NUREG-0733

Analysis of Ultimate-Heat-Sink Spray Ponds

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

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ABSTRACT

This report develops models which can be utilized in the design of certain types of spray ponds used in ultimate heat sinks at nuclear power plants, and ways in which the models may be employed to determine the design basis required by U.S. Nuclear Regulatory Commission Regulatory Guide 1.27.

The models of spray-pond performance are based on heat and mass transfer characteristics of drops in an environment whose humidity and velocity have been modified by the presence of the sprays. Drift loss from the sprays is estimated by a ballistics model.

The pond performance model is used first to scan a long-term weather record from a representative meteorological station in order to determine the periods of most adverse meteorology for cooling or evaporation. The identified periods are used in subsequent calculations to actually estimate the design-basis pond temperature. Additionally, methods are presented to correlate limited quantities of onsite data to the longer offsite record, and to estimate the recurrence interval of the design-basis meteorology chosen.

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Bill Nuttle (Massachusetts Institute of Technology) developed a large part of the meteorological scanning model for surface cooling ponds, which the author modified for spray ponds. He is also largely responsible for the drift-loss model.

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SYMBOLS

A = pond surface area, ft^2 or acres
A_c = total side area of the outermost segment, cm^2
A_d = cross-sectional area of the (assumed) spherical drop, cm
A_s = cross-sectional area of the spray field, cm^2
A_T = total area of top of spray field, cm^2
$A_{T,n}$ = top area of segment n, cm^2
$A_{T,N}$ = top area of segment N, cm^2
BDA = bone-dry air
C = cloud cover in tenths of the total sky obscured
C_d = drag coefficient for falling drops
C_p = heat capacity of water, cal/(gm °C)
C_{WA} = concentration of water in air in equilibrium at the temperature of the drop, gm water/cm^3 air
C_∞ = concentration of water in air in which the drop is immersed, gm water/cm^3 in air
= molecular diffusivity of air, cm^2/sec
D = drop diameter, cm
D_i = mean diameter, cm
D_3 = "Sauter" mean diameter, cm
$D_{\frac{1}{2}}$ = mean drop diameter for spray performance calculations, cm
drag = drag force, gm cm/sec^2
e_a = partial pressure of water vapor in the air, mm Hg
e_s = vapor pressure of water at the pond-surface temperature, mm Hg
E = equilibrium temperature, °F
ΔE = overall bias in pond temperature between the two data sets, °F
E_i = heat flowrate entering the segment, cal/sec
E_n = heat entering nth segment of sprays, cal/sec
f_i = fraction of drops in diameter range i whose diameter is D_i
F_b = buoyant force of rising air against the force of gravity, gm cm/sec^2
$F_{b,n}$ = buoyant force of rising air against force of gravity in segment n, gm cm/sec

$F(D)$ = probability density function for the drop-diameter distribution

$F_{d,n}$ = net drag force from falling droplets in segment n, gm cm/sec^2

$F(w)$ = wind function

g = acceleration of gravity, cm/sec^2

h_c = heat transfer coefficient for drop, cal/(sec cm^2 °C)

h_d = mass transfer coefficient for drop, cm/sec

h_n = heat flowrate of air leaving segment n, cal/sec

h_1 = heat flow rate of air leaving segment 1, cal/sec

H = humidity of air, gm water/cm^3 BDA

H_c = net rate of heat transfer from the pond due to conduction and convection, Btu/(ft^2 day)

H_n = humidity of air leaving segment n, gm water/gm BDA

H_0 = humidity of ambient air, gm water/gm BDA

$\dot{H}$ = rate of atmospheric heat transfer, Btu/(ft^2 day)

$\dot{H}_{AN}$ = net rate of longwave atmospheric radiation entering the pond, measured directly, Btu/(ft^2 day)

$\dot{H}_{BR}$ = net rate of back radiation leaving the pond surface, Btu/(ft^2 day)

$\dot{H}_C$ = net rate of heat flow from the pond due to conduction and convection, Btu/(ft^2 day)

$\dot{H}_E$ = net rate of heat loss due to evaporation, Btu/(ft^2 day)

$\dot{H}_{RJ}$ = net plant heat rejection, Btu/(ft^2 day)

$\dot{H}_{RJ,0}$ = steady-state heat load, Btu/(ft^2 day)

$\dot{H}_S$ = gross rate of solar radiation, Btu/(ft^2 day)

$\dot{H}_{SN}$ = net rate of shortwave solar radiation entering the pond, Btu/(ft^2 day)

$\dot{H}_{spray}$ = heat rejected by sprays, Btu/(ft^2 day)

I_i = evaporation from a single drop during its flight, gm

I_s = total daily solar radiation, Btu/(ft^2 day)

k = factor dependent on probability using Student's T distribution

k_a = thermal conductivity of air, cal/(cm sec °C)

K = equilibrium heat-transfer coefficient, Btu/(ft^2 hr °F)

m = mass of drop, gm

M = sample mean

$M_{i,n}$ = mass flowrate of water vapor entering segment n from the spray, from drops of diameter range i, gm/sec

M_n = total mass flowrate of water vapor entering segment n, gm/sec

M_w = molecular weight of water, 18 gm/gm mole

M_y = momentum of drop in vertical direction, gm cm/sec

$M_{y,i}$ = net downward momentum of the falling drops of diameter range i, gm cm/sec

p = atmospheric pressure, mm Hg

p_w = vapor pressure of water, mm Hg

P = probability

P_i = plotting position for ranked annual maximum values in probability coordinates

Pr = Prandtl number

q = evaporation rate, Btu/hr

$Q_{w,n}$ = flowrate of water into the nth section

Q = flowrate of water to spray field, cm^3/sec or ft^3/hr

ΔQ = evaporation correction factor, ft^3/hr

Q_A = flowrate of BDA, gm BDA/sec

$Q_{A,n}$ = flowrate of BDA leaving segment n, gm BDA/sec

$Q_{A,N}$ = net outward flowrate of BDA leaving the innermost segment N of the spray field, gm BDA/sec

$Q_{A,0}$ = quantity of BDA entering the first segment of the spray field, gm BDA/sec

$Q_{T,n}$ = quantity of BDA leaving top of segment n in LWS model, gm BDA/sec

r = drop radius, cm

r^2 = coefficient of determination

r_i = particular average radius of drop, cm

R_c = cooling range of the sprays

Re = Reynold's number of drop

R_g = universal gas constant, 82.02 cm^3 atm/(gm mole °K)

S = standard deviation

Sc = Schmidt number

t = time, sec or hr

t_f = time for drop to fall to water surface, sec

t_1 = one-half the length of daylight per day, hr

t_0 = time of the observation (in hours before or after midday)

T = temperature of drop, °C or °K

ΔT = correction factor for peak temperature

T_A = air temperature, °F or °C

$T_{A,0}$ = ambient air temperature, °C

T_{HOT} = temperature of the drop when it left the nozzle, °C or °F

T_{max} = highest observed value of pond water temperature, °F

T_{100} = 100-yr recurrence interval pond temperature, °F

T_s = pond surface temperature, °F

T'_s = pond ambient temperature, °F

ΔT_v = "virtual" temperature difference between the pond surface water and air above the pond, °F

$T_{w,n}$ = temperature of liquid water leaving segment n, °C

T_W = wet-bulb temperature, °F

$T_{w,1}$ = temperature of liquid water leaving segment 1, °F

u = velocity of drop in x direction, cm/sec

u' = ambient air velocity component, cm/sec

v = velocity of drop in y direction, cm/sec

v' = ambient air velocity component, cm/sec

v'_n = net upward- or downward-induced air velocity, cm/sec

V = absolute velocity of drop relative to air, cm/sec

V_h = humid volume of the ambient air, cm^3/gm BDA

$V_{h,N}$ = humid volume of the air in segment N, cm^3/gm BDA

V_i = volume of drop in size range i, cm^3

V_p = pond volume, ft^3

w = windspeed perpendicular to the pond, either naturally impinging or induced, cm/sec

w_0 = induced windspeed at the circumference, cm/sec

W = flowrate through pond or sprays, ft^3/hr

W_b = flowrate of the blowdown or leakage stream, ft^3/hr

W_{drift} = water loss attributable to drift, cm^3/sec

W_e = evaporation rate, ft^3/hr

W_l = total water loss attributable to sprays, cm^3/sec

W_{max} = maximum observed value of evaporation, ft^3/30 days

W_{100} = 100-yr recurrence interval 30-day evaporation, ft^3/30 days

W_{spray} = rate of water evaporated from all drops in the spray field, ft^3/hr

ΔZ = one-half the height of the spray field, cm

α = convergence parameter
η = spray efficiency
θ = excess temperature, °F
λ = heat of vaporization for water, cal/gm
μ = viscosity of air, gm/(cm sec)
ρ = density of water, lb/ft^3 or gm/cm^3
ρ_A = density of air , gm/cm^3
$\bar{\Delta}\rho_A$ = average density difference between the air in segment n and the ambient air, gm/cm^3
$\bar{\rho}_{A,n}$ = average density of the air in segment n, gm/cm^3
σ = standard error

ANALYSIS OF ULTIMATE-HEAT-SINK SPRAY PONDS

1 INTRODUCTION

The ultimate heat sink (UHS) is defined as the complex of cooling-water sources necessary to safely shut down and cool down a nuclear power plant. Cooling ponds, spray ponds, and mechanical draft cooling towers are some examples of the types of ultimate heat sinks in use today.

The U.S. Nuclear Regulatory Commission (NRC) has set forth in Regulatory Guide 1.27 (Ref. 1) the following positions on the design of ultimate heat sinks: (1) The ultimate heat sink must be able to dissipate the heat of a design-basis accident (for example, loss-of-coolant accident) of one unit plus the heat of a safe shutdown and cooldown of all other units it serves. (2) The heat sink must provide a 30-day supply of cooling water at or below the design-basis temperature for all safety-related equipment. (3) The system must be shown to be capable of performing under the meteorologic conditions leading to the worst cooling performance and the conditions leading to the highest water loss.

This report identifies methods that may be used to select the most severe combinations of controlling meteorological parameters for a spray-cooling pond of conventional design. The procedure scans a long-term weather record, which is usually available from the National Weather Service for a nearby station, and predicts the period for which either pond temperature or water loss would be maximized for a hydraulically simple spray pond. The principle of linear superposition is used to develop a procedure that allows the peak ambient pond temperature to be superimposed on the peak "excess" temperature, due to plant-heat rejection. This procedure determines the timing within the weather record of the peak ambient pond temperature. The true peak can then be determined in a subsequent, more-rigorous calculation.

Maximum 30-day water loss is determined directly from the scanning model.

The data-scanning procedure requires a data record on the order of tens of years to be effective. Since these data will usually come from somewhere other than the site itself (such as a nearby airport), methods to compare these data with the limited onsite data are developed so that the adequacy or at least the conservatism of the offsite data can be established. Conservative correction factors to be added to the final results are suggested.

These models and methods, provided as useful tools for UHS analyses of spray cooling ponds, are intended as guidelines only. Use of these methods does not automatically assure NRC approval, nor are they required procedures for nuclear-power-plant licensing. Furthermore NRC does not, by publishing this guidance, wish to discourage independent assessments of UHS performance or furtherance of the state of the art.

2 SPRAY-POND HEAT AND MASS TRANSFER PERFORMANCE MODELS

A set of models which consider the interaction of sprayed water with air in a spray pond has been developed to calculate cooling and water-loss performance. The models are developed along the line of other models of spray-pond performance (Refs. 2 and 3 and D. M. Myers, personal communication, 1976) and have been tested with field data on prototype ponds. These models form the bases of the analytical methods of spray-pond analysis.

The performance model is developed in two parts:

(1) A "microscale" submodel which considers the heat, mass, and momentum transfer of a single drop as it falls through the surrounding air.

(2) "Macroscale" submodels which consider the modification of the surrounding air resulting from the heat, mass, and momentum transfer from many drops in different parts of the spray field.

The microscale and macroscale submodels are combined into a model of performance of the entire spray field. This spray-field model may then be combined with a submodel of the pond itself to simulate the performance of the total UHS system.

2.1 Microscale Submodel

This portion of the model considers the heat, mass, and momentum transfer from a single water drop with the surrounding air.

