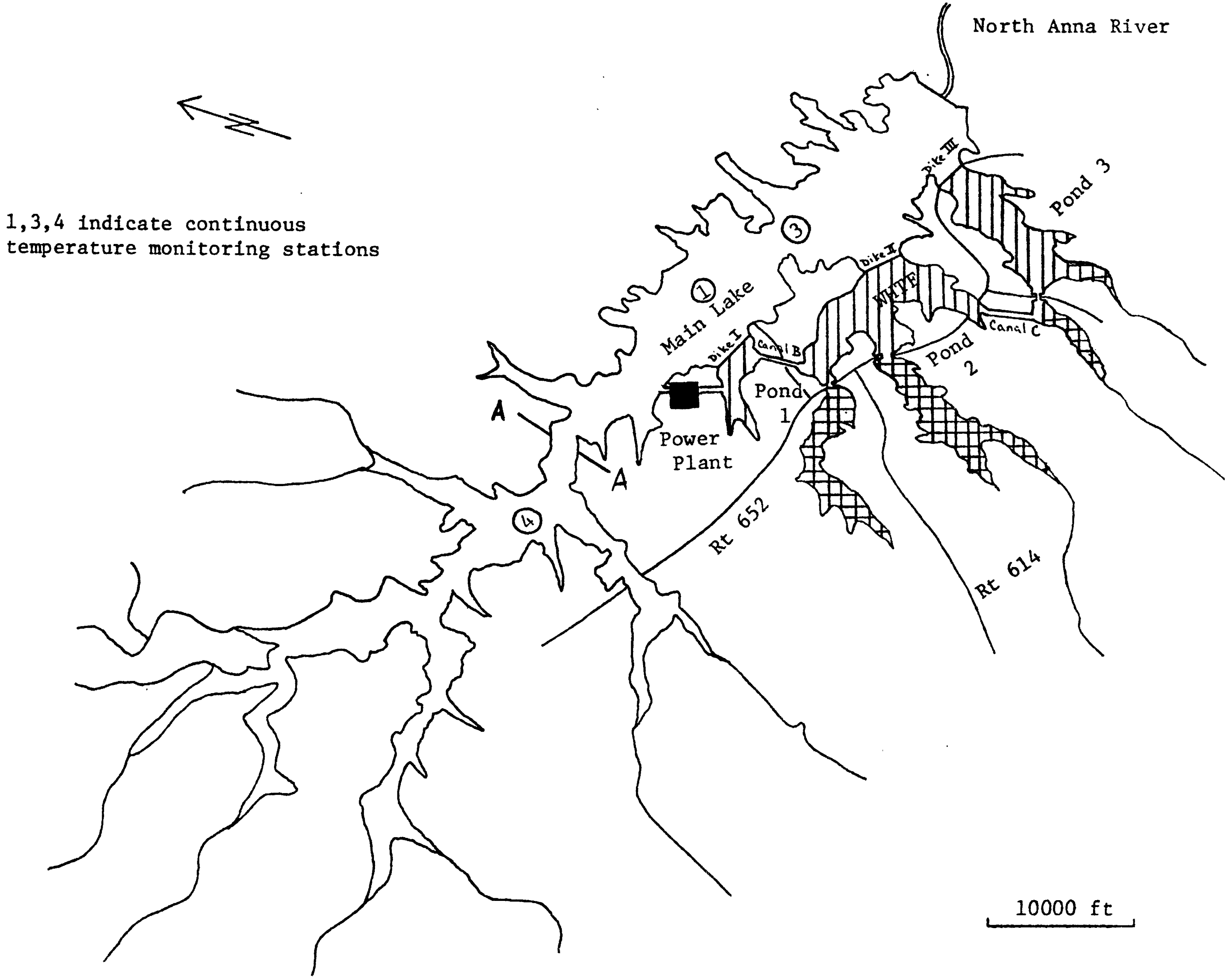
4.1.1 North Anna Cooling System, Virginia

(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 ft^3, and an average depth of 25 ft. The maximum depth at the dam is 70 ft. The lake receives an average annual inflow of about 270 cfs. The lake elevation is maintained by radial gates at the dam. The outflow rate equals the inflow minus the rate of evaporation from the lake surface (estimated at about 60 cfs, natural conditions).

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



1,3,4 indicate continuous
temperature monitoring stations

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

At its ultimate capacity, the North Anna Nuclear Power Station is expected to have four nuclear units with a combined capacity of 3784 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_o = 8,400 cfs):

L = 25,000 ft

W = 7,500 ft

H_{ave} = 40 ft

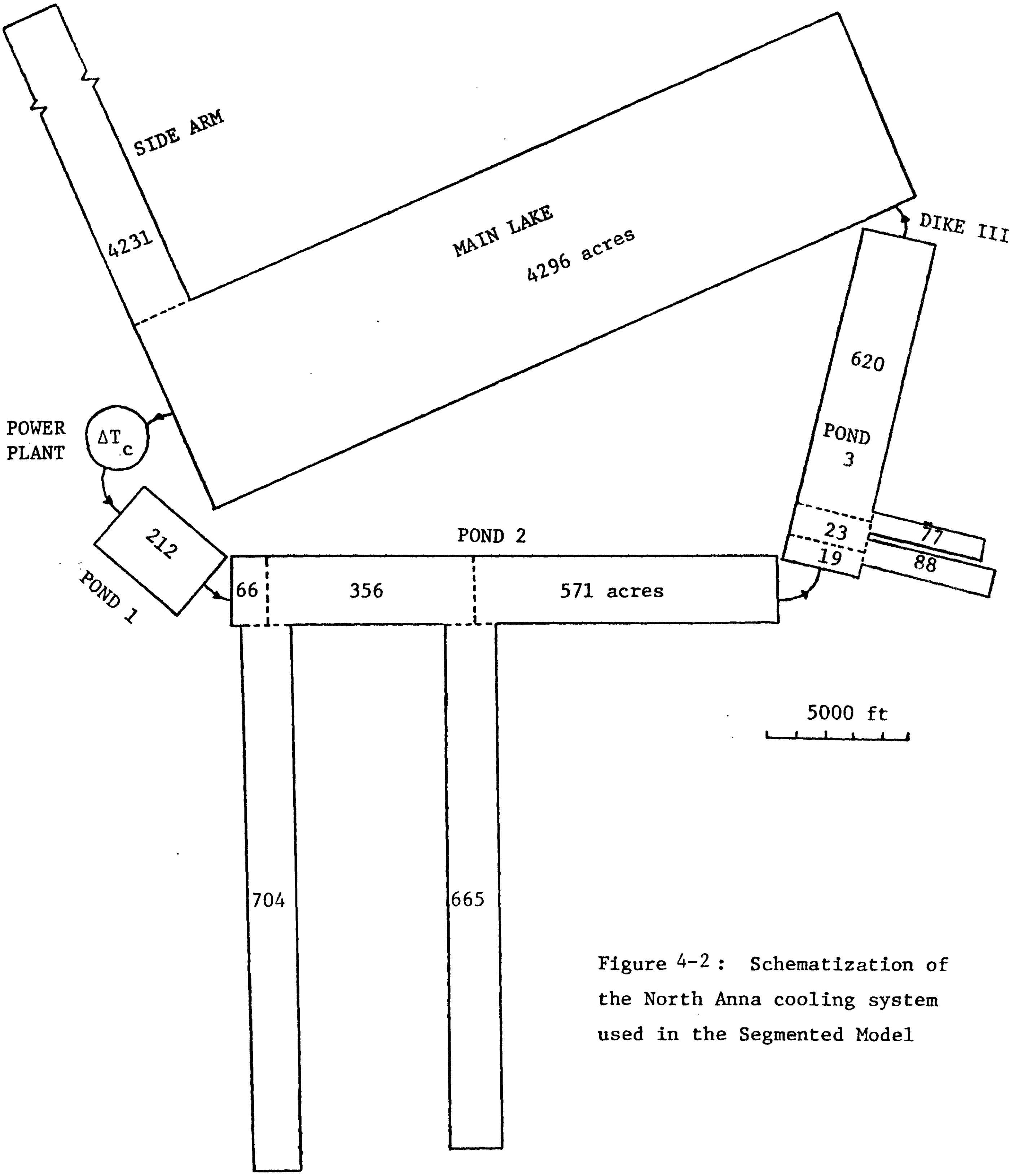


Figure 4-2 : Schematization of the North Anna cooling system used in the Segmented Model

$D_v = 1.5^*$

$\Delta T_o = 5°F$ (estimated in main lake)

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

This leads to a pond number, $\mathbb{P} = 0.34$ and determines the applicability of the deep, stratified cooling pond model as a first approximation. The heated surface layer depth is computed as $h_s = \mathbb{P} H_{ave} = 14$ 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, proportinally higher values of D_v are found.

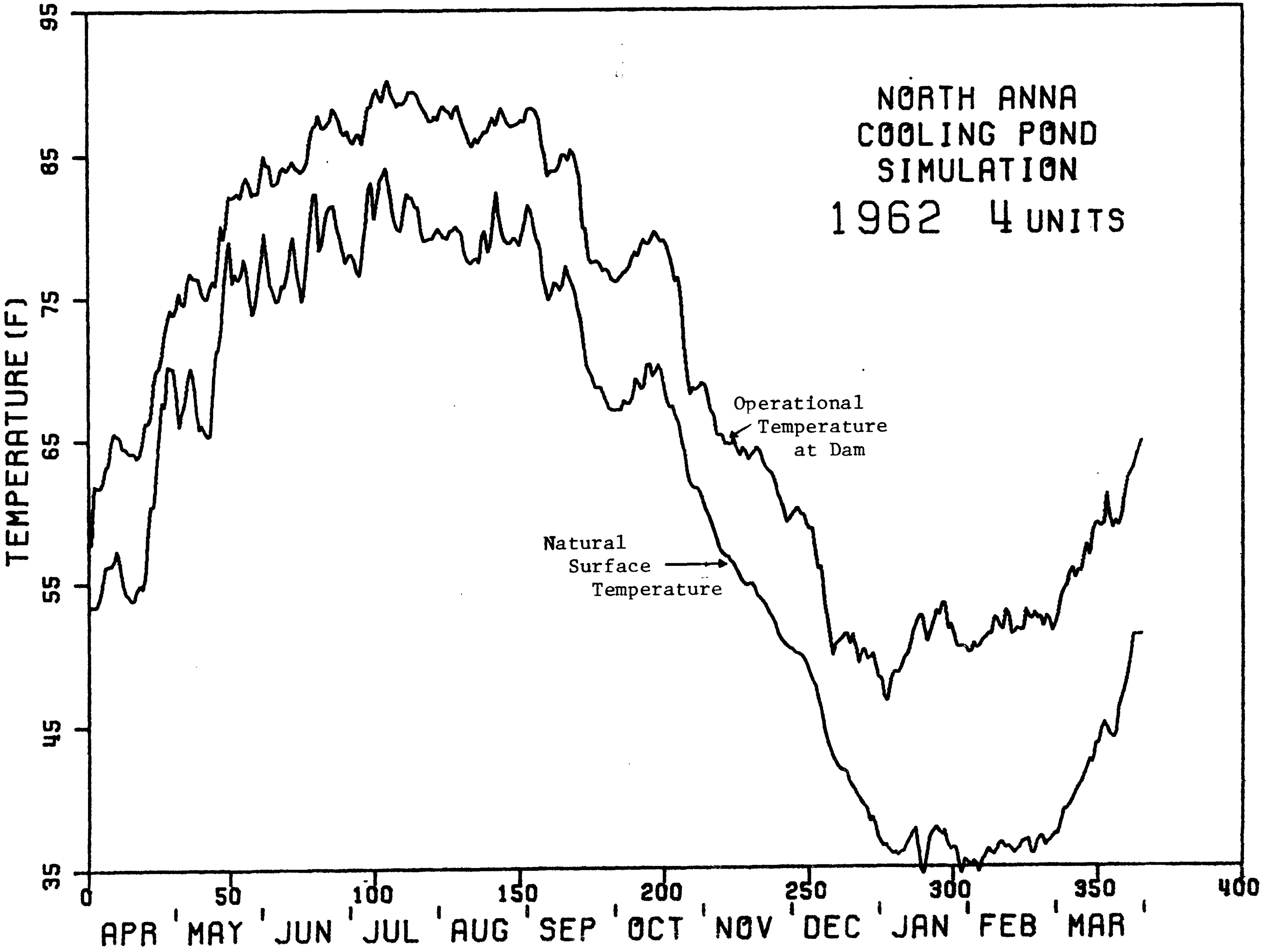


Figure 4-3: Loaded and Unloaded Temperature Variations at North Anna in 1962 with 4 Units Operational (After Jirka et al., 1977)

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 $23^{o}F$. The water circulates through the lake in a clockwise direction. An important aspect of the pond is a laterally crossing causeway with two restricted bridge openings of 60 ft width and 10 ft depth. This feature essentially forms three separate pond compartments.

b) Schematization and Classification

The schematic data for the three pond compartments has been summarized in Table 5-3 of Part A. For the second compartment, which comprises about 50% of the total pond area, a pond number $\mathbb{P} = 0.9$ can be predicted.* The length/width ratio is $L/W \stackrel{\sim}{\sim} 20$. Thus, a <u>vertically mixed dispersive cooling pond model</u> 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 $\Delta T = 12^{o}F$ has been used to evaluate $\mathbb{P}$. In a predictive mode, ΔT has to be estimated (for example, by using a steady-state approximation; see Appendix B of Part A).