2.1.1 Drop Motion

The motion of the drop after it leaves the spray nozzle is approximated by the classic ballistic problem as described in Figure 2.1. Drops leave the nozzle

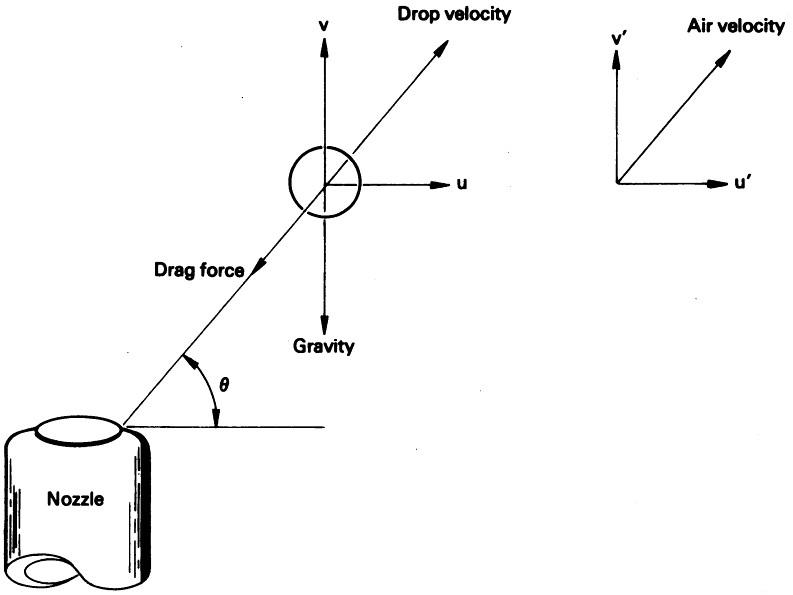

Figure 2.1 Ballistics of a drop leaving a spray nozzle

at an angle θ to the horizontal. After leaving the nozzle, the drop is subjected to the force of gravity and drag from the air. The motion of the drop is represented by the following differential equations:

$$\frac{du}{dt} = - \frac{C_d A_d \rho_A (u - u')V}{m} \tag{2.1}$$

$$\frac{dv}{dt} = - \frac{C_d A_d \rho_A (v - v')V}{m} - g \tag{2.2}$$

where

u = velocity of drop in x direction, cm/sec

v = velocity of drop in y direction, cm/sec

t = time, sec

C_d = drag coefficient for falling drops

A_d = cross-sectional area of drop, cm^2

ρ_A = air density, gm/cm^3

u', v' = ambient air velocity components, cm/sec

V = absolute velocity of drop relative to air

m = mass of drop, gm

g = acceleration of gravity, cm/sec^2

C_d, a drag coefficient for falling drops, is a function of Reynold's number Re. An approximation of C_d as a function of Re for rigid spheres is suggested by Bird, Stewart, and Lightfoot (Ref. 4):

For Re < 2

$$C_d = \frac{24}{Re} \tag{2.3}$$

For 2 < Re < 500

$$C_d = \frac{18.5}{Re^{0.6}} \tag{2.4}$$

For Re > 500

$$C_d = 0.44 \tag{2.5}$$

Reynold's number is defined in the following relationship:

$$Re = \frac{2rV\rho}{\mu}$$

where

r = drop radius, cm

μ = viscosity of air, gm/(cm sec)

and V and ρ are as previously defined.

2.1.2 Heat and Mass Transfer Relations

The falling drop exchanges heat and mass with the surrounding air. The rate of change of the drop's temperature may be expressed in terms of the following differential equation (Ref. 2):

$$\frac{dT}{dt} = - \frac{1}{\frac{4}{3}C_p \rho \pi r^3}\left[4\pi r^2 h_d\left(C_{WA} - C_\infty\right)\lambda + 4\pi r^2 h_c\left(T - T_{A,\infty}\right)\right] \qquad (2.6)$$

where

T = temperature of the drop, °C

C_p = heat capacity of water, cal/(gm °C)

ρ = density of water, gm/cm^3

h_d = mass transfer coefficient, cm/sec

C_{WA} = concentration of water in air in equilibrium at the temperature of the drop, gm water/cm^3 air

C_∞ = concentration of water in air in which the drop is immersed, gm water/cm^3 air

λ = heat of vaporization of water, cal/gm

h_c = heat-transfer coefficient, cal/(sec cm^2 °C)

$T_{A,\infty}$ = temperature of the air in which the drop is immersed, °C

and t and r are as previously defined.

The heat and mass transfer coefficients h_c and h_d, respectively, are based on the classic work of Ranz and Marshall (Ref. 5) on pendant drops. The heat-transfer coefficient h_c has been empirically determined to be:

$$h_c = \frac{k_a}{r}(1 + 0.3Pr^{1/3}Re^{1/2}) \text{ cal/(sec cm}^2\text{ °C)} \qquad (2.7)$$

where

k_a = thermal conductivity of air, cal/(sec cm °C)

Pr = Prandtl number

Re = Reynolds number

and h_c and r are as previously defined.

Similarly, the mass transfer coefficient has been empirically determined to be:

$$h_d = \frac{\mathcal{D}}{r}(1 + 0.3Sc^{1/3}Re^{1/2}) \text{ cm/sec} \tag{2.8}$$

where

$\mathcal{D}$ = molecular diffusivity of air, cm^2/sec

Sc = Schmidt number

and h_d, r, and Re are as previously defined.

The concentration C_∞ is determined from the ideal gas law:

$$C_\infty = \frac{p_w M_w}{R_g T} \tag{2.9}$$

where

p_w = vapor pressure of water, atm

M_w = molecular weight of water, 18 gm/gm mole

R_g = universal gas constant, 82.02 cm^3 atm/(gm mole °K)

T = absolute temperature of the drop, °K

and C_∞ is as previously defined.

The parameters ρ, μ, Pr, Sc, D and k_a (all previously defined) are thermodynamic properties of the air-water system. For the present purposes, these have been expressed by the following empirical relationships in terms of the absolute temperature of air, T_A, °K (Refs. 2 and 6):

$$\mu = 2.7936 \times 10^{-6}\, T_A^{0.73617} \text{ gm/(cm sec)} \tag{2.10}$$

$$\rho = 0.353\, T_A^{-1} \text{ gm/cm}^3 \tag{2.11}$$

$$Pr = 0.93176\ T_A^{-0.042784} \quad (2.12)$$

$$Sc = 2.2705\ T_A^{-0.21398} \quad (2.13)$$

$$\mathcal{D} = 5.8758 \times 10^{-6}\ T_A^{1.8615}\ \text{cm}^2/\text{sec} \quad (2.14)$$

$$k_a = 3.9273 \times 10^{-7}\ T_A^{0.88315}\ \text{cal/(cm sec °C)} \quad (2.15)$$

The vapor pressure of water may be expressed in terms of the absolute water temperature of the drop, T (^{o}K):

$$\begin{aligned} \ln p_w = {} & (71.02499 - 7381.6477/T - 9.0993037 \ln T \\ & + 0.0070831558\ T)\ \text{atm} \end{aligned} \quad (2.16)$$

2.1.3 Momentum Transfer

The falling water drops will impart momentum to the surrounding air because of drag. Since the spray from a single nozzle will be axially symmetrical, the net momentum in the x direction should be approximately zero.* In typical UHS designs the net momentum change in the vertical direction due to the drag from the drops will be in the downward direction. The net momentum is defined by the integral:

$$M_y = \int_0^{t_f} \frac{\text{drag}}{V}\, dt \quad \text{gm cm/sec} \quad (2.17)$$

where

t_f = time for drop to fall to water surface

drag = drag force, (gm cm)/sec^2

---

*In this analysis, oriented spray nozzles which are purposely arranged to induce a lateral flow are not considered.

2.1.4 Solution of Microscale Equations

The above equations are solved simultaneously with numerical integration in a fourth-order Runge-Kutta scheme. Mass, heat, and momentum transfer are calculated for a single drop, specifying as inputs the drop radius, the initial velocity from the nozzle, the spray angle, the height of the nozzle above the water surface, the sprayed temperature, and the temperature and humidity of the surrounding air. The outputs from this submodel are subsequently used in the macroscale submodel.

2.2 Macroscale Submodels

The performance of a single isolated spray nozzle might be adequately predicted by the microscale model alone. When many spray nozzles are arranged into a spray field, however, consideration must be given to the modification of the atmospheric environment in which the nozzle is immersed because of neighboring spray nozzles. The temperature and humidity of the air in the interior of a spray field are both raised and will lead to diminished spray performance with respect to an isolated nozzle in unaffected air. In addition, heated, humidified air is less dense than cooler, drier air. Therefore, it is likely that complicated convection currents will be generated, which may also be affected by the drag forces of the falling drops.

There are separate macroscale models dealing with high- and low-windspeed conditions. The high-speed model assumes that the momentum exchange in the pond due to drag and buoyancy are much less important than that due to the wind blowing through the spray field. The low-speed model assumes that the opposite is the case. The transfer of the air through the spray field is self-induced.

Both models are run at the same time in the simulation, since for some cases of high-heat loadings, natural convection might be greater than wind-induced convection. The higher performance model is then chosen as being representative of the spray field for that time interval.

2.2.1 High-Windspeed Submodel

The spray field is represented by a rectangular volume, in which the density of sprayed drops is great, as represented in Figure 2.2. The rectangular volume is divided into N equal segments. Each segment is then considered to be a compartment whose air temperature and humidity are determined by the preceding segment, as depicted in Figure 2.3.

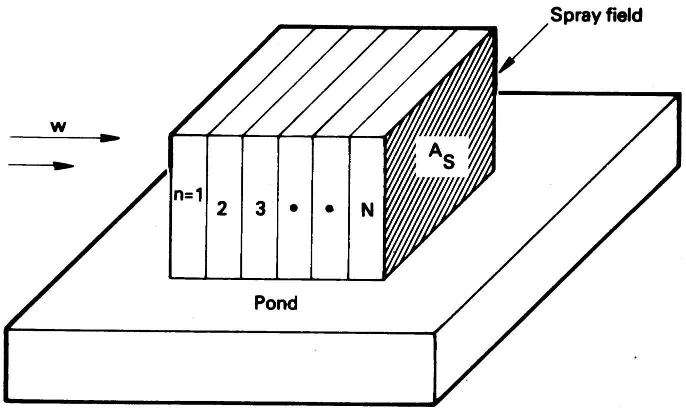

Figure 2.2 Segmentation of spray field for high-windspeed model

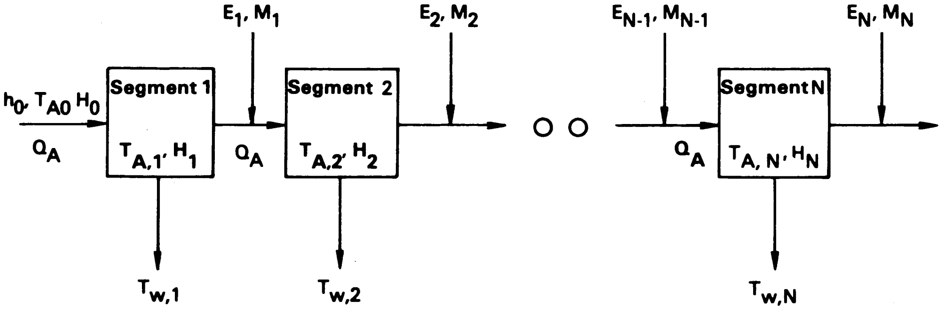

Figure 2.3 Compartment model of spray field for high windspeed

Ambient air of humidity H_0 (gm water/gm dry air) and temperature $T_{A,0}$ (°C) enters the first segment of the spray field at a volumetric rate wA_s cm³/sec, where w is the windspeed perpendicular to the long axis of the pond (cm/sec) and A_s is the cross-sectional area of the spray field (cm²). It is convenient to perform all mass and heat-transfer calculations on a "bone dry air" (BDA) basis (Ref. 6). The "humid volume" V_h is defined as the volume occupied by a parcel of air whose dry weight is 1 gm and at a pressure of 1 atm:

$$V_h = \left(81.86T_{A,0} + 22{,}387\right)\left(\frac{1}{29} + \frac{H_0}{18}\right) \text{ cm}^3/\text{gm BDA} \tag{2.18}$$

The quantity of BDA, Q_A, entering and passing through every segment of the pond (flow rate) is, therefore:

$$Q_A = w \times \frac{A_s}{\left(81.86T_{A,0} + 22{,}387\right)} \Bigg/ \left(\frac{1}{29} + \frac{H_0}{18}\right) \text{ gm BDA} \tag{2.19}$$

The concentration of water in air C_{WA} anywhere in the pond is related to the humidity H and temperature T_A by the relationship:

$$C_{WA} = \frac{H}{\left(81.86T_A + 22{,}387\right)\left(\frac{1}{29} + \frac{H}{18}\right)} \text{ gm water/cm}^3 \text{ wet air} \tag{2.20}$$

For a particular segment n, it can be assumed that the humidity and air temperature are determined only by what left the segment upwind, providing that all other parameters of the system, such as initial drop velocity, spray angle, nozzle height, and hot-water temperature, are known. Subroutine SPRAY is then called several times for each segment n or to solve the microscale equations of heat and mass transfer from drops over a range of radii whose distribution is typical of the particular nozzle design employed.

For drops of a particular average radius r_i (cm), the heat entering the segment, E_i, is proportional to the fraction of drops in that diameter range (diameter D_i); f_i, the flowrate of water into the nth section q_{wn}; and the difference between the temperature of the drop when it left the nozzle, T_{HOT}, and when it reached the pond surface, T_i(°C):

$$E_i = \rho C_p q_{wn} f_i \frac{T_{HOT} - T_i}{\frac{4}{3}\pi r_i^3} \text{ cal/sec} \tag{2.21}$$

The total rate of heat entering pond segment n is therefore:

$$E_n = \sum E_i = \frac{\rho C_p Q_{wn}}{\frac{4}{3}\pi} \sum_{i=1}^{j} \frac{T_{HOT} - T_i}{f_i r_i^3} \text{ cal/sec} \tag{2.22}$$

where j is the number of drop-diameter ranges used.

The heat flowrate in the air leaving segment n (and entering segment n + 1) is therefore:

$$h_{n+1} = h_n + E_n \text{ cal/sec} \tag{2.23}$$

where h_n = heat flow rate leaving segment n, cal/sec.

Liquid water leaving the segment is of temperature:

$$T_{w,n} = \sum_{i=1}^{j} f_i T_i \text{ °C} \tag{2.24}$$

For drops of a particular average radius r_i (cm), the mass flowrate entering the segment from the sprays will be:

$$M_{i,n} = \frac{f_i q_{wn} I_i}{\frac{4}{3}\pi r_i^3} \text{ gm/sec} \tag{2.25}$$

where I_i is the evaporation from a single drop during its flight, in grams.

The total mass flowrate of water vapor entering segment n is therefore:

$$M_n = \sum_{i=1}^{j} M_{i,n} = \frac{3q_{wn}}{\frac{4}{3}\pi} \sum_{i=1}^{j} \frac{f_i I_i}{r_i^3} \text{ gm/sec} \qquad (2.26)$$

Adding M_n gm/sec of water vapor to the air leaving the segment n increases the humidity of segment n + 1 by the following amount:

$$H_{n+1} = H_n + \frac{M_n}{Q_A} \text{ gm water/gm BDA} \qquad (2.27)$$

The temperature of the air leaving one segment and entering the next reflects the added heat and moisture:

$$T_{A,n+1} = \frac{\frac{h_{n+1}}{Q_A} - H_{n+1}\lambda}{0.24 + 0.45\, H_{n+1}} \quad {}^\circ\text{C} \qquad (2.28)$$

Calculations continue with segment n + 1, and step through all pond segments.

The properties of the air in the first segment are determined by the ambient air temperature $T_{A,0}$ and humidity H_0:

$T_{A,1} = T_{A,0}$ °C

$H_1 = H_0$ gm water/gm BDA

$$h_1 = Q_A\left[0.24T_{A,0} + H_0\left(\lambda \pm 0.45T_{A,0}\right)\right] \text{ cal/sec} \qquad (2.29)$$

The total cooling performance of the spray field is simply the average cooling from all sections:

$$\text{Range} = \frac{\sum_{n=1}^{N} q_{wn}\left(T_{HOT} - T_{w,n}\right)}{\sum_{n=1}^{N} q_{w,n}} \; {}^{\circ}C \qquad (2.30)$$

Cooling performance may also be expressed in terms of "efficiency" of approach to wet-bulb temperature:

$$\eta = \frac{\text{range}}{\left(T_{HOT} - T_{W}\right)} \times 100 \quad \text{percent} \qquad (2.31)$$

2.2.2 Low-Windspeed Macroscale Submodel

At low ambient windspeeds, the flow of air through the spray field is largely controlled by two mechanisms: drag from the spray droplets and buoyancy of the heated, humidified air. Since the spray-field arrangements in most conventional spray fields are already evenly distributed and symmetrical, it would appear that there would be little net effect of the spray droplet drag in the lateral direction. There would be a net downward drag due to the falling drops.*

In a conventional spray pond under loads typical of UHS service, buoyancy is the dominant force in the low-windspeed case.

For the low-windspeed model, the spray field is sectioned into N rectangular cylinders of equal volume as shown in Figure 2.4 (Ref. 3 and D. M. Myers, personal communication, 1976). Air enters the segment from all four sides,

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*However, at least one spray-equipment manufacturer, Ecolaire (Ref. 7), is marketing an oriented spray-field arrangement which induces the circulation of air laterally.

and leaves the segment to enter the next segment after being heated and humidified by the sprays. Unlike the high-windspeed model, however, air also leaves through the top of the segment because of buoyancy. Each segment is then considered to be a compartment whose air temperature, humidity, and air-flow rate are determined by the heat and mass transfer of the segment itself and the previous and next segments as depicted in Figure 2.5.

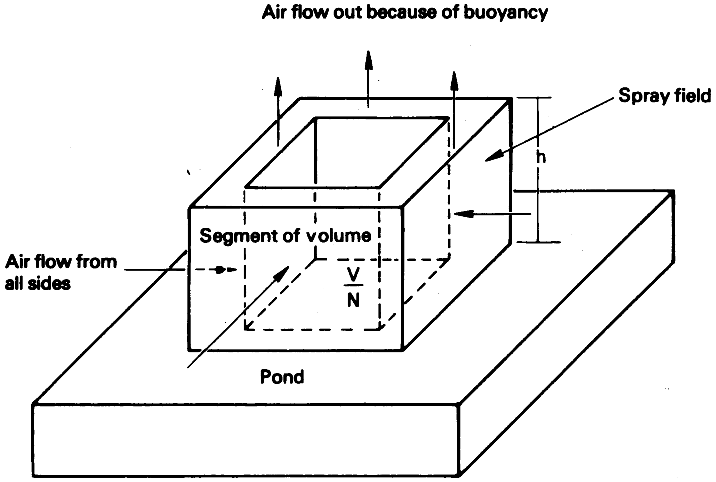

Figure 2.4 Segmentation of spray field for low-windspeed model

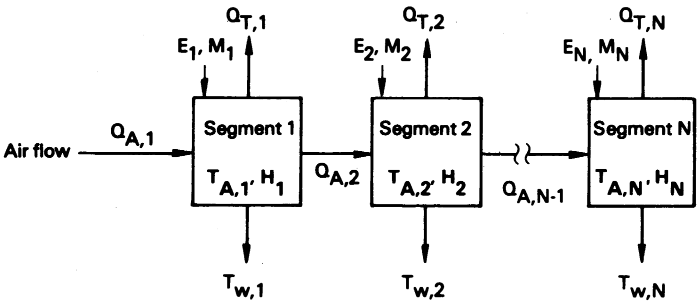

Figure 2.5 Compartment model of spray field for low windspeed

2.2.2.1 Material and Energy Balances of Segment n

If a control volume is drawn around segment n, the relationships between the air and water streams can be defined. The flow of air is described on a BDA basis:

$Q_{A,n}$ = air leaving segment n = $Q_{A,n+1} + Q_{T,n}$ gm BDA/sec (2.32)

and the water vapor entering segment n will be:

$$M_n = \frac{3q_{wn}}{4\pi} \sum_{i=1}^{j} \frac{f_i I_i}{r_i^3} \text{ gm/sec} \tag{2.33}$$

Adding M_n gm/sec of water vapor to the air leaving segment n increases the humidity of segment n + 1:

$$H_{n+1} = H_n + \frac{M_n}{Q_{A,n}} \tag{2.34}$$

The temperature of the air leaving segment n and entering the next is modified by the added heat and moisture:

$$T_{n+1} = \frac{\frac{h_{n+1}}{Q_{A,n}} - H_{n+1}\lambda}{0.24 + 0.45\, H_{n+1}} \quad {}^\circ\text{C} \tag{2.35}$$

where λ = heat of vaporization, cal/gm.

The quantity of BDA entering the first segment Q_{A_0} of the spray field is defined to be:

$$Q_{A_0} = \frac{w_0 \times A_c}{\left(81.86T_{A,0} + 22{,}387\right)\left(\frac{1}{29} + \frac{H_0}{18}\right)} \text{ gm BDA/sec} \tag{2.36}$$

where

w_0 = induced windspeed at the circumference, cm/sec

A_c = total side area of the outermost segment, cm²

and $T_{A,0}$ and H_0 are as previously defined.

Air leaving the last segment can leave only through the top, so:

$$Q_{A,N} = 0 \tag{2.37}$$

2.2.2.2 Momentum Balance

The movement of air and water vapor through the spray field is controlled by complicated aerodynamic effects. In the grossest sense, however, a balance of vertical momentum, i.e., Bernoulli's equation (Ref. 4), can be used to represent the movement of air streams. For any segment n,the vertical momentum of the entering and leaving streams of air is defined by the following equations:

<u>(1) Force of air leaving top of segment</u>:

$$v_n'^2\bar{\rho}_{A,n}A_{T,n} \tag{2.38}$$

where

v_n' = upward velocity of the air in segment n, cm/sec

$\bar{\rho}_{A,n}$ = average density of the air in segment n, gm/cm³

$A_{T,n}$ = top area of segment n, cm²

<u>(2) The buoyant force of rising air against the force of gravity in segment n</u>:

$$F_{b,n} = A_{T,n}g\overline{\Delta\rho}_{A,n}\Delta Z \text{ gm cm/sec}^2 \tag{2.39}$$

where

$\overline{\Delta\rho}_{A,n}$ = average density difference between the air in segment n and the ambient air, gm/cm³

ΔZ = one-half the height of the spray field, cm

and $A_{T,n}$, g, and $\bar{\rho}_{A,n}$ are as previously defined.

2.2.2.3 Net Drag Force From Falling Droplets in Segment n

$$F_{d,n} = \sum_i \frac{f_i M_{y,i} Q}{V_i A_T} \text{ gm cm/sec}^2 \qquad (2.40)$$

where

$M_{y,i}$ = net downward momentum of each of the falling drops in diameter range i (from Eq. 2.17), gm cm/sec

Q = flowrate of water to spray field, cm^3/sec

V_i = volume of drop in size range i, cm^3

A_T = total top surface area of the spray field, cm^2

The net upward or downward air velocity of the air in segment n, v'_n (cm/sec) is found by solving one of the following two expressions:

$$v'_n = \sqrt{(F_{b,n} + F_{d,n})/\rho_A} \text{ if } (F_{b,n} + F_{d,n}) > 0 \qquad (2.41)$$

for upward velocity or

$$v'_n = -\sqrt{-(F_{b,n} + F_{d,n})/\rho_A} \text{ if } (F_{b,n} + F_{d,n}) < 0 \qquad (2.42)$$

for downward velocity.

2.2.2.3 Solving for Air Flow

The velocity of air leaving each segment is calculated at each iteration based on the temperature and humidity of the segments in the previous iteration. The calculation of mass transport through the spray field starts at the innermost segment. The net outward flowrate of BDA leaving the innermost segment N of the spray field is:

$$Q_{A,N} = \frac{v'_N A_{T,N}}{V_{h,N}} \text{ if } v'_N \text{ is positive} \qquad (2.43)$$

$$Q_{A,N} = \frac{v'_N A_{T,N}}{V_h} \text{ if } v'_N \text{ is negative} \tag{2.44}$$

where

$A_{T,N}$ = top area of segment N, cm^2

$V_{h,N}$ = humid volume of the air within segment N, cm^3/gm BDA

V_h = humid volume of the ambient air, cm^3/gm BDA

and v'_N is as previously defined.

The flowrate of BDA for all other segments $Q_{A,n}$ is calculated by stepping from the innermost segment outward:

$$Q_{A,n} = Q_{A,n+1} + \frac{v'_n A_{T,n}}{V_{h,n}} \text{ if } v'_n \text{ is positive} \tag{2.45}$$

$$Q_{A,n} = Q_{A,n+1} + \frac{v'_n A_{T,n}}{V_h} \text{ if } v'_n \text{ is negative} \tag{2.46}$$

The temperature and humidity in each segment are next recomputed based on the new estimate of flowrate of BDA starting with the outermost segment and working in. The enthalpy of air entering the first segment is simply that of the ambient air H_0.

2.2.2.4 Convergence of Iterative Solution

The computations for the LWS (low-windspeed) model outlined above are iterative. The flowrate of air and water vapor depends on the computed temperature and humidity in each segment. Conversely, the temperature and humidity depend on the flow of air through the spray field. The computations proceed iteratively until the differences of temperature, humidity, and air flow between two computations are smaller than a certain tolerance.

Under certain circumstances, convergence may be very difficult. For example, a poor initiation of the computation may cause the first calculated flowrates to be very small, which in turn would cause the subsequently calculated temperatures to be very large. Because the equations are highly nonlinear, a wide initial oscillation may drive the iterative calculations beyond the region of convergence and into a region of divergence where the solution will degenerate or "blow up."

Other factors contribute to the divergence of the solution of the LWS model. The effect of the downward drag of falling drops seems to destabilize the calculation, especially if the net flow from any segment were to be downward instead of upward.

2.2.2.5 Measures To Aid Convergence

It is possible to assure convergence of the LWS model in almost every case by imposing several computational restrictions:

(1) Allow only positive (upward) air flow from each segment.
(2) Eliminate vertical drag as a force in the momentum balance.
(3) Introduce "damping" to smooth out oscillations.

Steps 1 and 2 above are compromises which could affect the computation accuracy. The effect of these restrictions on the resultant performances is shown later to be minor and in fact appears to improve the model's comparison to field data.

Damping is a computational trick which has the effect of smoothing large oscillations, but whose influence disappears at steady state (Ref. 8). The temperature and humidity in the ith segment are damped in the following manner:

$$T_{A,i}^{k'} = T_{A,i}^{k} - \alpha \left(T_{A,i}^{k-2} - 2T_{A,i}^{k-1} + T_{A,i}^{k}\right) \tag{2.47}$$

$$H_{i}^{k'} = H_{i}^{k} - \alpha \left(H_{i}^{k-2} - 2H_{i}^{k-1} + H_{i}^{k}\right) \tag{2.48}$$

where

$T_{A,i}^{k'}$ = smoothed value of air temperature in the segment $T_{A,i}^{k}$

$H_i^{k'}$ = smoothed value of the humidity in the segment H_i^k

α = convergence coefficient. Typically, its value should be about 0.05 to 0.1, but other values may be used.