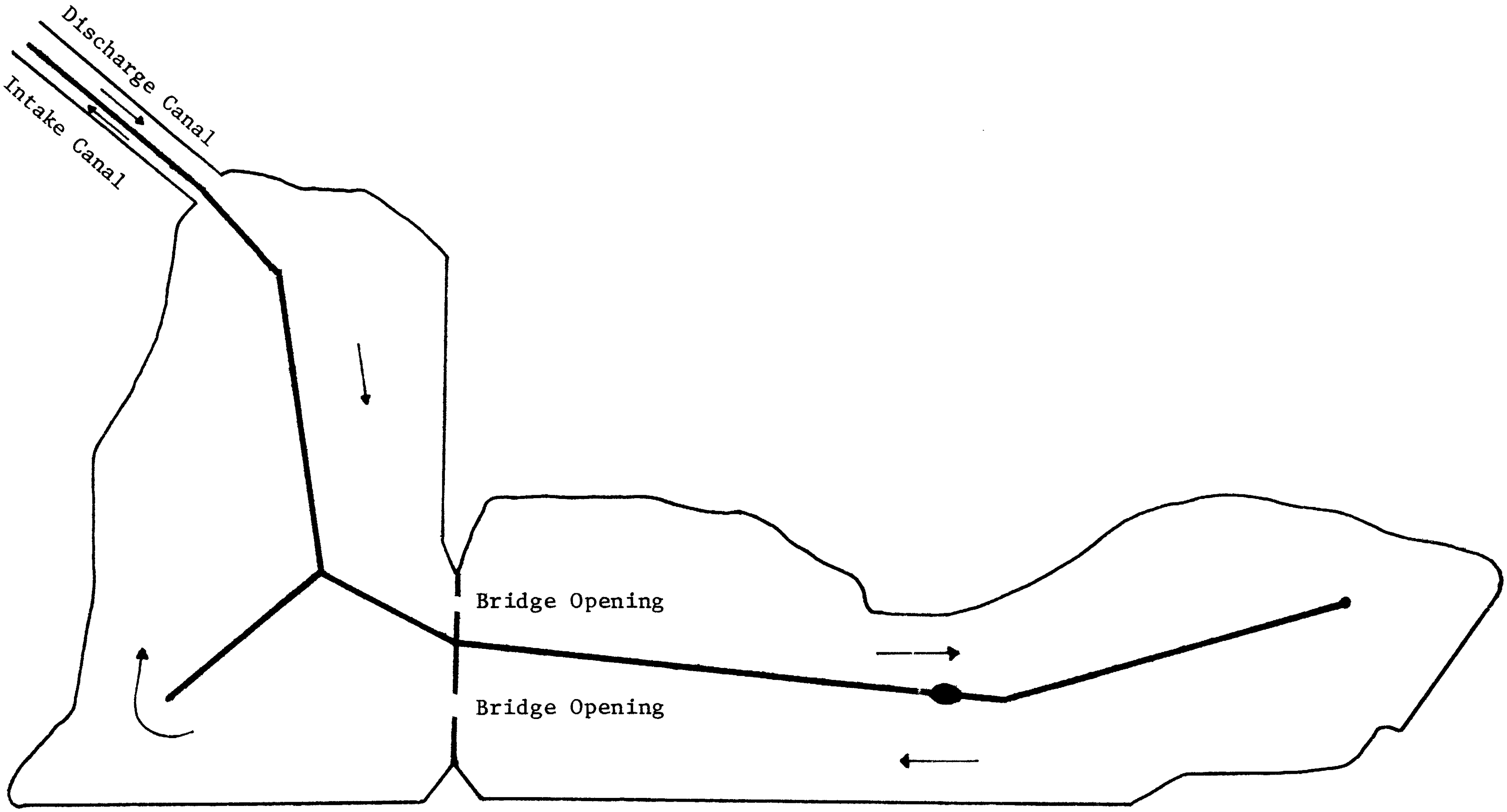


Figure 4-4: Plan View of Dresden Cooling Pond, Illinois

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

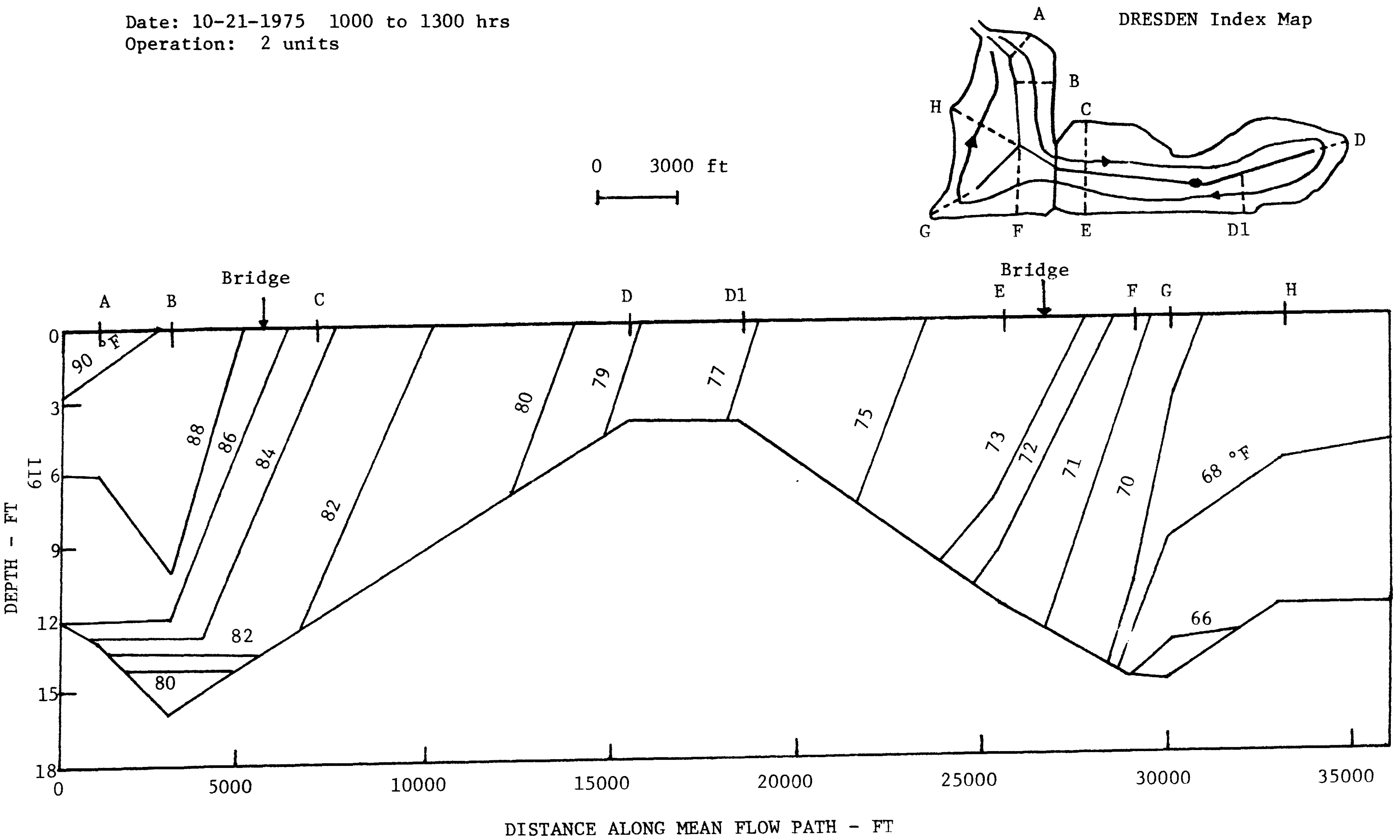


Figure 4-5: Longitudinal Temperature Profiles Indicating the Absence of Vertical Stratification in Dresden Cooling Pond

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 intermittant plant operation)
- on-site meteorological data for air temperature, relative humidity, cloud cover and wind velocity (meteorological tower is 2 miles away from the pond)
- solar radiation data from Argonne National Laboratory weather station (approximately 30 miles away)
- measured horizontal temperature distribution for the initial condition

The comparison between measured (T_i^*) and predicted (T_i) intake temperatures is shown in Figures 4-6 and 4-7 and relevant statistics are given. Further long-term simulations of Dresden Cooling Pond have been conducted by NUS Corporation (NUS, 1977) assuming plant operation at full capacity.

4.1.3 Powerton Cooling Pond, Illinois

a) Background Information

The Powerton Cooling Pond is a man-made cooling pond with internal dikes as shown in Figure 4-8. The lake can be divided into four compartments following the internal diking arrangement. The geometric characteristics of each compartment have been summarized in Table 5-4 of Part A. For two units operation of 1670 MW_e power production, the circulating flow rate is 1537 ft^3/sec with a temperature increase of approximately 23°F through the condensers.

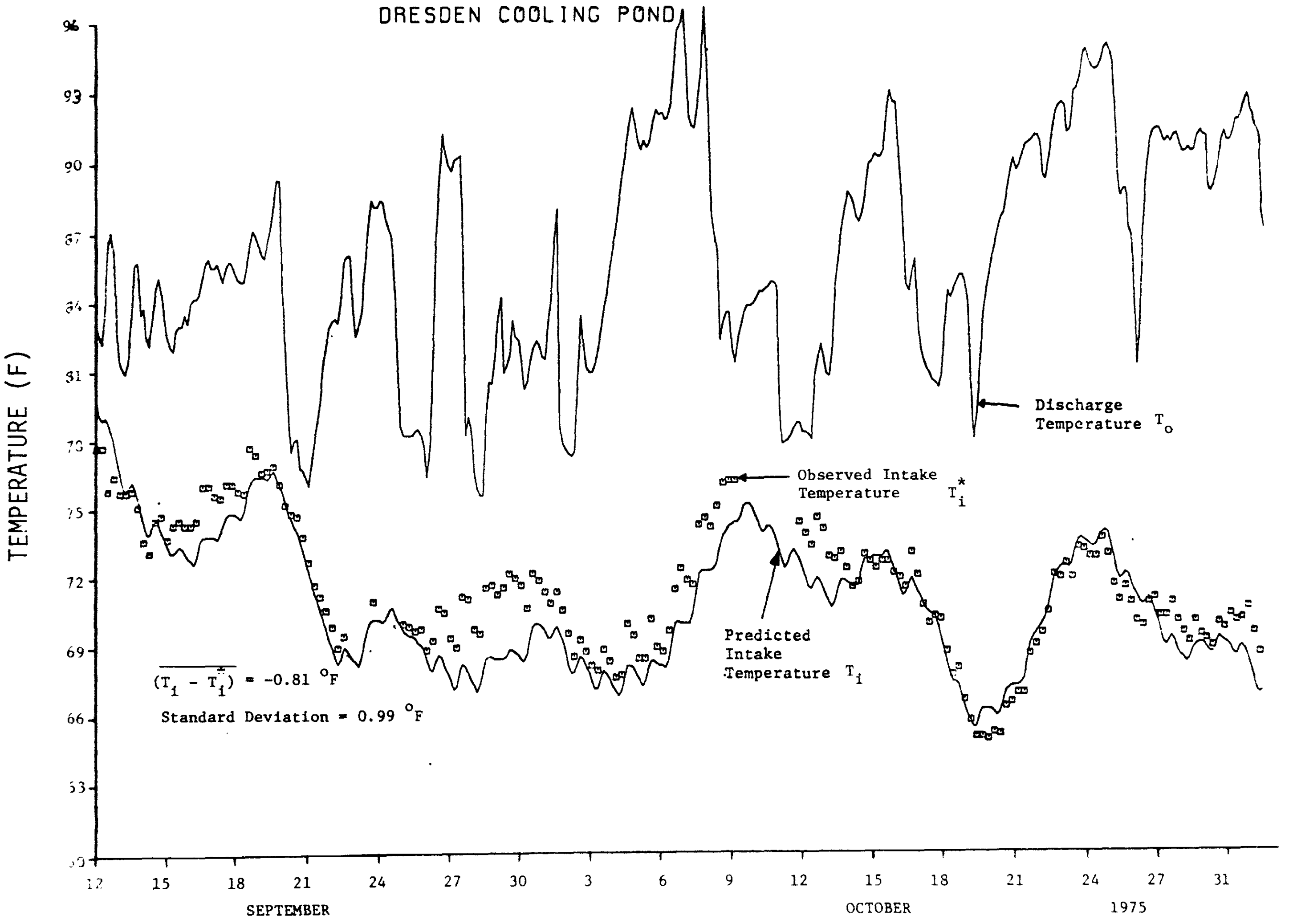


Figure 4-6: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from September 12 to October 31, 1975