The superscript k represents the present iteration; the superscripts k - 1 and k - 2 represent the previous two iterations, respectively.

An example of the effect of damping is illustrated in Figure 2.6. The temperature of the innermost segment oscillates around the steady-state value, but appears to converge faster with damping. The results for the damping case are identical until the third iteration since the damping factor depends on having results from two previous iterations.

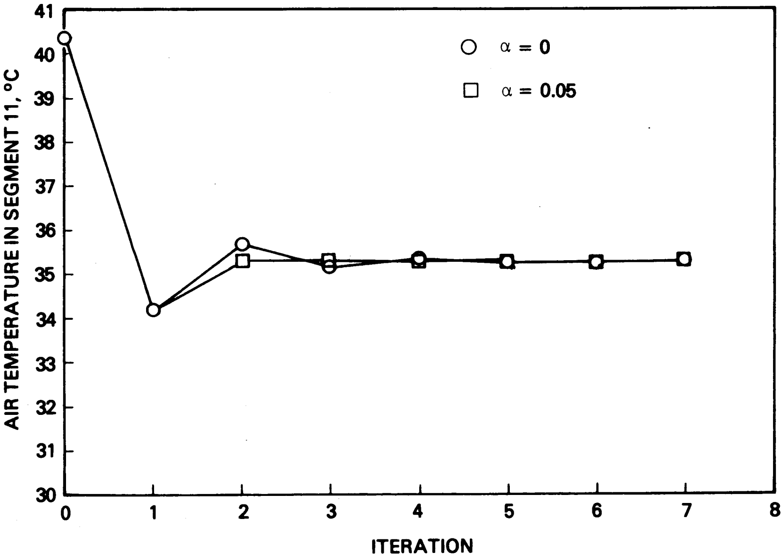

Figure 2.6 Convergence of low-windspeed model with and without damping

2.3 Comparison With Field Data

The results of the spray performance models were compared with available data on spray-pond performance.* Two sets of data were generally available at the

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*Actually, the "mean drop diameter" simplification was taken, as developed in Section 3, but the results are shown to be nearly identical.

time the comparison was made: (a) the Canadys test data (Ref. 9), and (b) the Rancho Seco spray-pond confirmatory tests (Ref. 10). Both data sets considered only the instantaneous cooling of the sprays, and did not attempt to include other heat-transfer mechanisms, such as cooling from the pond surface. The Canadys data were gathered on an operating spray-cooling pond used for condensor cooling at a fossil-fuel electric station in South Carolina. The Rancho Seco data were gathered at an actual UHS spray pond in California during a preoperational test requested by the NRC. The Rancho Seco tests were designed specifically to determine the performance of the spray field, while the Candys tests considered the performance of the pond as a whole, including heat transfer from the pond's surface. The Rancho Seco data are more appropriate for the present comparison.

2.3.1 Canadys Data Comparison

The Canadys spray pond is shown in Figure 2.7. Not all of the information on the basic physical parameters of the Canadys spray pond could be found, and some parameters had to be inferred. For example, the height of the nozzles, the height of the sprayed water, the nozzle distribution, and the drop-diameter

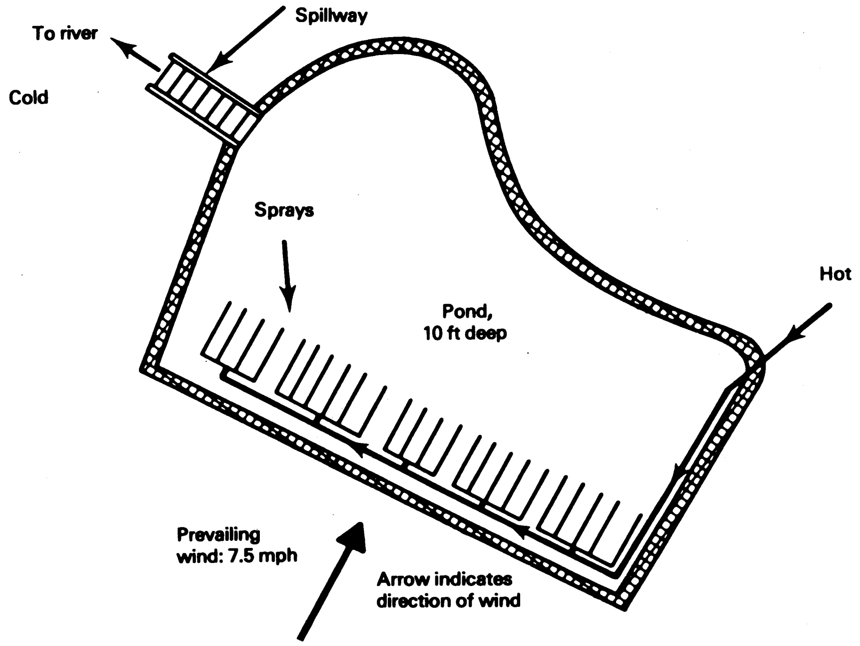

Figure 2.7 Canadys spray-cooling pond

distribution of the sprays (in 10 divisions shown in Table 2.5) were taken as those for the Spraco 1751 nozzle and recommended layout, although the design probably was somewhat different (Ref. 11). It should be noted that the performance models can be used with any nozzle as long as the drop-diameter distribution is known. Necessary pond parameters are shown in Table 2.1. Table 2.2 contains the measured atmospheric variables and pond performance in terms of spray efficiency η, as well as the predicted performance from the HWS model. Figure 2.8 plots the predicted efficiency versus the measured efficiency. There is a great deal of scatter evident from Figure 2.8, but the points distributed on the diagonal, indicating no systematic bias.

Table 2.1 Physical Characteristics of Canadys Spray Pond Used in Spray-Field Model

Variable	Measurement
Length of spray field	304.8 m
Width of spray field	30.48 m
Height of spray field	3.66 m
Initial drop velocity	6.67 m/sec
Angle of drop with respect to horizon	76°
Height of nozzles from water surface	1.52 m
Barometric pressure	29.92 in. Hg
Flowrate through all nozzles	11,400 liters/sec

It should be noted that the Canadys pond has a sprayed-water loading about twice that recommended by spray-nozzle manufacturers. The cooling efficiency of this pond and that predicted by the NRC model were well below the efficiencies predicted by conventional techniques before the pond was constructed.

2.3.2 Rancho Seco Data

The Rancho Seco pond is shown in Figure 2.9. This pond incorporates a standard Spraco design for spray configuration and the employment of the 1751 nozzle. Most operational characteristics of the pond were well documented. The basic

Table 2.2 Measured Atmospheric Parameters and Spray Efficiency, and Efficiency Predicted From High-Windspeed Model With Drag Terms Included

T_w-°C	T_A,°C	T_{HOT},°C	w, cm/sec	$\eta_{measured}$	$\eta_{predicted}$
25.4	30.4	43.6	163.2	0.443	0.250
27.1	35.6	45.0	244.8	0.248	0.334
27.1	34.6	44.7	204.0	0.279	0.301
23.2	24.7	44.2	244.8	0.275	0.310
25.8	27.2	41.7	201.0	0.346	0.279
26.1	30.3	42.8	191.0	0.270	0.276
26.1	31.7	43.6	201.0	0.325	0.288
24.2	27.5	43.3	163.2	0.257	0.244
26.6	31.3	42.2	175.9	0.320	0.261
25.4	28.5	44.2	163.2	0.252	0.253
26.8	31.1	43.6	226.1	0.265	0.312
25.6	35.2	45.3	163.3	0.198	0.257
26.6	30.9	45.6	276.4	0.263	0.353
27.4	34.1	44.4	271.0	0.351	0.350
25.4	36.7	45.6	246.4	0.252	0.328
26.5	36.1	44.4	246.4	0.302	0.329
21.3	25.8	43.9	427.2	0.339	0.378
22.1	25.0	44.4	305.1	0.372	0.339
21.6	24.3	43.9	276.4	0.343	0.319
20.8	24.4	44.4	226.1	0.335	0.288
16.8	21.7	36.1	376.9	0.346	0.305
17.8	24.7	37.8	414.6	0.275	0.330
18.5	25.6	38.3	194.8	0.287	0.229

physical parameters for the pond are given in Table 2.3. The measured meteorological variables and spray performance (in terms of efficiency η) are shown in Table 2.4, as well as the NRC model predictions. Figure 2.10 shows the predicted efficiency versus the measured efficiency.

The scatter is much smaller than in the comparison of the model to the Canadys data. This is probably an indication that the experiments were conducted more carefully at Rancho Seco. The NRC model clearly underpredicts the efficiency, and should, therefore, be considered conservative for temperature computations.

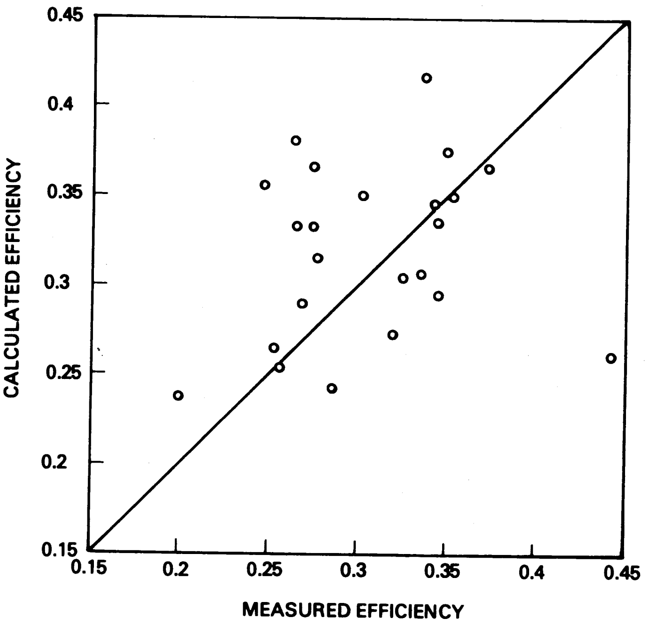

Figure 2.8 Measured and predicted performance of Canadys pond, complete spray model (high windspeed)

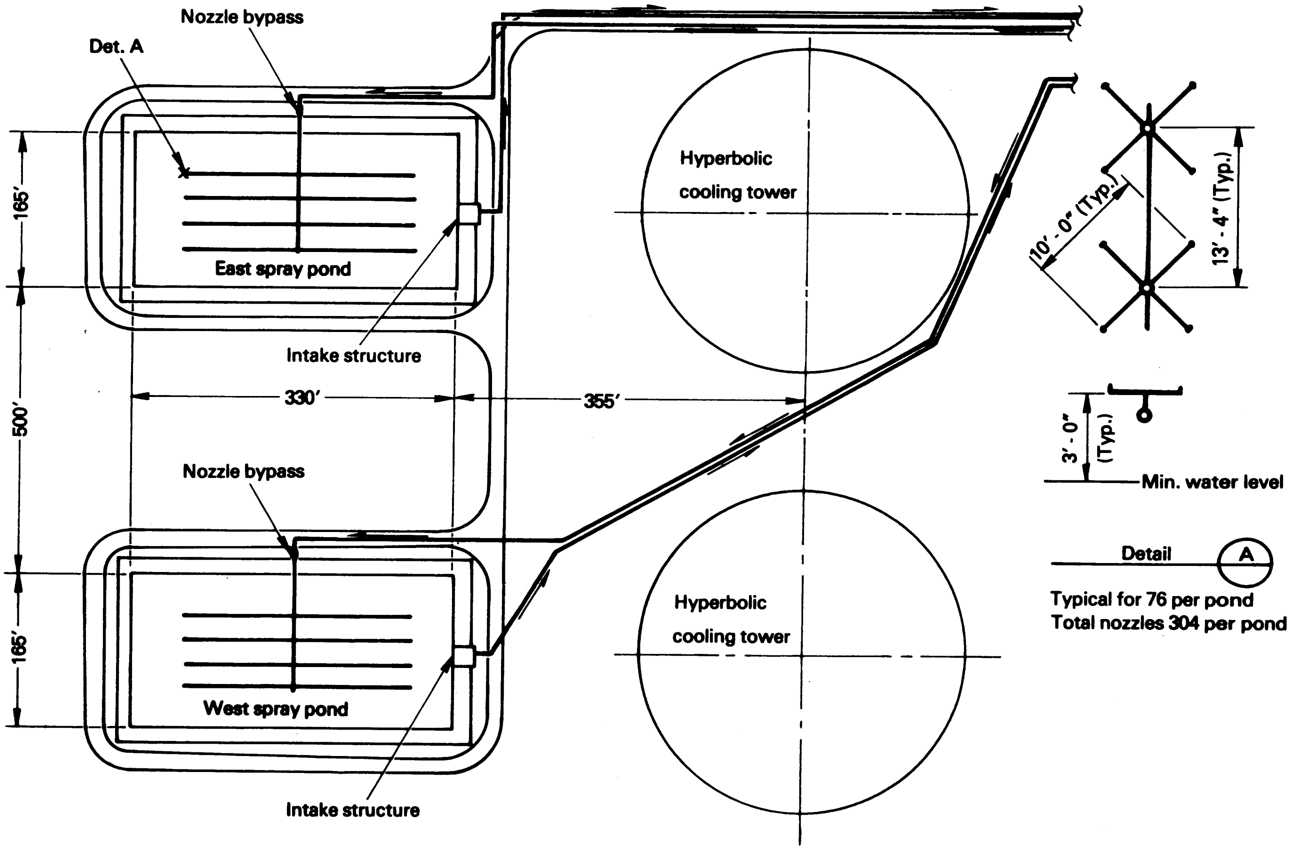

Figure 2.9 Rancho Seco spray-cooling ponds (not to scale)