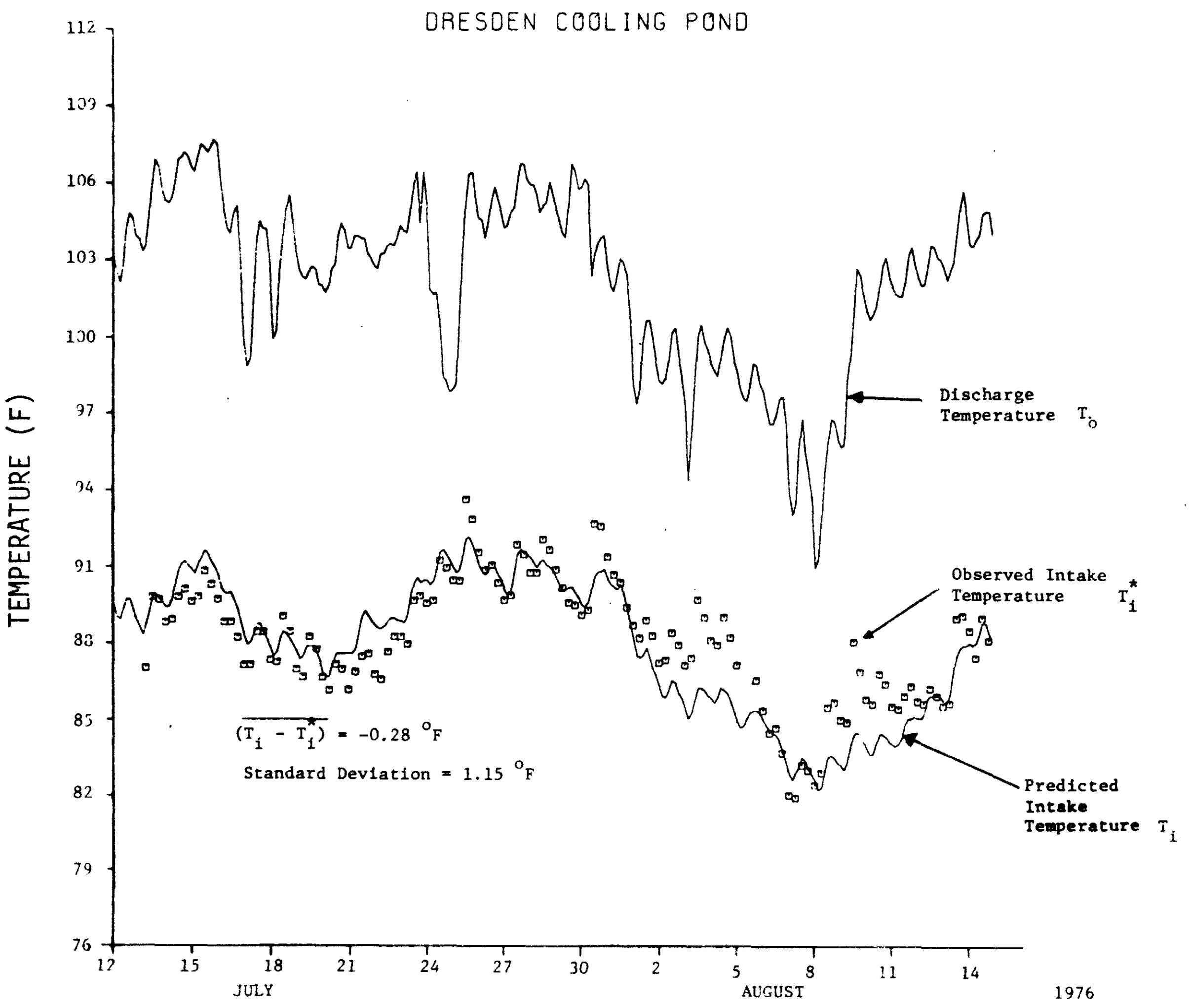


Figure 4-7: Predicted vs. Measured Intake Temperatures at Dresden Station, Illinois from July 12 to August 15, 1976

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 availabe 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 preceeds 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.

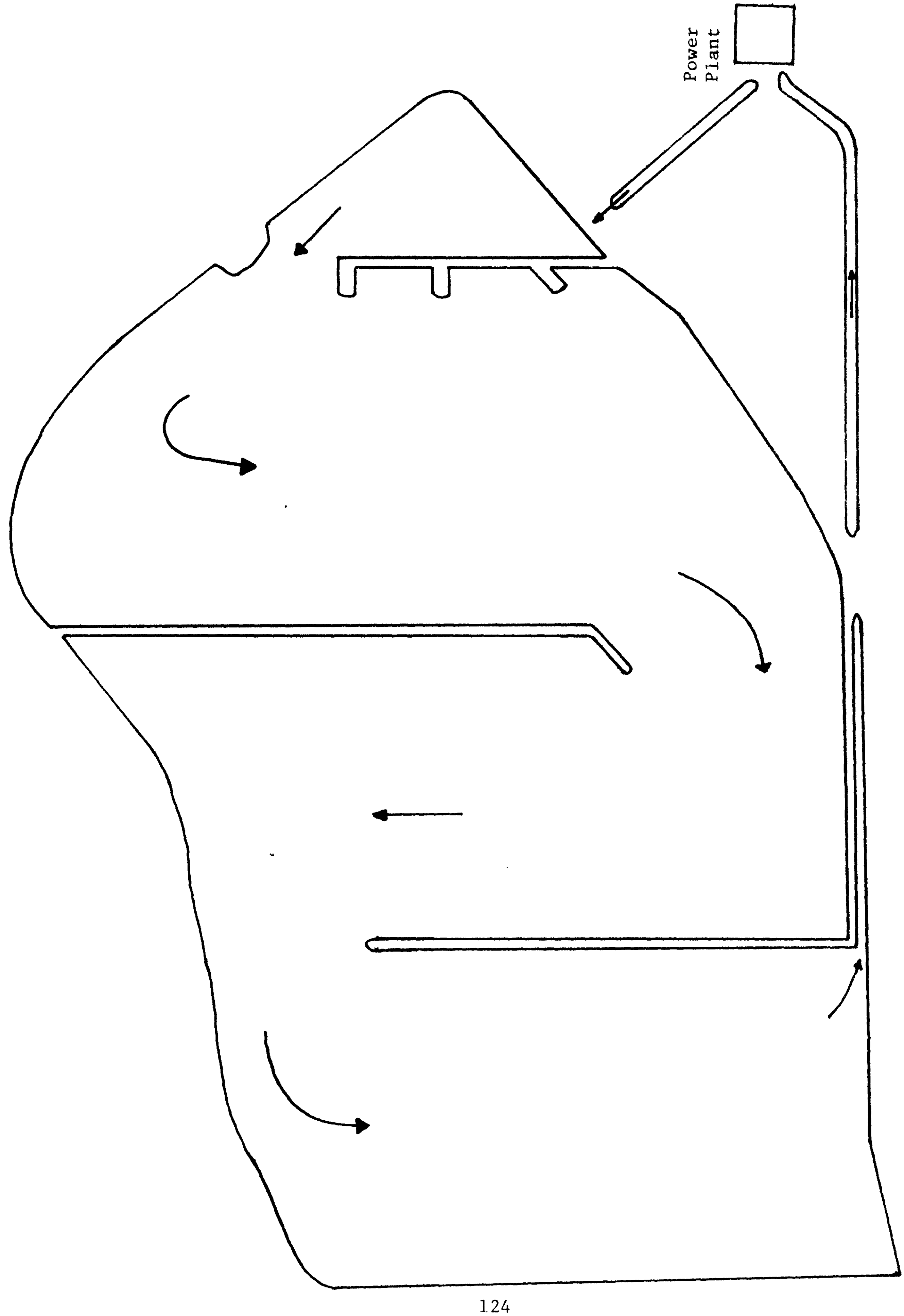


Figure 4-8: Plan View of Powerton Cooling Pond

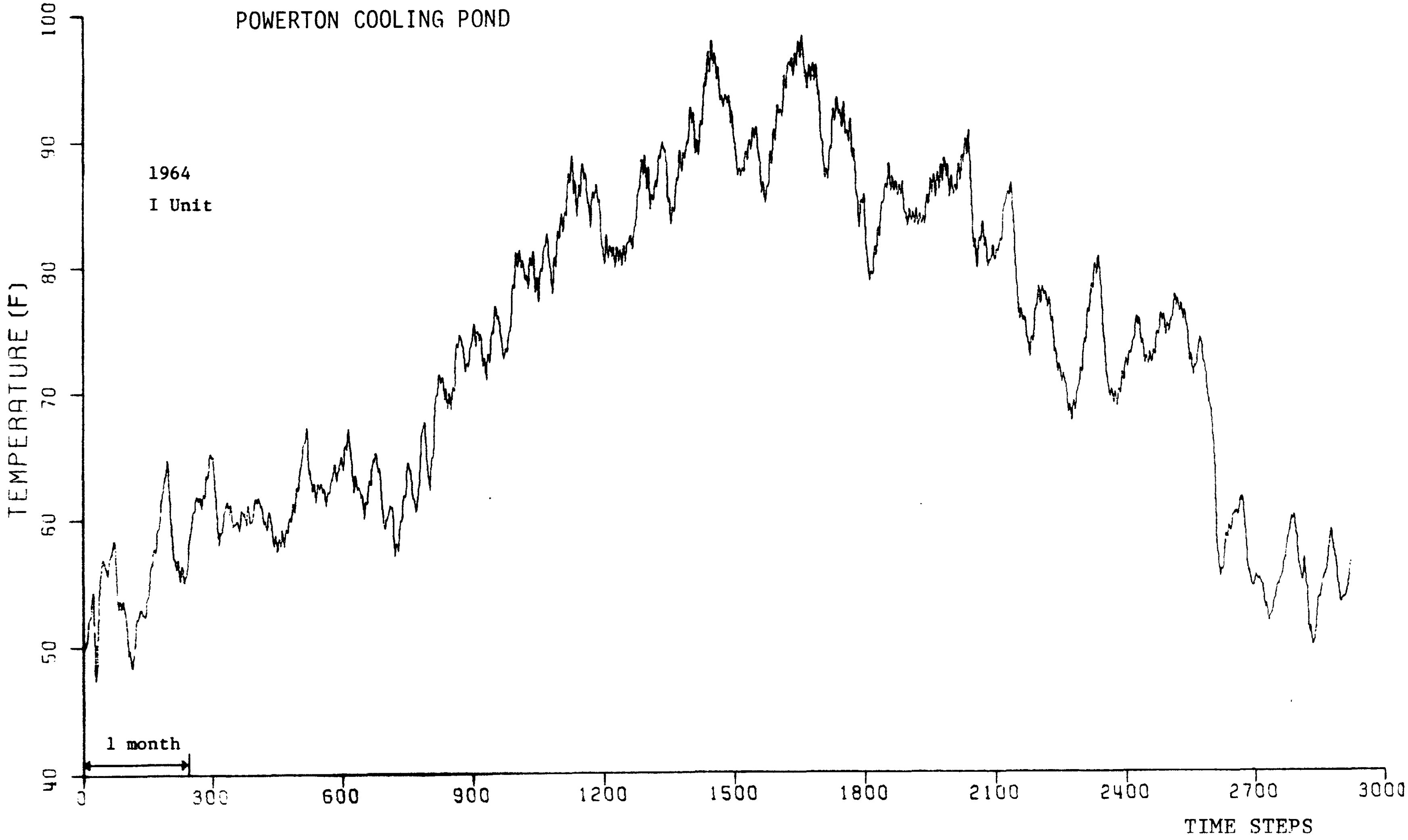


Figure 4-9: Simulated Intake Temperatures for 1 Unit Operation at Powerton Station, Illinois using 1964 Meteorological Data

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:

	Surface Area (Acres)	Average width (ft)	Average Depth (ft)	Average Length (ft)
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: 2009.3 acres

For full load operation, the fossil-fired station produces 2520 MW_e and the circulating flow rate is 2250 ft^3/sec with a temperature increase of approximately 22^oF through the condensers.

b) Schematization and Classification

Based on full load operation, a temperature drop of 10^oF ($\beta\Delta T_o \simeq 0.001$) and some minimal entrance dilution $D_v = 1.25$, a pond number $\mathbb{P} = 0.66$ 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

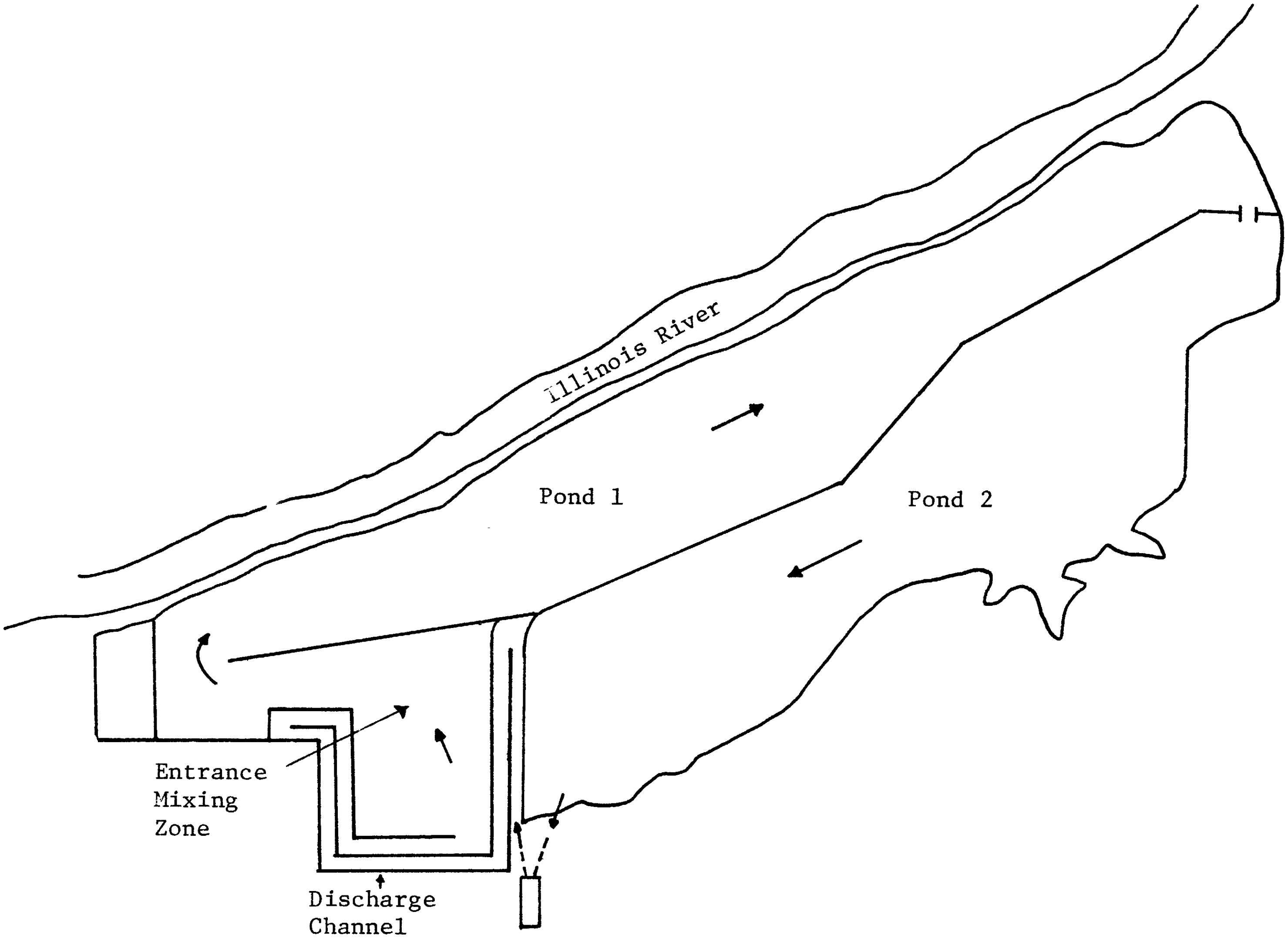


Figure 4-10: Plan View of Collins Cooling Lake

completely mixed model has been applied:

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

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

$\forall$ = 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

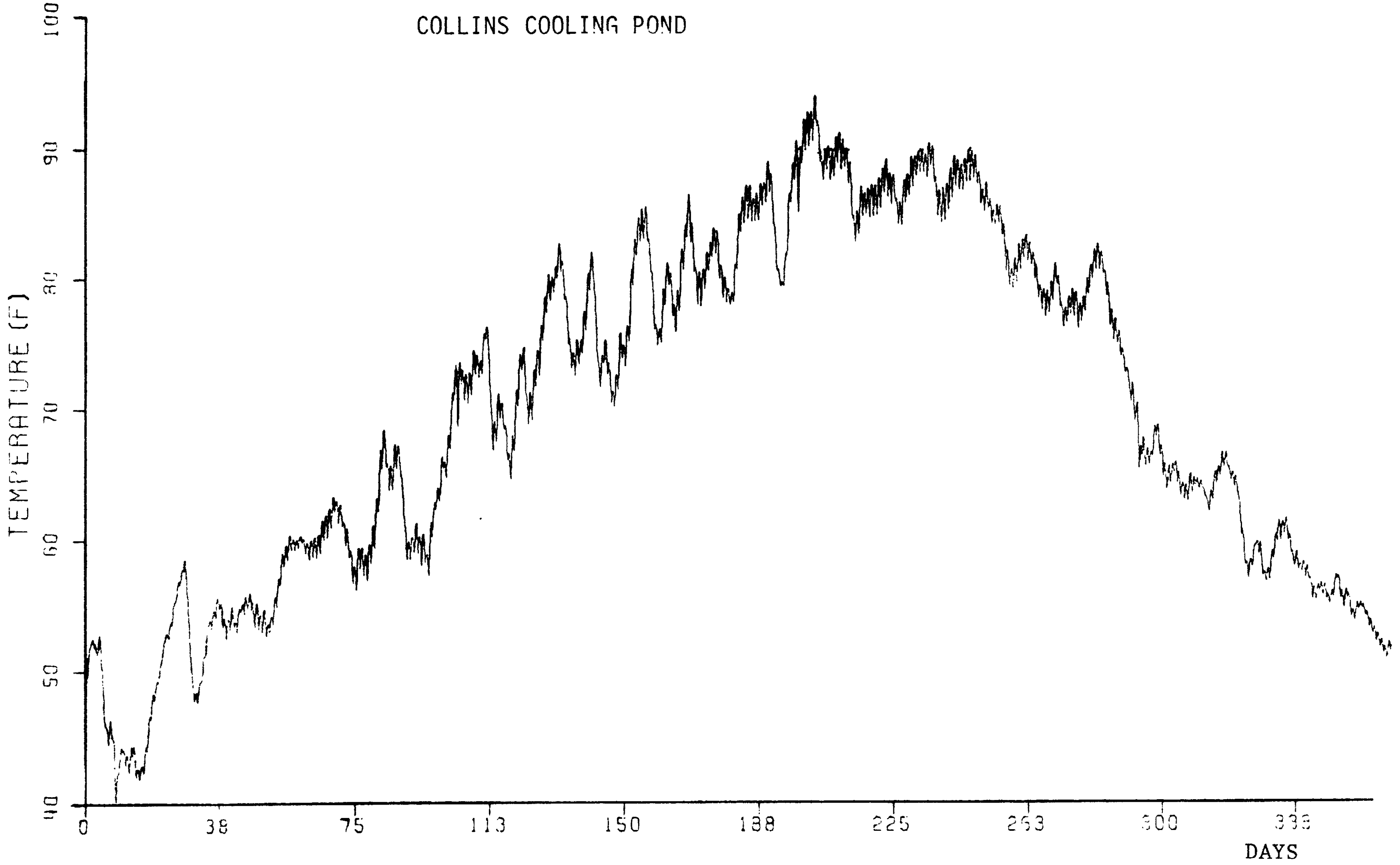


Figure 4-11: Simulated Intake Temperatures for Full Load Plant Operation at Collins Station, Illinois using 1969 Meteorological Data.

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 $1.25\mathrm{x}10^9$ ft^3. 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 ft^3/sec, temperature rise ΔT_o = 24°F ($\beta \Delta T_o \simeq 0.0024$) 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 $\mathbb{P}$ = 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.

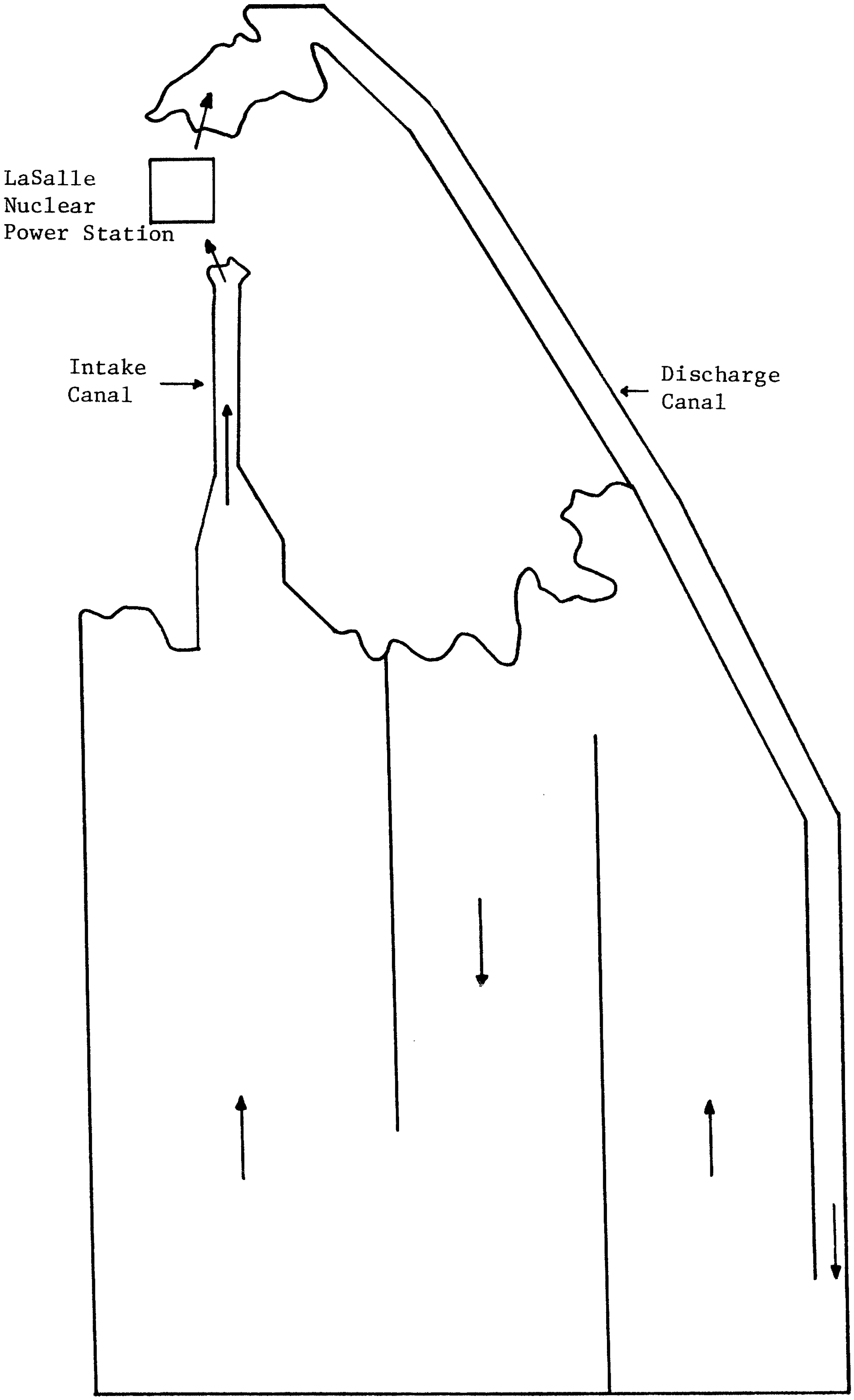


Figure 4-12: Plan View of LaSalle Cooling Pond

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 ft^3/sec with a temperature increase of approximately 20°F through the condenser. The heated water is discharged into the lake through a channel which has a depth of 5 ft, a width of 375 ft and a length of 2815 ft.