Table 2.3 Physical Characteristics of Rancho Seco Spray Pond Used in Spray-Field Model

Variable	Measurement
Length of spray field	84.8 m
Width of spray field	35.1 m
Height of spray field	3.66 m
Initial drop velocity	6.67 m/sec
Angle of drop with respect to horizon	76°
Height of nozzles from water surface	1.52 m
Barometric pressure	29.92 in. Hg
Flowrate through all nozzles	1590 liters/sec

Table 2.4 Measured Atmospheric Parameters and Spray Efficiency, and Efficiency Predicted From Combined High-Windspeed and Low-Windspeed Model With and Without Drag Terms Included

T_W, °C	T_A, °C	T_{HOT}, °C	w, cm/sec	$\eta_{measured}$	$\eta_{calculated}^{*}$	$\eta_{calculated}^{**}$
16.1	27.5	26.6	581.8	0.417	0.383	0.415
16.4	27.2	26.7	558.8	0.475	0.381	0.414
10.6	12.8	25.2	236.9	0.325	0.259	0.276
9.2	11.1	25.2	44.7	0.288	0.248	0.277
13.6	18.3	25.3	268.2	0.309	0.287	0.307
14.2	21.7	25.9	290.6	0.355	0.303	0.324
22.4	35.0	26.7	312.9	0.389	0.398	0.423
20.9	33.9	27.3	295.0	0.343	0.368	0.391
19.2	29.8	27.1	375.5	0.458	0.373	0.400
16.1	22.4	26.8	169.9	0.345	0.256	0.261
15.7	20.7	26.5	169.9	0.285	0.250	0.270
12.3	14.4	38.6	44.7	0.352	0.324	0.350
11.7	13.9	37.8	71.5	0.362	0.318	0.348
11.1	13.3	36.6	58.1	0.344	0.310	0.340
9.4	11.7	38.7	44.7	0.345	0.315	0.340
8.9	10.6	36.3	17.9	0.346	0.302	0.330

*With drag terms.
**Without drag terms.

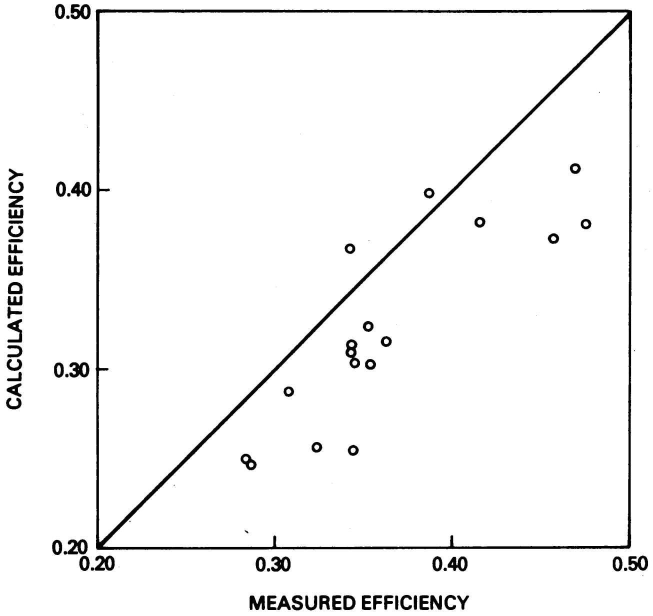

Figure 2.10 Measured and predicted performance of Rancho Seco pond, complete spray model (with drag terms)

2.4 Simplifying Assumptions for Performance Models

The microscale model of the falling drop has been formulated in considerable detail. The possibility of simplifying this facet of the model is explored by starting with a more complete numerical solution of the falling drop and comparing the results to simplified versions of the model (for example, by eliminating one or more terms from the equations). If the results using the simplified model can be shown to be acceptable, substantial reductions in computing time can be realized. In addition, troublesome aspects of the computations can be eliminated if it can be shown that their effects on the performance of the model are negligible.

2.4.1 Simplification for Average Drop Diameter

The motion of the drop and its heat, mass, and momentum-transfer properties depend strongly on its diameter. The drop-diameter distribution in 10 divisions for the Spraco 1751A nozzle is illustrated in Table 2.5. As suggested in

Table 2.5 Drop-Diameter Distribution for Spraco 1751A Nozzle

Diameter, cm.	Percent of total	Cumulative volume, %
0.075	10	10
0.12	10	20
0.15	10	30
0.184	10	40
0.22	10	50
0.245	10	60
0.27	10	70
0.31	10	80
0.36	10	90
0.45	10	100

Source: Summarized from Reference 3.

Section 2.1, the heat, mass, and momentum transfers in any segment of the pond can be found by integrating the contributions over the range of drop diameters. In practice, the drop-diameter distribution may be broken up into j diameter ranges and the contribution from each diameter range summed to get the average. For example, the average drop temperature T is:

$$T = \sum_{i=1}^{j} f_i T_i \quad {}^\circ C \tag{2.49}$$

The problem with this approach is that there must be a solution of the equations for each of the j drop diameters. If instead, a single average drop diameter could be found, which gave the same results as the summation of the results for the j individual drop diameters, the computational effort would be reduced by a factor of about 1/j.

It is not obvious that an average drop diameter exists which would consistently duplicate the performance of the spray model using the distributed drop-diameter formulation. In order to test the theory that an acceptable mean diameter could be used, the HWS and LWS models were run over a wide range of conditions, using an observed drop-diameter distribution. The resulting performances were then compared to the results of the HWS and LWS models using a single drop diameter over the same range of conditions.

In all cases for which it was tested, it appears that a single average drop diameter can be chosen to very nearly represent the drop-diameter distribution over a wide range of operation for both the LWS and HWS models. Figures 2.11 and 2.12 illustrate that for the HWS and LWS models, the "average" drop diameter which gives results closest to the distributed drop for the Spraco 1751 nozzle is about 0.208 cm for the LWS model and 0.196 cm to 0.202 cm for the HWS model. Figure 2.13 demonstrates for the HWS model how closely the "average drop diameter" model compares to the "distributed drop diameter" model.

2.4.1.1 Estimating the Average Drop Diameter

The average diameter illustrated above was determined by experimentation with the model on a single drop-diameter distribution and spray-pond configuration. It is difficult to generalize how one would estimate the average drop diameter under completely general conditions, except to illustrate how well the empirically determined average diameter works over a wide range of conditions for both the HWS and LWS spray-pond models.

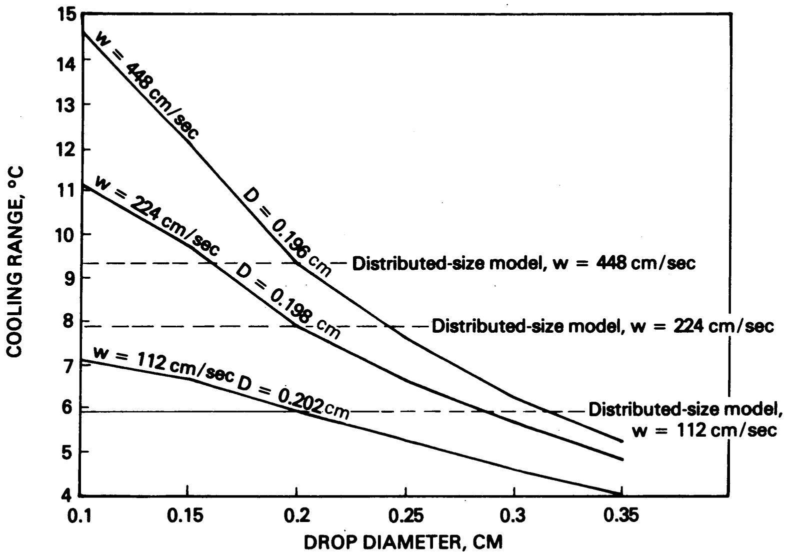

Figure 2.11 Determination of "average drop diameter" for high-windspeed model

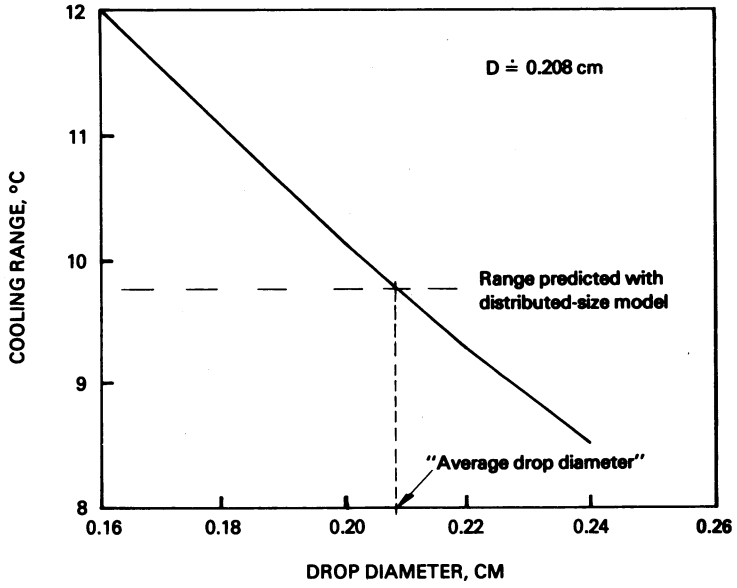

Figure 2.12 Determination of "average drop diameter" for low-windspeed model

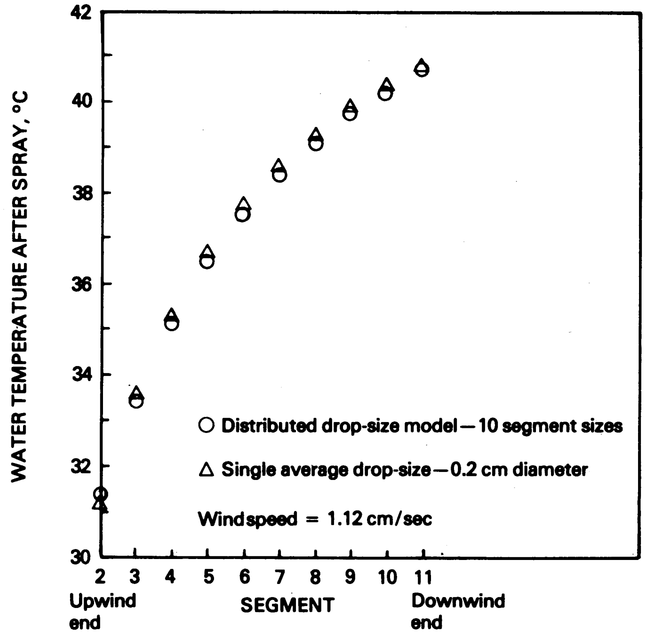

Figure 2.13 Performance of high-windspeed model for mean and distributed drop diameter

A formula which has been developed on physical principles to represent the mean drop diameter in heat and mass transfer from drops is the "Sauter" mean (Ref. 12), which is based on an area-weighted mean volume:

$$D_3 = \frac{\int_0^\infty D^3 F(D)}{\int_0^\infty D^2 F(D)} \doteq \frac{\sum_{i=1}^{j} D_i^3 f_i}{\sum_{i=1}^{j} D_i^2 f_i} \tag{2.50}$$

where

F(D) = probability density function (PDF) for the drop-diameter distribution = differential of cumulative distribution function (CDF)

D = drop diameter, cm

D_i = drop diameter in diameter range i, cm

f_i = fraction of drops by mass in diameter range i.

For the Spraco 1751 nozzle drop-diameter distribution shown in Table 2.5, the Sauter mean calculated by the discrete form of Eq. 2.50 is D_3 = 0.339 cm. This is somewhat larger than the mean diameter from 0.2 cm to 0.208 cm, which was determined to give the best agreement with the distributed diameter model.

Use of the Sauter mean would result in a lower cooling efficiency than would be predicted by the "correct" method using the distributed drop diameters.

It is possible to define a general class of mean diameters D_n:

$$D_n = \frac{\int_0^\infty D^n F(D)}{\int_0^\infty D^{(n-1)} F(D)} \doteq \frac{\sum_{i=1}^{j} D_i^n f_i}{\sum_{i=1}^{j} D_i^{(n-1)} f_i} \tag{2.51}$$

For example, the Sauter mean would be called D_3. Figure 2.14 shows the nth order mean diameter D_n calculated from the discrete form of Eq. 2.51 versus the order n for the distribution shown in Table 2.5. The order of the mean which yields the empirically determined mean diameter of 0.208 cm is about n = +0.45. Since larger drop diameters are conservative, we will arbitrarily pick an order of the mean n = 0.5, which gives a mean diameter of 0.211 cm. Equation 2.51 for n = 0.5 reduces to:

$$D_{\frac{1}{2}} = \frac{\int_0^\infty \sqrt{D}\ F(D)}{\int_0^\infty \frac{F(D)}{\sqrt{D}}} \doteq \frac{\sum_{i=1}^{j} \sqrt{D_i}\ f_i}{\sum_{i=1}^{j} \frac{fi}{\sqrt{D_i}}} \tag{2.52}$$

This is the suggested diameter to be used in the HWS and LWS performance models.

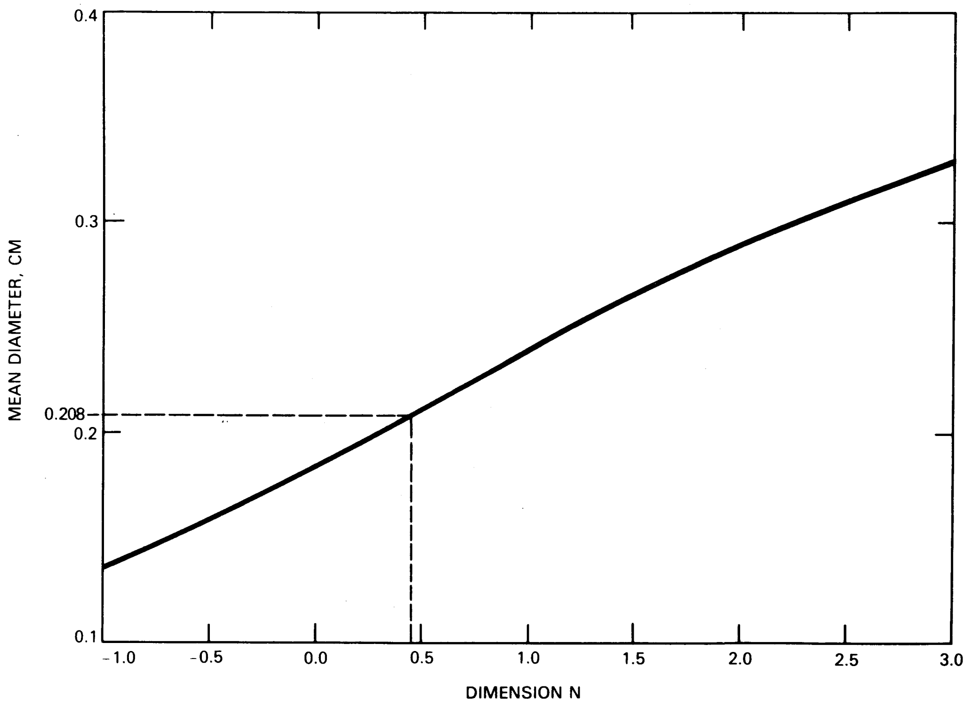

Figure 2.14 Determination of order of the mean for Spraco 1751A drop-diameter distribution

2.4.2 Effect of Drag on Performance Models

Including drag on the falling drops introduces several complications to the model, most notably:

(1) The drag term makes the equations of motion for the drop (Eqs. 2.1 and 2.2) nonlinear, requiring a numerical integration solution. By eliminating the drag term, the motion of the drop can be described analytically.

(2) On the LWS model, the net downward drag of the drops is a destabilizing influence on the iterative solution, especially at low heat loads.

For these and other reasons, it would be highly desirable to eliminate the drag term from Eqs. 2.1 and 2.2. The effect of eliminating the drag term from the HWS and LWS models was tested for a typical spray-pond configuration over a wide range of heat loading and atmospheric conditions. The following is a discussion of the various effects resulting from drag elimination.

2.4.2.1 Microscale Submodel

Eliminating the drag terms in Eqs. 2.1 and 2.2 has two effects:

(1) The time of flight is shortened.

(2) The rate of heat and mass transfer is increased because the average drop velocity is higher.

These two phenomena counteract each other to a certain extent, but the net effect is that the falling drops are predicted to experience more cooling and evaporation once drag is eliminated.

2.4.2.2 Macroscale Model

Eliminating the drag term increases the efficiencies predicted by both the HWS and LWS models. In addition, it increases the stability of the iterative solution in the LWS model. Table 2.4 shows the predicted efficiencies for the HWS and LWS models with and without drag over a range of heat and meteorological conditions for the Rancho Seco spray-pond test. Figure 2.15 compares the combined HWS-LWS "no-drag" model results (choosing the higher η of the two) with the Rancho Seco test data. The model-prototype agreement is good, and the no-drag model results are still conservatively low. In fact, agreement is better without drag than with drag, because the elimination of drag raises the predicted efficiency.

On the basis of the good agreement to data shown by the model and the improvement in stability of the LWS model, the drag term can be eliminated for typical spray-pond applications. This would not be a correct assumption for certain oriented spray configurations that are designed to induce lateral air flows (Ref. 7). In those cases, the effects of drag would have to be included. In addition, drag cannot be neglected in the drift-loss model described in the next section, since the smaller drop diameters which are most prone to drift, are strongly affected by drag.

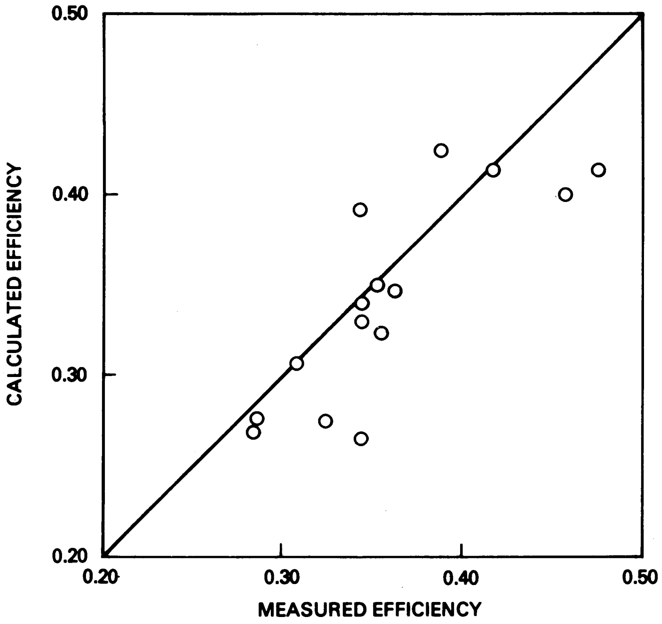

Figure 2.15 Comparison of NRC model with Rancho Seco data for "no-drag" model

3 DRIFT-LOSS MODEL

A fraction of the water droplets sprayed from the nozzles will be lost because they are physically carried by the wind beyond the pond borders. This "drift" loss can be estimated by means of a mathematical model showing the trajectory of droplets in a wind field and where the droplets fall in relation to the borders of the pond. Drift losses are generally small compared with evaporative losses.

3.1 Model Assumptions

The model is formulated for a spray pond of conventional design, with the Spraco 1751A nozzle operating at the recommended pressure and height. The trajectories of drops leaving the spray nozzles are simulated using a ballistics approach, in a similar manner as the "microscale" submodel of Section 2.1, but for 21 drop diameters which represent the drop-diameter distribution of the Spraco 1751 nozzle rather than the 10 drop diameters used in performance models. The equations in Section 2.1.1 apply exactly. No interaction of drops is presumed. It is likely that this is a conservative assumption, since small drops in some cases would collide to form larger drops which are less prone to be carried by wind.

The process of drop formation is complicated. Water will generally leave the nozzles in a continuous stream. Once the stream is airborne, forces of surface tension tend to cause the breakup of the stream into drops of varying sizes. Aerodynamic forces may also cause the larger drop diameters to become unstable and break up into smaller, more-stable drops. In every case, the breaking apart of larger drops into smaller drops causes the formation of one or more very small particles separate from the two major components of the fission. The drop-diameter distribution is not only a function of the type of spray nozzle and pressure, but of the distance from the nozzle, since the breakup into smaller drops occurs along the entire path.

If the assumption were made that all particles were already formed leaving the nozzle, drift loss would be underestimated. This is because the smallest particles most prone to drift also have small momentum, and would not be predicted to attain a very great height with respect to the nozzle. The most conservative assumption in this case would be that all droplets are formed at the apogee of the trajectory of the largest drop diameter, even though many small drops form close to the nozzle.

The buoyancy of the heated, humidified air in a heavily loaded spray pond could cause an updraft on the order of tens to hundreds of centimeters per second during low wind conditions. A single value of updraft velocity is chosen and inputted to represent an average for the 30-day period of an accident. The default value is 50 cm/sec.

3.1.1 Ballistics Model for a Drop

The model for the flight of the drops is the same as that developed in Section 2.1.1 and will not be repeated. It should be noted, however, that more emphasis is placed on the trajectory of small drops in the drift model; these are relatively less important for the spray-heat-loss calculations of Section 2. Therefore, a finer drop-diameter distribution is needed. The default drop-diameter distribution used for the drift model is shown in Table 3.1.

3.1.2 Initial and Boundary Conditions

The Spraco 1751 under a design pressure of 7 psig demonstrates a nozzle velocity of about 24 ft/sec. The spray would form a cone of water with an average angle of 58° from the horizontal. In calm conditions, the sprayed water forms an "umbrella" of about 12 ft in height and up to 16 ft in radius when the nozzle is 5 ft above the water surface according to Spraco promotional literature (Ref. 11).

Under the influence of wind, the spray umbrella is distorted. The circular pattern of droplets falling on the water surface is shifted downwind. The apogee of the drops is decreased in the upwind direction and increased in the

Table 3.1 Default Drop-Diameter Distribution for Spraco Nozzle 1751A for Use in Drift Model

Diameter, microns	Percent of total	Cumulative volume, %
200	0.05	0.05
260	0.05	0.1
300	0.05	0.2
330	0.1	0.3
365	0.1	0.4
400	0.1	0.5
425	0.2	0.7
460	0.3	1.0
520	0.4	1.4
580	0.6	2.0
640	2.0	4.0
855	3.0	7.0
1000	3.0	10.0
1190	5.0	15.0
1340	5.0	20.0
1650	10.0	30.0
2000	10.0	40.0
2290	10.0	50.0
2800	20.0	70.0
3600	15.0	85.0
4000	15.0	100.0

Source: See Reference 3

downwind direction. The smaller drop diameters would naturally be affected more than the larger ones. All drops of the same diameter would fall roughly in a circular pattern, however. This last assumption simplifies the analysis somewhat, because the diameter of the circular pattern for a particular drop diameter can be determined from just the straight upwind and straight downwind trajectories of the spray.

The starting point for the trajectory computations for all drop diameters is conservatively chosen as the apogee of the largest drop diameter, for reasons previously discussed.

The velocities and vertical and horizontal coordinates of both the upwind and downwind apogees for the largest drop diameter are calculated for a range of windspeeds and stored. These stored values are then used as the initial conditions for each windspeed in Eqs. 2.1 and 2.2 for the range of 22 drop diameters representing the spray-diameter distribution.

The circular patterns for each windspeed and each drop diameter, which are predicted from the drop ballistics, are used subsequently to predict the fraction of water passing beyond the boundaries of the pond. A drop is assumed to be lost if it does not fall on the pond surface. No allowance is made for runoff from the berms back into the pond.

The critical pond boundary is a straight line, arbitrarily oriented to be closest to the greatest number of nozzles in the downwind direction, as illustrated in Figure 3.1. The distance of the nozzles, or group of nozzles, equidistant from this line and the fraction of water in each group is specified. The part of the circular pattern for each drop diameter and wind falling outside of the critical pond boundary is then calculated for each nozzle or group of nozzles, which is the drift loss.

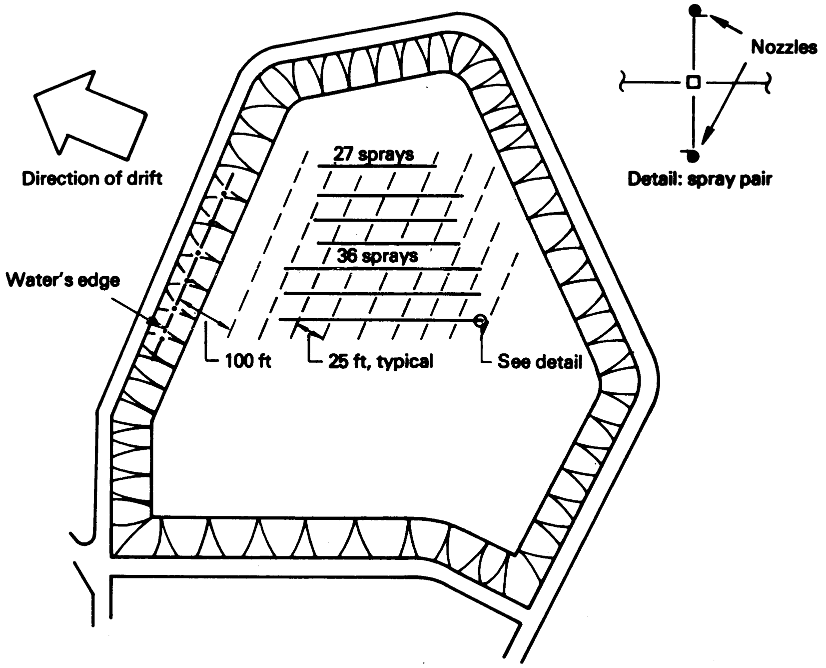

Figure 3.1 Typical layout of pond sprays and determination of critical pond boundary

3.2 Model Validation

3.2.1 Rancho Seco Data

Only limited field data are available on actual spray ponds with which the drift model can be validated.