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

b) Schematization and Classification

The pond can be schematized as a two compartment sequence. The pond number criterion is applied to the first pond to check for any stratification. For this purpose a vertical dilution $D_v = 1.25$ and a temperature drop

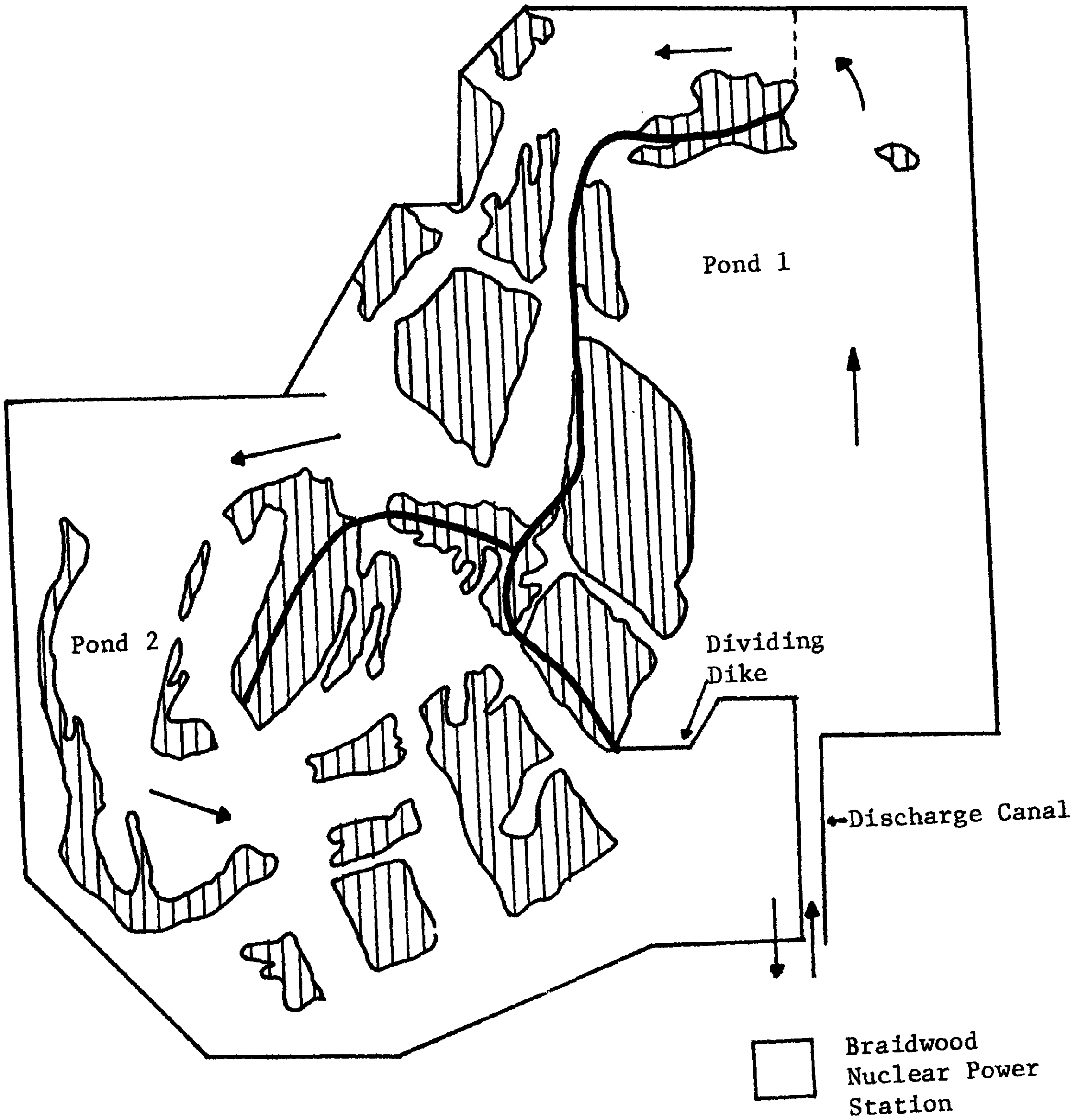


Figure 4-13: Plan View of Braidwood Cooling Pond

$\Delta T = 10^{o}F$ ($\beta\Delta T_o \simeq 0.001$) are used. The resulting pond number $\mathbb{P} = 0.60$ indicates a predominantly vertically mixed flow structure. Due to the low L/W ratio, L/W $\approx$ 1.3, it is expected that a significant recirculation pattern will exist in the first pond. The structure of the shallow, vertically mixed recirculating pond model with a symmetric discharge configuration (Figure 3-5 of Part A) is shown in Figure 4-14. By using Eq. (5.8) of Part A for the lateral jet mixing (L_{jet} = 8400 ft, $2b_o$ = 375 ft) a dilution factor $D_s = 3$ is computed, and a value of $q = 1/3$ is assumed.

In the <u>second</u> 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 <u>shallow, vertically mixed dispersive cooling pond model</u> is used. The dispersion coefficient is computed according to Eq. (5.5) of Part A as a <u>lower</u> 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

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

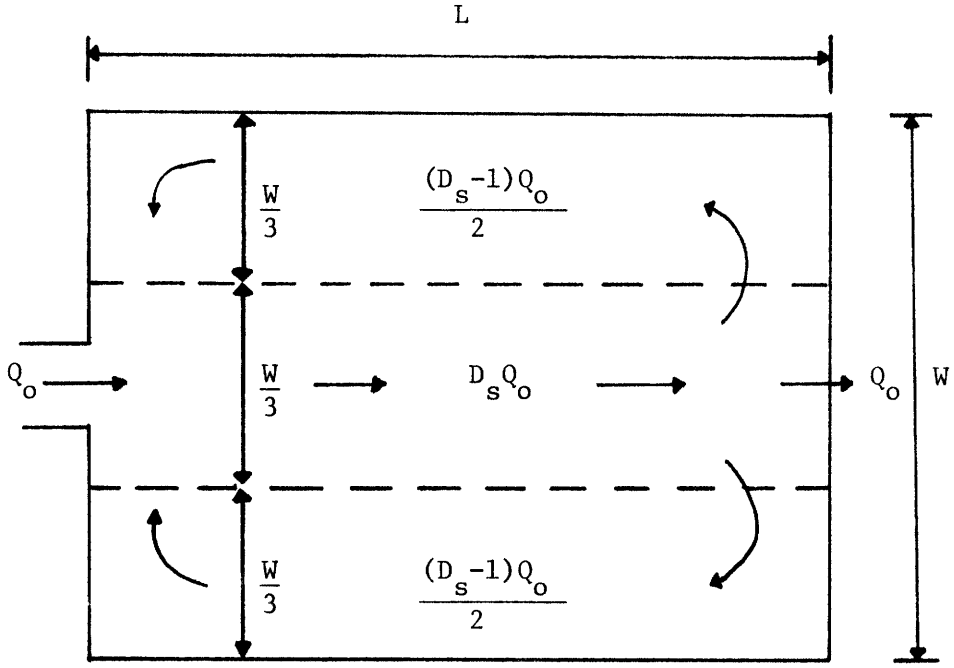

Figure 4-14: Schematic View of Pond 1 at Braidwood Cooling Pond

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 $\mathbb{P}$ = 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 $h_s = \mathbb{P}H \approx 3.0$ 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

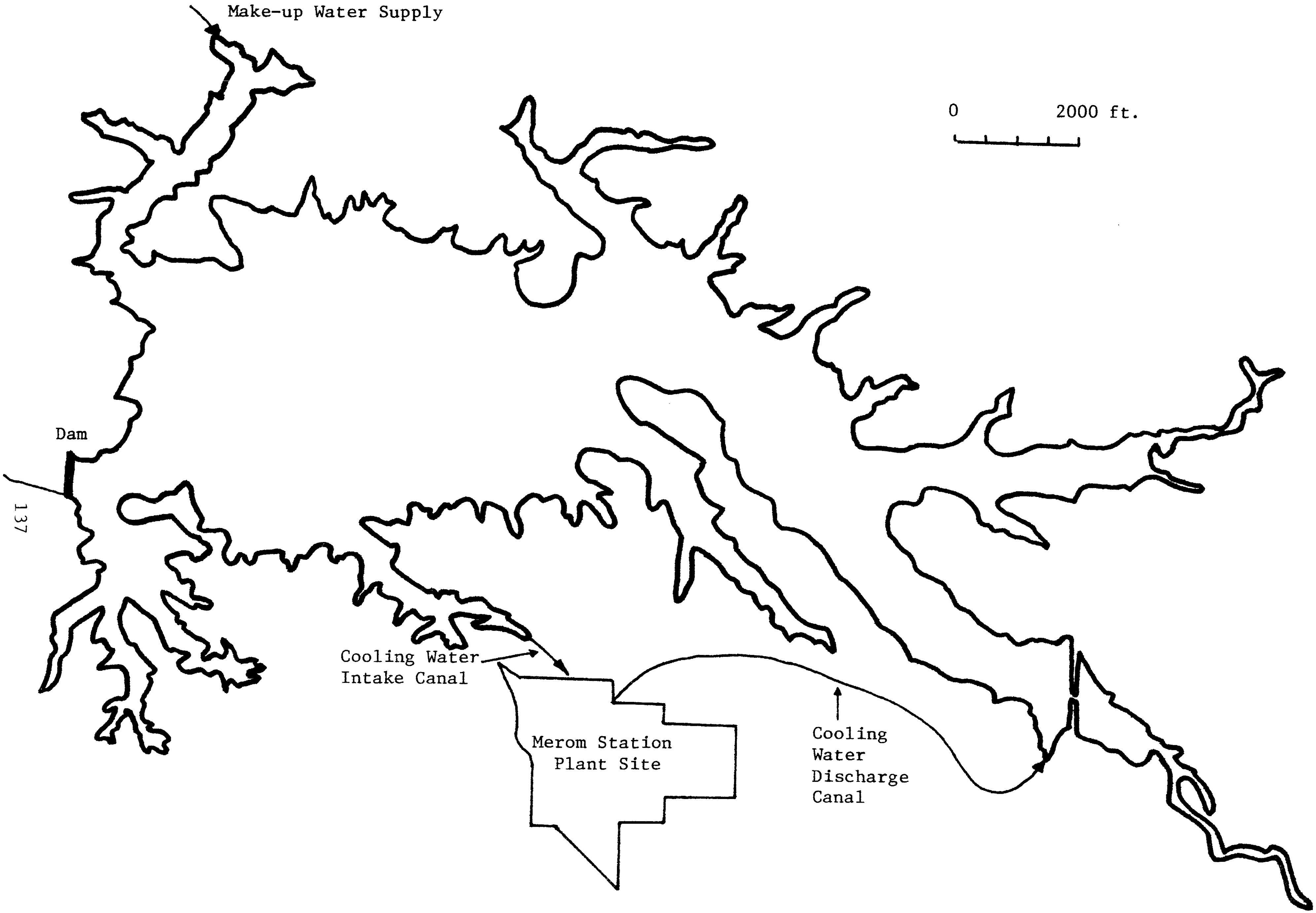

Figure 4-15: Plan View of Merom Lake

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).

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

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

4.2.2 Presentation of Results

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

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

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

2. Establish measures for temporal temperature variability and extremes.

a) Variability: A simple measure is the computation of standard deviations from the long-term simulation record. This procedure is included in Figure 4-16.

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

3. Establish measures for spatial temperature distributions. Cumulative distribution curves (either surface area - temperature, or volume - temperature) can be drawn for selected dates or seasons of the year (including natural and operational conditions (see Jirka et al. (1977)). Other forms of data presentations may be appropriate on an ad hoc basis, e.g. the detailed temperature response of short-term events (hot spells) to assess the survival of specific fish populations, etc.

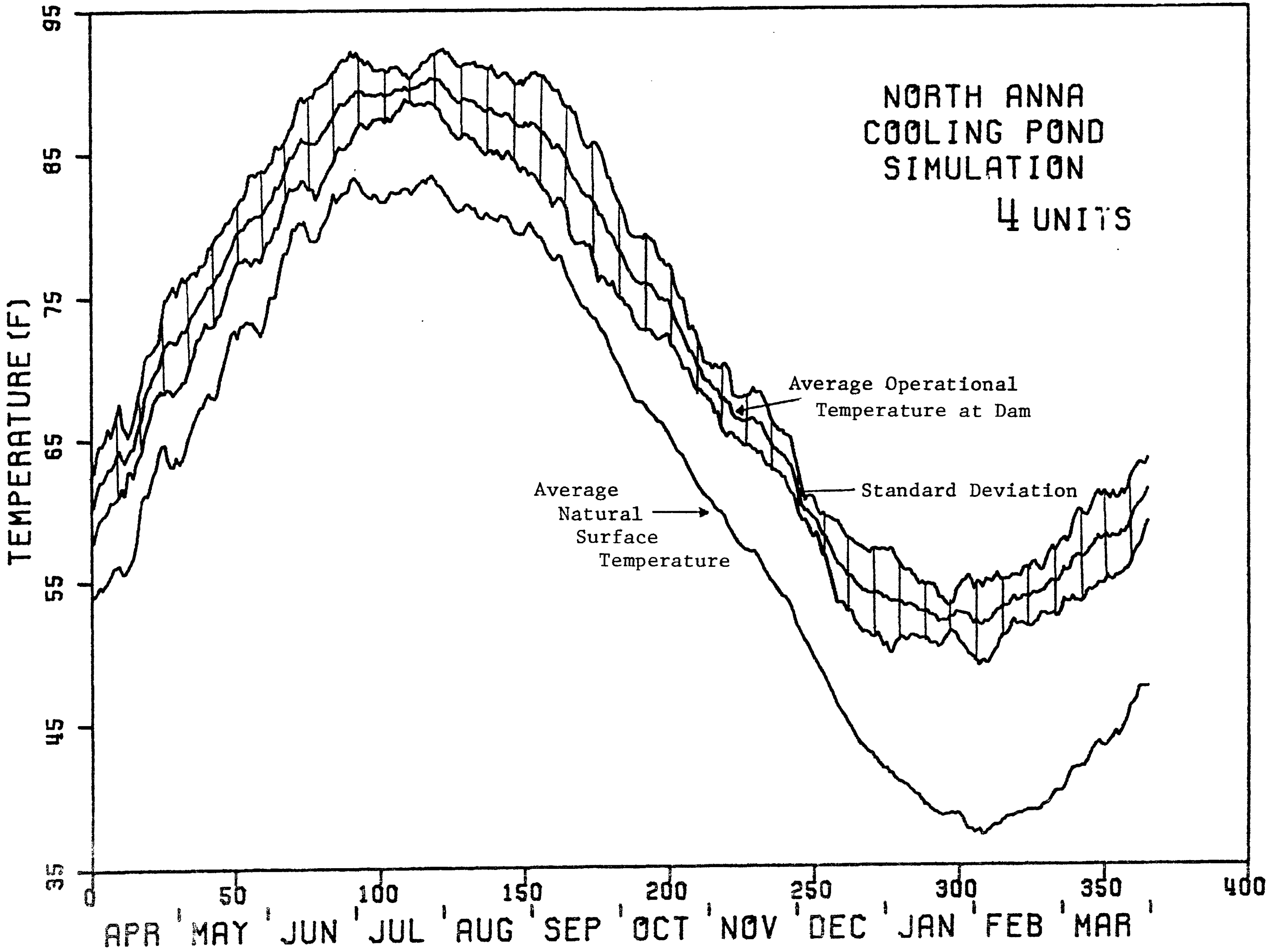

Figure 4-16: Average Yearly Temperature Cycle for Natural and Operational Conditions (Obtained from 10-year Simulation of the North Anna Cooling System)(After Jirka et al. 1977)

Table 4-1: **Selected characteristics of the long term temperature simulations. (Surface temperatures at the North Anna Dam, in °F).** (From Jirka et al. 1977)

	Natural	loaded with			
		1 unit	2 units	3 units	4 units
10 year averaged data					
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
Non-averaged data					
Maximum temperature .... (in 10 years studied, occurred June 30, 1959)	92.2	90.2	92.0	93.7	95.8

---

*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 /HFLOWS/ 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 /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,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /GAUS/ SIGMAI,SPREAD,SIGMIN(3)
      COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
      COMMON /EQUIL/ TE,IDT
      COMMON /ENTRN/ DSS(5),DS
      COMMON /ETIME/ ET,NPOND
      COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
      COMMON /ENGYA/ 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 /DELTTS/ 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 (ICOUNT,I,III)
      CALL DISPER(ICOUNT,I,III)
      DO 120 J=1,NAR
120   THLM(J,I,III)=TEMP(J)
130   CONTINUE
      CALL ENERGY(ICOUNT,I)
         CALL PRINT(ICOUNT,I)
150   CONTINUE
      GO TO 500
C  STRATIFIED HEATED POND
200   CONTINUE
      IF (I.GT.1)  GO TO 201
      R=(ET-DTAU)/DTQHIN
      L=R
      RR=R-L
      QHIN=QQHIN(L+1)+RR*(QQHIN(L+2)-QQHIN(L+1))
      IF(KOPERA.EQ.2) GO TO 209
      NN1=NOUT(NPOND)
      LLL=LOUT(NN1,NPOND)
      IF(ICOUNT.GT.1) GO TO 206
      THIN=TLOW(LLL,NPOND)+DTEMP
      GO TO 201
  206 THIN=TOUTC(ICOUNT-1,NN1)+DTEMP
      GO TO 201
209   THIN=TTHIN(L+1)+RR*(TTHIN(L+2)-TTHIN(L+1))
201   CONTINUE
      NINI=NIN(I)
      NOUTI=NOUT(I)
      III=1
      DHL=DZ(I,III)
      NAR=NSEG(I,III)+1
      MP1=NSEG(I,III)+1
      DS=DSS(I)
      DO 210 J=1,NAR
210   TEMP(J)=THLM(J,I,III)
      JM=NEL(I)
      JM1=NELSV(I)
      AYSUR=AYSURI(I)
      SAREA=SAREAI(I)
      SAREAP=SAREA
      DYSUR=DYSURI(I)
      DYSURP=DYSUR
      DY=DYY(I)
      YSUR=YSURI(I)
C  THIS NEXT STATE HAS BEEN CHANGED, DYSUR INSTEAD OF DHL
      ELBSL=YSUR-DYSUR
      JMP=NELMAX(I)
      DO 181 J=1,JMP
```

```
      B(J)=BI(J,I)
      XL(J)=XLI(J,I)
      A(J)=AI(J,I)
      EL(J)=ELL(J,I)
181   CONTINUE
      YBOT=YYBOT(I)
      DO 230 J=1,JM
230   T(J,1)=TLOW(J,I)
      D1=DZ(I,III)
      CALL HEAT (ICOUNT,I,III)
      CALL DISPER(ICOUNT,I,III)
      CALL SPEED(ICOUNT,I)
      CALL SUBLAY(ICOUNT,I)
      CALL AVER(ICOUNT,I)
      DO 260 J=1,NAR
260   THLM(J,I,III)=TEMP(J)
      DO 270 J=1,JM
270   TLOW(J,I)=T(J,1)
      CALL ENERGY(ICOUNT,I)
      CALL PRINT(ICOUNT,I)
250   CONTINUE
      GO TO 500
C  NATURAL RESERVOIR
300   CONTINUE
      JM=NEL(I)
      JM1=NELSV(I)
      ELBSL=YSURI(I)+DYY(I)
      AYSUR=AYSURI(I)
      SAREA=SAREAI(I)
      SAREAP=SAREA
      DYSUR=DYSURI(I)
      DYSURP=DYSUR
      DY=DYY(I)
      YSUR=YSURI(I)
      JMP=NELMAX(I)
      NINI=NIN(I)
      NOUTI=NOUT(I)
      NAR=1
      DHL=0.0
      DO 325 J=1,JMP
      B(J)=BI(J,I)
      XL(J)=XLI(J,I)
      A(J)=AI(J,I)
      EL(J)=ELL(J,I)
325   CONTINUE
      YBOT=YYBOT(I)
      DO 330 J=1,JM
330   T(J,1)=TLOW(J,I)
      IF(KSUR.EQ.2) CALL SUREL(ICOUNT,I)
      CALL HEAT (ICOUNT,I,III)
      CALL SPEED(ICOUNT,I)
      CALL SUBLAY(ICOUNT,I)
      CALL HTMIX(ICOUNT,I)
      NAR=2
```

```
      III=1
      DXX(I,III)=0.0
      WDTH(I,III)=0.0
      NSEG(I,III)=1
      TEMP(1)=T(JM,1)
      TEMP(2)=T(JM,1)
      CALL AVER(ICOUNT,I)
      DO 370 J=1,JM
370   TLOW(J,I)=T(J,1)
      CALL ENERGY(ICOUNT,I)
      CALL PRINT(ICOUNT,I)
350   CONTINUE
500   CONTINUE
501   CONTINUE
      GO TO 20
600   CONTINUE
  700 CONTINUE
      STOP
      END
      SUBROUTINE MET
      REAL LENGTH
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /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,DCLOUD,DTFIN,DATRAD
      COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQ1,IFREQ2,IFREQA
      COMMON /ETIME/ ET,NPOND
      COMMON /METWD/ WHGT,TAU
      COMMON /CONST/ RHO,HCAP,GRAV
      COMMON /ENGY/ EFXIN(5),EFXOT(5),EOUT(5),EIN(5),E0(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
      E0(I)=0.0
      EOUT(I)=0.0
      EIN(I)=0.0
      EFXIN(I)=0.0
      EFXOT(I)=0.0
5     READ (5,910) KSTRT(I),KCIRC(I)
      READ (5,910) KFIN,KATRAD,KUNITS,KSUR,KHEAT,KOPERA
```

```
      WRITE (6,800) KFIN,KATRAD,KUNITS,KSUR,KHEAT,KOPERA
800   FORMAT (////10X,'KFIN ',I3,8X,'KATRAD',I3,8X,'KUNITS',I3,8X,
     ,'KSUR',I3,8X,'KHEAT',I3,8X,'KOPERA',I3)
C  KFIN   = 1   MEASURED SOLAR RADIATION
C         = 2   COMPUTED SOLAR RADIATION
C  KATRAD = 1   MEASURED ATMOSPHERIC RADIATION
C         = 2   COMPUTED ATMOSPHERIC RADIATION
C  KUNITS = 1   UNITS ARE KCAL, METERS, DAY, DEG.C, M/S(WIND SPEED ONLY)
C         = 2   UNITS ARE BTU, FEET, DAY, DEG.F, MPH(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
```

```
      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 /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 /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   LOUT        GRID NUMBER CORRESPONDING TO OUTLET ELEVATION
C   ELOUT       OUTLET ELEVATION
C   NQO         NUMBER OF OUTFLOW RATES TO BE READ IN FOR OUTLET K
C   DTQO        TIME INTERVAL BETWEEN VALUES OF QO
C   QO          OUTFLOW RATES
      READ (5,910) NELSV(I),NELMAX(I)
      NEL(I)=NELSV(I)
      READ(5,950) DYY(I),YSURI(I)
      READ(5,925) NAA(I),DAA(I),AAB(I)
      NA=NAA(I)
      READ(5,927) (AA(J,I),J=1,NA)
      READ(5,925) NXXL(I),DXXL(I),XXLB(I)
      NX=NXXL(I)
      READ(5,927) (XXL(J,I),J=1,NX)
C  READ INITIAL TEMPERATURE DISTRIBUTION
      JM=NEL(I)
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) NIN(I)
      NINI=NIN(I)
      DO 20 K=1,NINI
      READ (5,905) KOH,KMIX,MIXED(K,I),RMIX(K,I)
      SIGMIN(K)=SIGMAI
      READ (5,920) NQIN(K,I),DTQIN(K,I)
      NQINN=NQIN(K,I)
      READ (5,951) (QQIN(J,K,I),J=1,NQINN)
C  READ IN VALUES OF THE TEMPERATURE OF THE WATER ENTERING THE POND
20    READ (5,930) (TTIN(J,K,I),J=1,NQINN)
      WRITE (6,888)DD(1,I)
  888 FORMAT(/5X,'VERTICAL DIFFUSION COEFF.= ',F10.5)
      WRITE (6,809)
  809 FORMAT (//5X,'STRATIFIED PORTION INFLOW PARAMETERS')
      DO26 K=1,NINI
26    WRITE (6,810) KOH,KMIX,K,MIXED(K,I),K,RMIX(K,I)
810   FORMAT (10X,'KOH',I3,5X,'KMIX',I3,5X,'MIXED(',I2,')',I3,5X,'RMIX('
     ,,I2,')',F5.2)
C  READ OUTFLOW DATA
      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 /HFLOWS/ 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
```

```
      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)*WDTH(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
      WDTH(I,III)=WDTH(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)
```

```
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),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,DCLOUD,DTFIN,DATRAD
      COMMON /CONST/ RHO,HCAP,GRAV
      COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /EQUIL/ TE,IDT
      COMMON /ETIME/ ET,NPOND
C  DETERMINE METEOROLOGICAL DATA FROM READ IN VALUES
C  AIR TEMPERATURE
      R=ET/DTTA
      L=R
      RR=R-L
      TAIR =TA(L+1)+RR*(TA(L+2)-TA(L+1))
      TAIRF=TAIR*9./5.+32.
C  RELATIVE HUMIDITY
      R=ET/DTSIGH
      L=R
      RR=R-L
      PSI=(SIGH(L+1)+RR*(SIGH(L+2)-SIGH(L+1)))
C  EXPONENTIAL APPROXIMATION FOR VAPOR PRESSURE OF THE AIR IN MM HG
      EA=PSI*(25.4*EXP(17.62-9500./(TAIRF+460.)))
```