The Rancho Seco drift-loss data were collected during an operational test of the spray-pond system required by NRC for the licensing of the plant (Ref. 10). Pond inventory and windspeed measurements were made during the test period, and then used to estimate the fraction of sprayed water lost versus windspeeds, which were typically from 0 to 15 mph.

To account for evaporation under zero heat load, the investigators conservatively estimated the drift loss by subtracting the water-loss rate at zero windspeed from the rest of the data. They erroneously assumed that evaporation from the pond and sprays would be independent of windspeed. Actually, evaporation from both the pond surface and spray increases directly with the windspeed. They therefore overestimated the water loss due to drift by neglecting the additional evaporation from the sprays. The water-loss data for the no-heat-load run (No. 4) of the Rancho Seco test are plotted versus windspeed in Figure 3.2.

The results of the drift-loss model cannot be directly compared to the prototype data in Figure 3.2 without first estimating the evaporative losses of the sprays, even without external heat loads. Unfortunately, there were no meteorological data other than windspeeds readily available from the no-heat-load test. On the basis of data that were available from other tests in the series, however, two combinations of wet-bulb/dry-bulb temperature values were estimated, which probably bound the range of meteorological conditions other than wind during the test.

The correction factor for evaporation of the sprays was computed directly from the high windspeed (HWS) performance model described in Section 2.2.1, which was run under no-heat-load conditions for a range of windspeeds. The sprayed

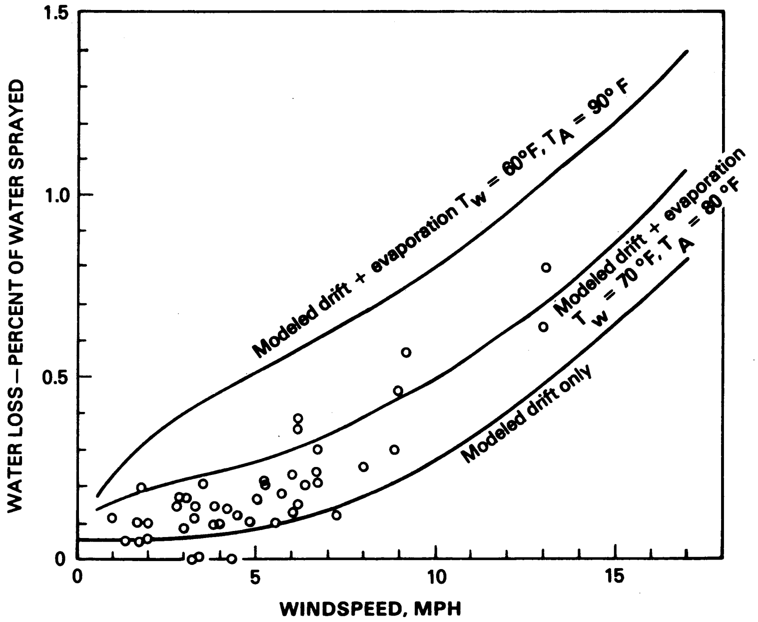

Figure 3.2 Measured and modeled water loss from Rancho Seco test 4

temperature T_{HOT} was forced to be equal to the temperature after spraying T by running the program iteratively until convergence. Two cases were run:

(1) Wet-bulb temperature = 70°F
Dry-bulb temperature = 80°F

(2) Wet-bulb temperature = 60°F
Dry-bulb temperature = 90°F

Additionally, a correction factor has been added to account for the relatively minor contribution of heat to the spray pond from solar radiation. Mean daily solar radiation during May is about 2,450 Btu (ft^2 day) (Ref. 13). The surface area of the full pond is about 66,470 ft^2. If 80% of this added heat is lost through evaporation, it would correspond to a water loss of 0.0239 ft^3/sec. The quantity of sprayed water during the test was about 35.4 ft^3/sec, which means that water evaporated because of solar heat load would be about 0.067% of the volume sprayed.

The water loss during the no-heat-load test is, therefore, calculated to be:

$$W_1 = \text{drift loss} + \begin{pmatrix}\text{evaporative loss} \\ \text{for no-heat load}\end{pmatrix} + \begin{pmatrix}\text{solar heat} \\ \text{load correction}\end{pmatrix} \qquad (3.1)$$

Water loss versus windspeed is plotted in Figure 3.2 for the two assumed meteorologic conditions, along with data from the no-heat test at Rancho Seco. The model appears to conservatively follow the field data on water loss, although it must be recognized that no detailed meteorological conditions were readily available for this comparison.

3.2.2 Validity of Drift-Loss Model

The drift-loss model presented here has been shown to perform acceptably well when compared to the limited field data available and incorporates a number of conservatisms in its formulation. Greater emphasis on the drift-loss model is probably not warranted, since the total quantity of water lost to drift is generally much smaller than water lost to evaporation. Drift loss may exceed evaporation momentarily during high winds but it is unlikely that these conditions could be sustained for a sufficient length of time to change this conclusion.

4 POND MODEL

The pond model is used to calculate the temperature and water loss from the pond. It combines the model of heat and mass loss from the sprays, the model of circulation and heat retention in the mass of water in the pond, and additional heat and mass transfer from the surface of the pond. The pond model developed here is similar to the mixed-tank model of NUREG-0693 (Ref. 14).

A typical spray pond differs from surface-cooling ponds by having smaller volume and surface areas. The rates of heat and water loss from the sprays to heat and water loss from the pond surface is generally high.

The heat and water loss from the pond surface may in most cases be considered a secondary effect with regard to the sprays. In addition, the small volumes of the ponds relative to the water circulation through them diminishes the effects of such phenomena as thermal stratification, which are of importance in surface-cooling ponds (Ref. 15). For this reason, the modeling of the balance of the pond other than the sprays is fairly straightforward and simple. The "mixed tank" model of the pond assumes total mixing of all water throughout the volume of the pond. It must be noted, however, that some spray ponds may have a relatively large surface area and volume, or the sprays may be operated only intermittently. In these cases, surface-heat transfer and the effects of stratification may take on greater importance than in a typical spray-pond situation. The effects of "short-circuiting" of pond water are not nearly as important in typical spray ponds as they could be in surface-cooling ponds.

The mixed-tank model depicted in Figure 4.1 presumes that the heated effluent is instantaneously and uniformly mixed throughout the volume of the tank, and that the water in the tank is uniform in temperature. Atmospheric-heat transfer from the surface is related to the pond-surface temperature.

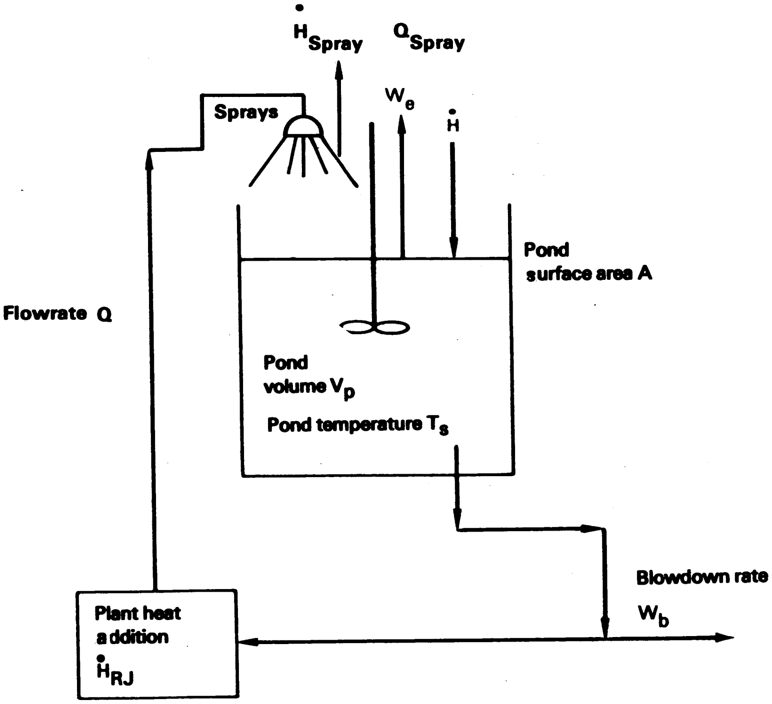

Figure 4.1 Mixed-tank model

4.1. Heat Balance

A heat-and-mass balance can be formulated for the mixed-tank model. The terms of the heat balance are:

4.1.1 Heat Load Into Ponds

$$\text{Heat in} = \dot{H}_{RJ} \qquad \text{Btu/(ft}^2\text{ day)} \qquad (4.1)$$

4.1.2 Heat Out From Surface

A relation for the rate of net heat flow across the surface of the pond can be developed through consideration of each heat source and heat loss. The net rate of heat flow $\dot{H}$ into the pond is:

$$\dot{H} = \dot{H}_{SN} + \dot{H}_{AN} - \dot{H}_{BR} - \dot{H}_E - \dot{H}_C \qquad \text{Btu/(ft}^2\text{ day)} \qquad (4.2)$$

where

$\dot{H}_{SN}$ = net rate of shortwave solar radiation entering the pond, measured directly, Btu/(ft^2 day)

$\dot{H}_{AN}$ = net rate of longwave atmospheric radiation entering the pond, measured directly, Btu/(ft^2 day)

$\dot{H}_{BR}$ = net rate of back radiation leaving the pond surface, Btu/(ft^2 day)

$\dot{H}_E$ = net rate of heat loss attributable to evaporation, Btu/(ft^2 day)

$\dot{H}_C$ = net rate of heat flow from the pond attributable to conduction and convection, Btu/(ft^2 day)

The relationships are illustrated graphically in Figure 4.2.

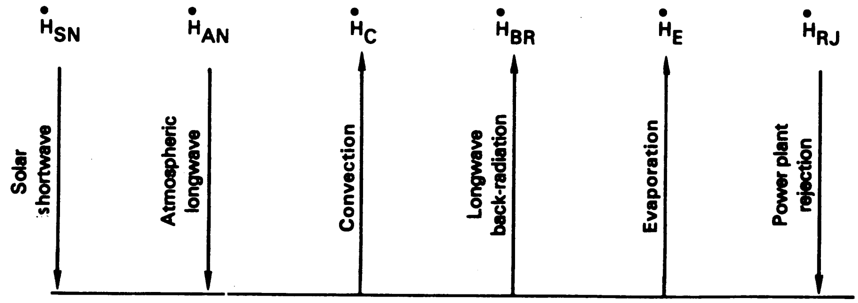

Figure 4.2 Heat loads on the surface of a pond

The net atmospheric radiation term can be approximated using air temperature T_A and cloud cover C. Ryan and Harleman (Ref. 16) develop the following formula for $\dot{H}_{AN}$:

$$\dot{H}_{AN} = 1.2 \times 10^{-13}\left(T_A + 460\right)^6\left(1 + 0.17C^2\right) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (4.3)$$

The back radiation term may be expressed using the relation for radiation from a black body (Ref. 17):

$$\dot{H}_{BR} = 4.026 \times 10^{-8}\left(460 + T_s\right)^4 \qquad \text{Btu/(ft}^2\text{ day)} \qquad (4.4)$$

The evaporative-heat-transfer component is a function of surface temperature at atmospheric temperature and humidity:

$$\dot{H}_E = (e_s - e_a)F(w) \qquad \text{Btu/(ft}^2\text{ day)} \tag{4.5}$$

where

e_s = vapor pressure of water at the pond-surface temperature, mm Hg

e_a = partial pressure of water vapor in the air (that is, the vapor pressure of water at the dewpoint), mm Hg

F(w) = wind function

A semiempirical wind function is proposed by Ryan and Harleman (Ref. 16) which agrees well with field data on large ponds:

$$F(w) = \left[22.4 \times (\Delta T_v)^{1/3} + 14w\right] \tag{4.6}$$

where

w = windspeed, mph

ΔT_v = "virtual" temperature difference between the pond surface water and air above the pond, rewritten:

$$\Delta T_v = \frac{T_s + 460}{1 - \frac{0.378 \times e_s}{p}} - \frac{T_A + 460}{1 - \frac{0.378 \times e_a}{p}} \tag{4.7}$$

and p = atmospheric pressure, mm Hg

The net rate of heat transfer from the pond attributable to conduction and convection, H_c, is also a function of the pond surface and atmospheric humidity and temperature (Ref. 16):

$$H_c = 0.26 \times (T - T_A) \times F(w) \tag{4.8}$$

4.1.3 Heat Out in Blowdown or Leakage Stream

With reference to the pond temperature T, heat loss from blowdown is by definition zero:

$$q_b = W_b \rho C_p (T - T) \equiv 0 \quad \text{Btu/hr} \tag{4.9}$$

where

W_b = flowrate of the blowdown or leakage stream, ft^3/hr

and ρ and C_p are as previously defined.