```
C  WIND SPEED
      R=ET/DTWIND
      L=R
      RR=R-L
      W=WIND(L+1)+RR*(WIND(L+2)-WIND(L+1))
      WINDY=W
C  SOLAR RADIATION , MEASURED
      R=ET/DTFIN
      L=R
      RR=R-L
      SR=FIN(L+1)+RR*(FIN(L+2)-FIN(L+1))
      GO TO (20,10),KFIN
C  SOLAR RADIATION , COMPUTED
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
```

```
      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,DCLOUD,DTFIN,DATRAD
      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,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /CWU/ H,EEMASS(5),EEVAP(5),EBRAD(5),EATRAD(5)
      COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
      COMMON /EQUIL/ TE,IDT
      COMMON /ETIME/ ET,NPOND
C  HEAT LOSS COMPUTATIONS
      DO 200 K=1,NAR
      IF(NAR.GT.1) GO TO 60
      TS=T(JM,1)
      DY1=DYSUR
      SURAR=AYSUR
      GO TO 70
60    TS=TEMP(K)
      DT=DTAU
      DY1=DHL
      SURAR=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    CONDUC=RHO*0.01*269.1*(TS-TAIR)*FW
      GO TO 100
C  EVAPORATION RYAN EQUATION FOR HEATED LAKE
90    TAIRF=TAIR*9./5.+32.
      TAIRV=(TAIRF+460.)/(1.-0.378*EA/760.)-460.
      TSV=(TSF+460.)/(1.-.378*ES/760.)-460.
      DTV=TSV-TAIRV
      IF(DTV.LE.0.) DTV=0.
C  IN BRITISH UNITS THIS EQN IS FW=22.4*DTV**.33+14.*W
      FW=22.4*DTV**.333+14.*W/.447
C  IN BRITISH UNITS THIS EQN IS FW=17.*W
      FW2=17.*W/.447
      IF(FW2.GT.FW) FW=FW2
      FW=0.85*FW
      EVAP=FW*DE*2.712
C  CONDUCTION
      CONDUC=EVAP*(TS-TAIR)/DE*.46
      IF (EVAP.LE.0.0) EVAP=0.0
C  BACK RADIATION
100   RAD=1.13587E-6*(TS+273.16)**4
C  ENERGY CHECK CALCULATIONS FOR HEAT LOADED CONDITIONS
      IF (KHEAT.EQ.1)  CALL SUMFLX(I)
      GO TO (110,120),KSTRAT
C  VERTICALLY FULLY MIXED
110   R=1.0
      ARATIO=1.0
      GO TO 150
C  VERTICAL STRATIFICATIOM
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+CONDUC+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,CONDUC,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+CONDUC+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 /HFLOWS/ 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),VTM(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 /HFLOWS/ 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=FRICTION FACTOR
C  VKRMN=VON KARMAN CONSTANT
      VKRMN=0.4
      GO TO (50,60), KSTRAT
60    F=0.01
```

```
      GO TO (61,62), KMIX
62    NIN1=NIN(I)+1
      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
```

```
      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
```

```
100   TEDDY(I)=TEMP(MP1)
      RETURN
      END
      SUBROUTINE TRIDAG (IF, L, A, B, C, D, V)
      DIMENSION A(1), B(1), C(1), D(1), V(1), BETA(101), GAMMA(101)
C  TRIDAG SOLVES THE SYSTEM OF LINEAR SIMULTANEOUS EQUATIONS
C  GENERATED BY THE IMPLICIT SCHEME
C  COMPUTE INTERMEDIATE ARRAYS BETA AND GAMMA
      BETA(IF)=B(IF)
      GAMMA(IF)=D(IF)/BETA(IF)
      IFP1=IF + 1
      DO 1 I=IFP1,L
      BETA(I)=B(I)-A(I)*C(I-1)/BETA(I-1)
    1 GAMMA(I)=(D(I)-A(I)*GAMMA(I-1))/BETA(I)
C  COMPUTE FINAL SOLUTION VECTOR V
      V(L)=GAMMA(L)
      LAST=L-IF
      DO 2 K=1,LAST
      I = L - K
    2 V(I)=GAMMA(I)-C(I)*V(I+1)/BETA(I)
      RETURN
      END
      SUBROUTINE SPEED(N,I)
      REAL LENGTH
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
     ,DTQHIN
      COMMON /MIX/ KMIX,MIXED(3,5),RMIX(3,5),KOH
      COMMON /FLOWS/ QQIN(366,3,5),TTIN(366,3,5),TIN(3),QIN(3),
     ,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),DXX(5,2),
     ,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
      COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
      COMMON /ENFLW/ TININ(3),QININ(3),NOUT1
      COMMON /ETIME/ ET,NPOND
      COMMON /FLVL/ JIN(3)
      COMMON /ENTRN/ DSS(5),DS
      COMMON /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
```

```
      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
      ARGI=S(J)/2.0/SIGMIN(K)/SIGMIN(K)
      IF(ARGI-20.0)4,4,5
```

```
    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
```

```
   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)
```

```
      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,DCLOUD,DTFIN,DATRAD
      COMMON /METEOA/ TA(3000),SIGH(3000),WIND(3000),CLOUD(3000)
      COMMON /METEOB/ FIN(3000),ATRAD(3000)
      COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /VELS/ V(102,1),UI(102,5),UO(102,5),UOT(102,5)
      COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
     ,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
      COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
      COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),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 /DELTTS/ 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-CONDUC-RAD+AR)*AYSUR/RHO/HCAP/DYNEW/SARNEW
      GO TO 2101
C  HEATED POND
2100  CONTINUE
      DELTS=0.0
      DELTA=(1.0-BETA)*SR*( EXP(-ETA*DHL)*A(JM)- EXP(-ETA*(DHL+DYNEW))*
     .(A(JM)+A(JM-1))/2.0)/A(JM)/DYNEW/HCAP/RHO
2101  CONTINUE
C  ADVECTION TERMS
      IF (V(JM,1))1163,1164,1164
1164  DELTB=V(JM,1)*T(JM-1,1)*(A(JM)+A(JM-1))/2./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,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
      COMMON /METWD/ WHGT,TAU
      COMMON /DELTTS/ DELSAV,DELTS,DELTT(10),TSAVE
      DIMENSION FLX(10)
      FLX(1)=EVAP+CONDUC+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+CONDUC+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(DELTT(MM)-DELTT(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 /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 /CONST/ RHO,HCAP,GRAV
      COMMON /METWD/ WHGT,TAU
      COMMON /FLXES/ SR,EVAP,RAD,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      DIMENSION D(100)
      GRAV=73150000000.
      DO 100 J=1,JM
  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 CO=C1
      TAU=CO*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),NOUT(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
```

```
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 40.0F
      IF (LOOP.GE.25) GO TO 15
      IF((T2.LT.4.0).AND.(T1.GT.T2)) GO TO 10
      IF((T2.GE.-18.0).AND.(T1.LT.T2)) GO TO 20
C LAYER IS STABLE
    5 IFLG=1
      RETURN
   10 IF(T1-4.0) 30,30,15
   15 D1=1000.0-0.00663*(T1-4.0)*(T1-4.0)
      D2=1000.0-0.00663*(T2-4.0)*(T2-4.0)
      IF(D1-D2) 5,5,30
   20 IF(T1-4.0) 25,25,30
   25 IF(T2-4.0) 30,30,15
C LAYER IS UNSTABLE
   30 IFLG=2
      RETURN
      END
      SUBROUTINE TOUTQ(N,LT)
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /TEMPB/ T(100,2),TLOW(100,5),NEL(5),NELMAX(5)
      COMMON /GEOMB/A(100),B(100),XL(100),DD(1,5),DY,JM,JMP,YSUR,EL(100)
      COMMON /SURF/ SAREAP,DYSURP,DYSUR,AYSUR,SAREA,SURAR
      COMMON /VELS/ V(102,1),UI(102,5),UO(102,5),UOT(102,5)
      COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
C  COMPUTE OUTLET TEMPERATURE
      HEATOT(LT)=HEATOT(LT)+T(JM,1)*B(JM)*UOT(JM,LT)*DYSUR
      HEATOT(LT)=HEATOT(LT)+T(1,1)*B(1)*UOT(1,LT)*DY/2.
      FLOWOT(LT)=FLOWOT(LT)+B(JM)*UOT(JM,LT)*DYSUR+B(1)*UOT(1,LT)*DY/2.
      JMM=JM-1
      DO 210 J=2,JMM
      HEATOT(LT)=HEATOT(LT)+UOT(J,LT)*B(J)*DY*T(J,1)
210   FLOWOT(LT)=FLOWOT(LT)+UOT(J,LT)*B(J)*DY
```

```
      RETURN
      END
      SUBROUTINE PRINT(ICOUNT,I)
C     THIS SUBROUTINE DECIDES WHEN TO PRINT OUTPUT DATA
      COMMON /SWITCH/KUNITS,KSTRAT,KHEAT,KSTRT(5),KOPERA,KCIRC(5)
      COMMON /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
     ,DTQHIN
      COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
      COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
     ,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
      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,CONDUC,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/ NDAYS(13)
      COMMON /ISTART/ ATIME1,MMO,MDY,MYR,NDD
      COMMON /IPR/ KMODE,IPRINT(20),IFREQT
      COMMON /EXTIN/ DTAU,DT,ETA,BETA,TAUMAX,IFREQA,IFREQ1,IFREQ2
      DO 10 II=1,NDD
         IF(ICOUNT.EQ.IPRINT(II)) GO TO 200
   10 CONTINUE
  100 IF(I.GT.1) GO TO 150
      IF((ICOUNT/IFREQT)*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
```

```
      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 /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
     ,DTQHIN
      COMMON /TEMPA/ TEMP(100),THLM(100,5,2),TLOSS(100),TOUT(3000,5)
      COMMON /GEOMA/ VTOTAL(5),VFM(5),VDF(5),LENGTH(5,2),DXX(5,2),
     ,DZ(5,2),WDTH(5,2),AREA(5,2),DHL,THETA(5),NSEG(5,2),NAR,MP1
```

```
      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
      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)
```

```
      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 /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
     ,DTQHIN
      COMMON /FLXES/ SR,EVAP,RAD,CONDUC,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+CONDUC+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
```

```
      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 /HFLOWS/ QQHIN(3000),TTHIN(3000),THIN,QHIN,QHINI,NQHIN,
     ,DTQHIN
      COMMON /CONMIX/ DMIX,MIXH
      COMMON /FLOWS/ QQIN(366,3,5),TTIN(366,3,5),TIN(3),QIN(3),
     ,QOUT(5),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,CONDUC,AR,TAIR,TAIRF,PSI,EA,W,WINDY,CC
      COMMON /FLVL/ JIN(3)
      COMMON /TOUTT/ TOUTC(3000,5),HEATOT(5),FLOWOT(5)
      COMMON /TENGY/ TENRAT(5)
      COMMON /PRNTKT/ KT1,KT2,KTA
      COMMON /SURFLR/ KSUR
      DIMENSION TINF(3),QINB(3)
      DIMENSION 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
```

```
  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  .67  .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
        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
 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
 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    2253.8    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
```

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


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

      POND   CUMULATIVE EVAP MASS LOSS
        1                 14648437.0
        2                 11045575.0


  VERTICALLY MIXED REGION

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

           103.56      99.58      98.14      96.81      95.58      94.45      93.43      92.55      91.86      91.43


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

            85.97      84.33      84.17      84.03      83.92      83.85      83.81

            83.81      81.45      81.23      81.04      80.90      80.80      80.75
```

Run 2 Input Data

```
   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
         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          POND    1
    TOTAL VOLUME                  576000000.
    HORIZONTALLY MIXED FRACTION         0.10
```

```
VOLUME DFR                          518399744.
VOLUME FM                            57600000.
CROSS SECTIONAL AREA                   24000.00
DEPTH                                      4.00
WIDTH                                   6000.00
LENGTH                                 24000.00
ELEMENTS IN DFR                              12
DISTANCE INCREMENT                      1800.00
ENTRAINMENT                                0.30


INITIAL TEMPERATURE DISTRIBUTION IN POND   1

 75.00      74.50      74.00      72.50      71.00      70.00      69.00      68.00      67.00      66.00
 65.00      64.00      63.00



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


METEOROLOGICAL DATA

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

     POND   CUMULATIVE EVAP MASS LOSS
       1              18150400.0


VERTICALLY MIXED REGION

     INFLOW TEMPERATURE     81.55         FLOW RATE     172799952.
          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      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  .69  .57  .67  .63  .74  .77  .82  .82  .90  .94  .64  .70
 .53  .48  .68  .89  .60  .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
60000000.102000000.144000000.144000000.
         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.
48.0 50.0 53.0 50.0 48.0 47.0 47.0
         1
        11      50.0
         2      32.0
  17280000.  17280000.
```

Run 3 Output Data

```
                EXAMPLE: NATURAL LAKE
            *********************************************************************************



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

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

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

STARTING DATE FOR THE RUN   5/ 1/1979


ETA= 0.300     BETA= 0.500

VERTICAL DIFFUSION COEFF.=    1.29000


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



STRATIFIED PORTION GEOMETRY

         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
```

```
***ELAPSED TIME=     8.000         NO. TIME STEPS=    8        DATE   5/ 9/1979


  METEOROLOGICAL DATA

        EQUILIBRIUM TEMPERATURE        70.4
        SOLAR RADIATION              2331.        ATMOS RADIATION            2428.       AIR TEMPERATURE          65.60
        REL HUMIDITY                 0.63      WIND SPEED                4.95     CLOUD COVER            0.10
        HEAT LOSS=        3933.

        POND   CUMULATIVE EVAP MASS LOSS
          1                    15810770.0


  VERTICALLY STRATIFIED REGION

        ENERGY RATIO=  0.9987

        COMPUTED SURFACE ELEVATION   99.98

        INFLOW    LEVEL   INFLOW TEMP   INFLOW RATE   MIXED TEMP
            1        15       51.80     17279984.0         60.06

        OUTFLOW   LEVEL  OUTFLOW TEMP  OUTFLOW RATE
            1        11       53.64     17279984.0

 J ELEV   TEMP      J ELEV   TEMP      J ELEV   TEMP      J ELEV   TEMP      J ELEV   TEMP      J ELEV   TEMP      J ELEV   TEMP
 1   0.0 48.00     11   50.0 53.71     21 100.0 67.05
 2   5.0 48.00     12   55.0 55.71
 3  10.0 48.01     13   60.0 57.85
 4  15.0 48.05     14   65.0 59.54
 5  20.0 48.17     15   70.0 60.61
 6  25.0 48.38     16   75.0 61.37
 7  30.0 48.73     17   80.0 62.04
 8  35.0 49.35     18   85.0 63.31
 9  40.0 50.34     19   90.0 65.27
10  45.0 51.70     20   95.0 67.05
```

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

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

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 ($\mathbb{P} \lesssim 0.5$), (2) shallow cooling ponds with longitudinal dispersion ($\mathbb{P} \gtrsim 0.5$; L/W $\gtrsim$ 4) and (3) shallow cooling ponds with lateral recirculation ($\mathbb{P} \gtrsim 0.5$; L/W $\lesssim$ 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

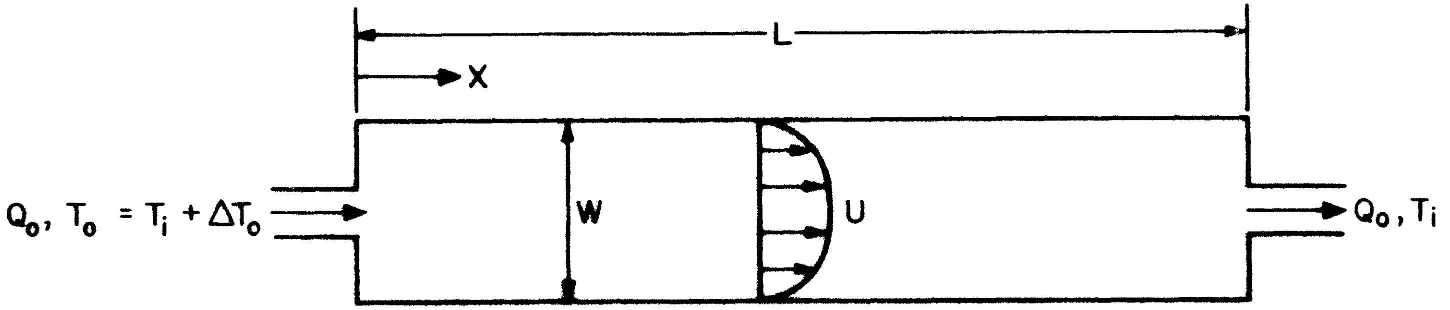

Figure 1 Plan View of Shallow Cooling Pond with Longitudinal Dispersion (Depth = H)

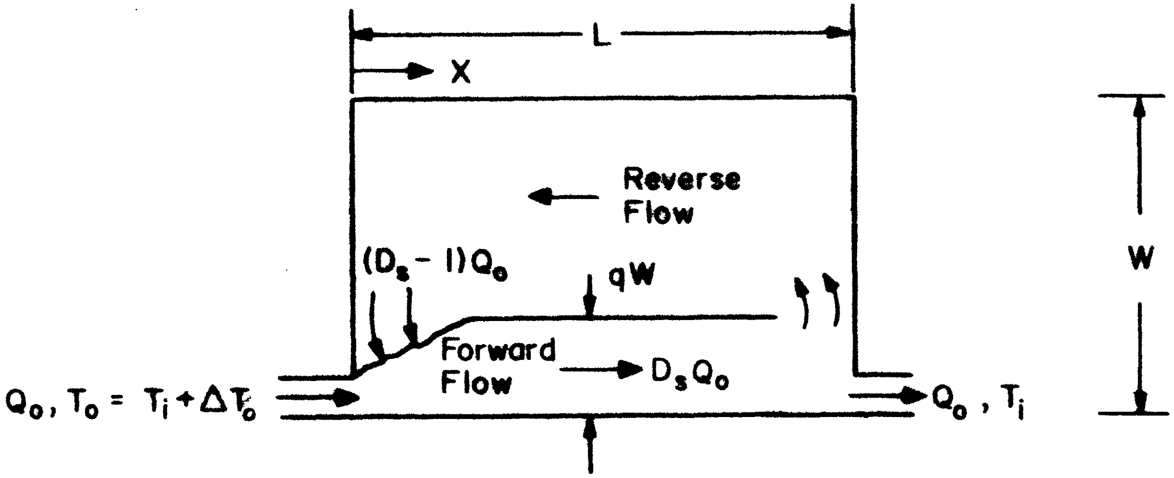

Figure 2 Plan View of Shallow Cooling Pond with Lateral Recirculation (Depth = H)

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 fraciton 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:

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

with boundary conditions

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

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

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

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

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

$$\phi_n = K(T - T_E) \tag{6}$$

and Eq. 2 is rewritten

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

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 significantly. 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

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

Similarly the equilibrium temperature is written

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

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

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

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

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

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

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

In Eq. 13 $r_1 = (1 + a)/(2E_L/UL)$, $r_2 = (1 - a)/(2E_L/UL)$, and $a = \sqrt{1 + 4KAE_L/\rho c Q_o UL}$. 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

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

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:

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

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 - nΔt 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

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

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 $K = 100 - 300$ BTU-ft^{-2}-°F^{-1}-day^{-1} (25-75 W-m^{-2}-°C^{-1}) and $H = 5$ to 12 ft. (1.5 to 4 m.), this constant ranges between about one day and one week which, significantly, is in the same range of time scales associated with synoptic weather changes. Coincidently 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

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

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

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

and

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

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

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

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

$$<y(t)> = \frac{1}{N} \sum_{n=0}^{N-1} y(t-n\Delta t) \qquad (20)$$

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

$$T(x,t) = T_{ss}(x,T_E(<\chi(t)>)) \qquad (21)$$

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

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

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

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

with

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

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

Boundary conditions for the two zones are

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

and

$$T_f(L,t) = T_r(L,t) \qquad (27)$$

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

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

and

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

with

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

and

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

The solution to this set of equations is

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

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

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

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

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 m^3/s) and ΔT_o = 20°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 $BTU\text{-}ft^{-2}\text{-}°F^{-1}\text{-}day^{-1}$ ($55\ W\text{-}m^{-2}\text{-}°C^{-1}$), 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

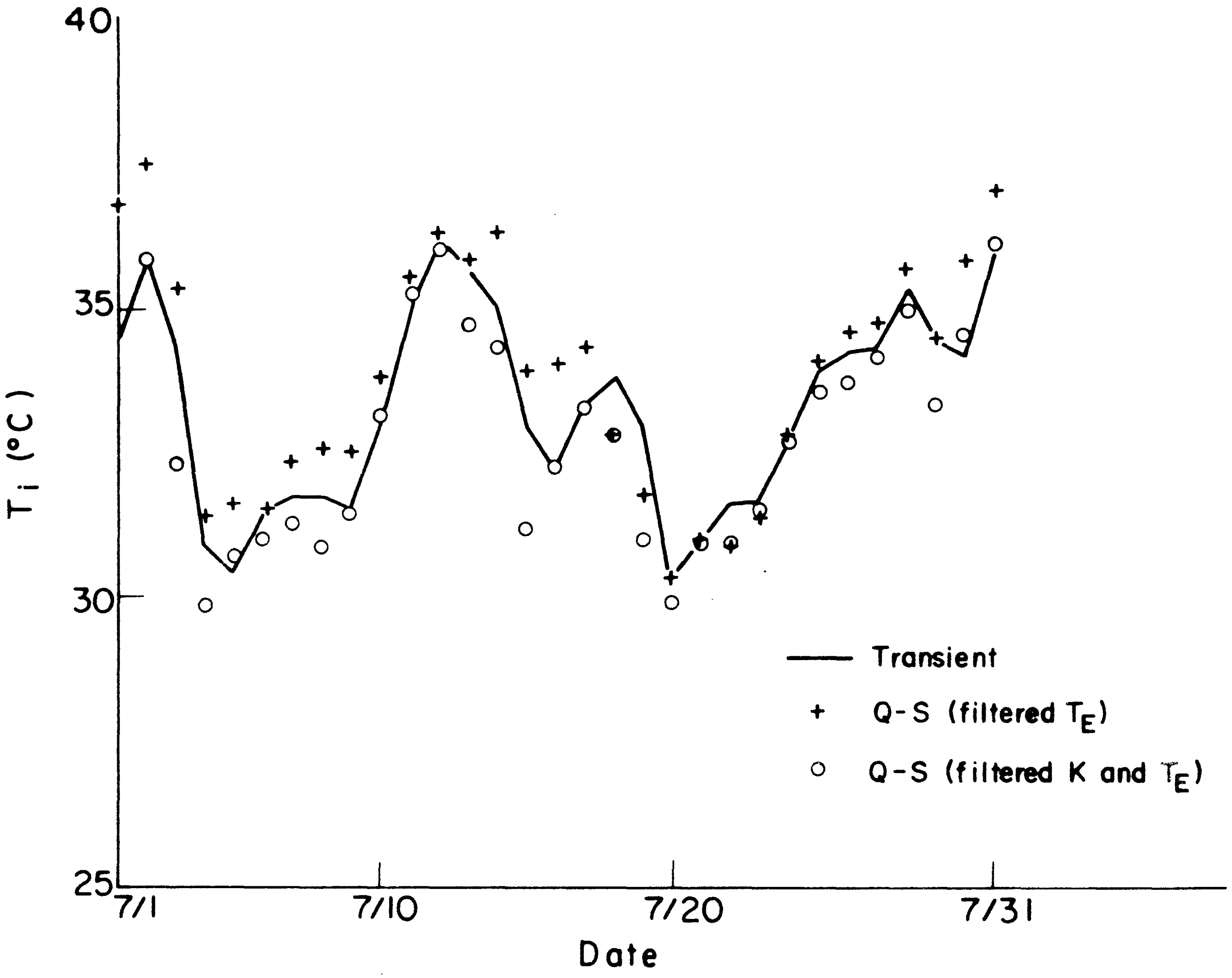

Fig. 3 Comparison of Transient and Quasi-Steady Models for July 1970

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 $K = 234$ BTU - ft^{-2}-$°F^{-1}$-day^{-1}(55 W-m^{-2}-$°C^{-1}$).

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, $T_E = 77°F(25°C)$ and $K = 234$ BTU-ft^{-2}-$°F^{-1}$-day^{-1}(55 W-m^{-2}-$°F^{-1}$), 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°F(4.6°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 $\rho cH/K$. This indicates that the main design variable affecting the transient response is the pond depth; variables characterizing the station heat rejection and the horizontal size and shape of the pond affect mainly the steady state response. In the case study example the transient response of a shallow, longitudinally dispersive, pond was shown to be as important as the variation in the steady state response which would result from various pond shapes ranging from those characterized by plug flow to those characterized by horizontally well-mixed conditions.

The transient models were than viewed as quasi-steady models in which steady state pond temperatures are computed as a function of filtered meteorology. For linear heat transfer, a constant heat transfer coefficient K is used while equilibrium temperatures T_E are filtered exponentially. Non-linear heat transfer can be treated by filtering both

K and T_E. Comparison of model results with those from the numerical model MITEMP with fully non-linear heat loss suggests that the simpler model, involving constant K and filtered T_E, provides acceptable results and errors on the conservative side of overpredicting extreme temperatures. More accurate, though not necessarily conservative, results are obtained with the non-linear approximation using filtered K and T_e. Acceptable results can also be obtained using a steady state model with averaged meteorology if an averaging interval of between one and two times the time constant $\rho cH/K$ 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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