4.1.4 Heat Rejected by Sprays

$$H_{spray} = Q \rho C_p R_c \quad \text{Btu/(ft}^2\text{ day)} \tag{4.10}$$

where

R_c = cooling range of the sprays determined from either the HWS-LWS model or the regression equations

and Q, ρ, and C_p are as previously defined.

Combining all heat inputs to and outputs from the pond, and using the relationship relating temperature to heat, the following relationship is obtained:

$$\frac{dT}{dt} = \frac{\dot{H}_{RJ} - \dot{H} - \dot{H}_{spray}}{\rho C_p V_p} \quad {}^{\circ}\text{F/hr} \tag{4.11}$$

where

V_p = pond volume in cubic feet

and all other elements of the equation are as previously defined.

Note that there is no provision for a makeup stream in either the heat or mass balance, since Regulatory Guide 1.27 specifically denies makeup during the operation of a UHS pond.

4.2 Mass Balance

The mass balance on the pond includes evaporative loss from the surface, drift, and blowdown or leakage. The terms of the mass balance are:

Blowdown or leakage flow = W_b, ft^3/hr
Evaporative loss from surface = W_e, ft^3/hr

$$W_e = \frac{\dot{H}_E}{\rho\lambda} \tag{4.12}$$

where

λ = heat of vaporization of water, Btu/lb

ρ = density of water, lb/ft^3

and $\dot{H}_E$ is defined by Eq. 4.5.

Combining all terms of the mass balance yields the expression:

$$\frac{dV}{dt} = -W_b - \frac{\dot{H}_E}{\rho\lambda} - W_{drift} - W_{spray} \tag{4.13}$$

where

W_{drift} = drift loss

W_{spray} = rate of water evaporated from all drops in the spray field, ft^3/hr

determined from the evaporative heat-transfer component of Eq. 2.7.

5 DATA-SCREENING METHODOLOGY

In this section, a method is developed with which long-term weather records can be screened to find the period in which the spray-pond temperature or water loss will be maximized.

5.1 Development of Method

The "equilibrium temperature" heat-transfer approach is used in a method that decouples the plant-heat-input effects from environmental effects on the pond. The temperature of the pond, T_s, may be determined by the solution of the differential equation for the mixed-tank model:

$$\frac{dT_s}{dt} = \frac{\dot{H}}{\rho C_p V_p} + \frac{Q\eta}{V_p}\left(T_s + \frac{\dot{H}_{RJ}A}{\rho C_p Q} - T_W\right) \tag{5.1}$$

where

V_p = pond volume, ft^3

A = pond surface area, ft^2

T_W = wet-bulb temperature, °F

and all other elements are as previously defined.

For the purpose of developing the model, V_p and η are temporarily assumed to be constant. The "equilibrium temperature" E (Ref. 17) is a useful invention at this point in the model development. The rate of atmospheric-heat transfer can be assumed to be proportional to the difference between the pond temperature and the equilibrium temperature:

$$\dot{H} = KA\left(T_s - E\right) \tag{5.2}$$

where

K = equilibrium-heat-transfer coefficient, Btu/(ft^{2}hr°F)

If we further assume that K is a constant, Eq. 5.1 will be linear with respect to T_s, and it will be possible to consider that the pond temperature is the sum of the pond "ambient" temperature T'_s and an "excess" temperature θ:

$$T_s = T'_s + \theta \tag{5.3}$$

T'_s would be determined by the solution of Eq. 5.1 for a steady heat load $\dot{H}_{RJ,0}$:

$$\frac{dT'_s}{dt} = \frac{AK}{\rho C_p V_p}\left(T'_s - E\right) - \frac{Qn}{V_p}\left(T'_s + \frac{\dot{H}_{RJ,0}A}{\rho C_p W} - T_W\right) + \frac{\dot{H}_{RJ,0}A}{\rho C_p V_p} \tag{5.4}$$

where

$\dot{H}_{RJ,0}$ = steady-state heat load, Btu/(ft^2 day)

and all other values are as previously defined.

Subtracting Eq. 5.4 from Eq. 5.1 gives the differential equation for excess temperature:

$$\frac{d\theta}{dt} = \frac{AK}{\rho C_p V_p}\theta + \left(\frac{\dot{H}_{RJ} - \dot{H}_{RJ,0}}{\rho C_p V_p}\right) - \frac{Qn}{V_p}\left(\theta + \frac{\dot{H}_{RJ} - \dot{H}_{RJ,0}}{\rho C_p Q} - T_W\right) \tag{5.5}$$

The determination of pond temperature has, therefore, been separated into two simpler problems, because now the ambient and excess pond temperatures can be determined independently from one another. The excess temperature θ does not depend on the meteorological record, so it can be solved directly from Eq. 5.5

using the plant-heat-rejection rate. The pond ambient temperature T_s' does not depend on the heat rejection from the plant, so it can be calculated from Eq. 5.4 using only the long-term meteorological record. The peak pond temperature can, therefore, be found by summing (superimposing) the peak of T_s' and θ:

$$\left(T_s\right)_{peak} = \left(T_s'\right)_{peak} + \theta_{peak} \tag{5.6}$$

Unfortunately, the basic premise that Eq. 5.1 is linear is incorrect. Both K, E, and η are functions of T_s and atmospheric variables. In addition, the pond volume V_p will change as water on the pond is lost as a result of seepage, drift, and evaporation. (Makeup water is assumed to be unavailable during the operation of the pond.) The function of the procedure outlined above is to identify the timing of the maximum ambient and maximum excess temperatures so that more accurate computation can be performed in which the spray-pond temperature is determined directly. Since the heat- and mass-transfer relationships are nonlinear with respect to pond and spray temperature, temperature calculations may be different from those used in the screening. There are, however, no firm guarantees that the optimal starting time for peak temperature will necessarily be found by this procedure. A series of model runs spaced several hours apart, over the length of the data record, is an alternative method of determining the optimal timing.

5.2 Meteorological Inputs to Screening Model

The screening model developed in Section 5.1 requires two types of data: (a) weather data such as wet- and dry-bulb temperatures, dewpoint, windspeed, and atmospheric pressure, which may be obtained from National Weather Service records, and (b) rates of net solar radiation which generally do not exist for long periods of record. A method for synthesizing solar radiation using cloud-cover data has been developed. National Weather Service tapes of "Tape Data Family-14" (TDF-14) are used by the model as a source of temperature, windspeed, and cloud-cover observations. These tapes are available for major observation points throughout the United States.

5.2.1 Solar Radiation

The solar radiation term for the heat-exchange relation must be either taken from direct measurements or estimated. The model estimates hourly solar radiation rates in a three-step process. First, given the latitude of the pond and the time of year, the maximum solar radiation available to the pond for the given day is estimated. Second, this gross figure is fitted to a sinusoidal relation to find the rate of insolation for each hour of daylight. Finally, these hourly rates are modified to take into account the effect of cloud cover.

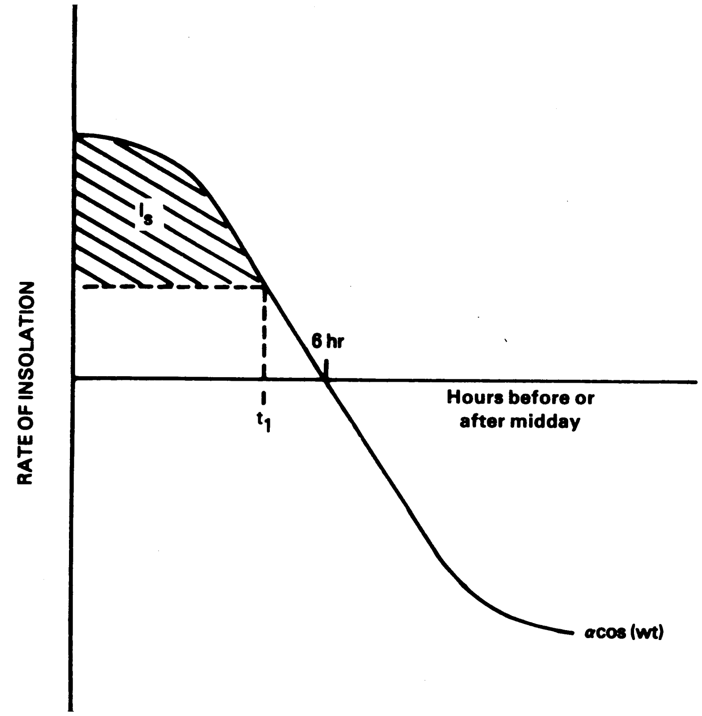

Figure 5.1 Insolation as a function of time

A procedure based on the work of Hamon, Wiess, and Wilson (Ref. 18) is used to estimate the maximum daily solar radiation. This total daily radiation figure is fitted to a sinusoidal function as shown in Figure 5.1. The hourly variation of radiation is:

$$\dot{H}_S(t_0) = 2t_1 \quad \beta\cos\left(\frac{\pi t_0}{12}\right) - \beta\cos\left(\frac{\pi t_1}{12}\right) \quad \text{Btu/(ft}^2\text{ day)} \qquad (5.7)$$

where

$\dot{H}_S$ = gross rate of solar radiation, Btu/(ft^2 day)

t_0 = time of the observation in hours before or after midday

t_1 = one-half the length of daylight per day, hr

and

$$\beta = \left[\left(\frac{1}{I_s}\right)\left(\frac{\pi}{12}\right)\sin\left(\frac{\pi t_1}{12}\right) - \frac{1}{I_s}t_1\cos\left(\frac{\pi}{12}t_1\right)\right]^{-1}$$

where

I_s = total daily solar radiation, Btu/(ft^2 day)

Solar radiation ultimately reaching the earth's surface is greatly affected by atmospheric conditions, especially cloud cover. The amount of cloud cover, in tenths of the total sky obscured, is available from the data tapes. This information is used in a relationship developed by Wunderlich (Ref. 19) to modify the hourly insolation rates:

$$\dot{H}_{SN} = H_S(1 - 0.65C^2)0.94 \qquad \text{Btu/(ft}^2\text{ day)} \tag{5.8}$$

in which 0.94 is a factor which adjusts for the average 6% reflection from the water surface.

5.3 Scanning-Performance Models

In order to determine the design-basis conditions for evaluation of the spray pond, a long-term weather record is searched for key conditions which would predict the highest pond temperature or water-loss rate. Basically, a long-term weather record is searched by using a model which is nearly the same as the model in Section 4 to simulate the performance of a loaded spray pond. The scanning model differs from the model of Section 4 in that the HWS and LWS spray-performance models are not used directly. Using the rigorous performance models for a long (tens of years) simulation would be prohibitively costly and inefficient.

5.3.1 Approximate Spray-Performance Model

The HWS and LWS spray-performance models are steady state. Therefore, they do not depend on any history of input conditions, but predict instantaneous heat rejection and evaporation for a given set of meteorological and heat-load conditions.

If the spray-performance models can be exercised over a wide range of inputted independent meteorological variables, the resulting performances can be formulated into regression models. These regression models can then be used to predict the performance of the sprays for other conditions that are within the ranges of the correlating independent variables. This procedure is much more efficient than using the original models directly.

5.3.2 Functional Dependencies of Spray-Performance Models

Before the regression models are formulated, it is useful to perform numerical experiments using the LWS and HWS models to determine the approximate dependence of predicted performance on the independent variables T_W, T_{HOT}, and w for a typical spray-pond situation. Figures 5.2 through 5.5 show, respectively, the different "spray efficiencies" η of both the HWS and LWS models, that occurred upon variations in wet-bulb temperature, dry-bulb temperature, sprayed-water temperature, and windspeed. The higher of the two predicted efficiencies (LWS or HWS) would be used in the actual performance model, which is depicted on the figures as a bold line.

Figure 5.2 shows the dependence of η on the wet-bulb temperature T_W. Over the range tested, both models show a nearly linear dependence on T_W.

Figure 5.3 demonstrates the dependence of η on sprayed temperature T_{HOT}. The HWS model shows a nearly linear dependence, whereas the LWS model has a decreasing slope with increasing temperature.

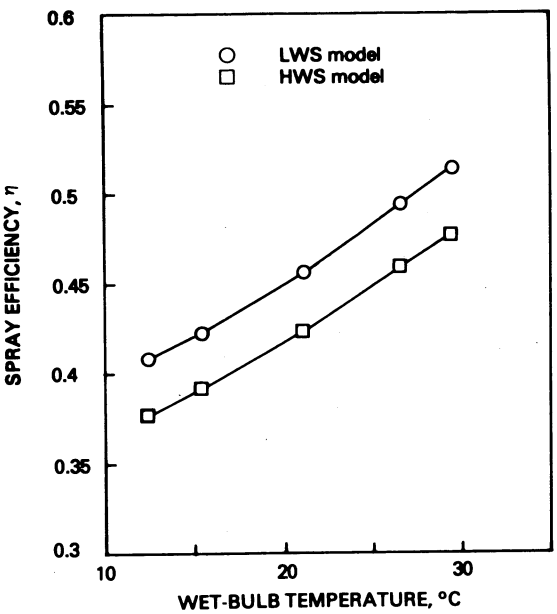

Figure 5.2 Dependence of η on wet-bulb temperature

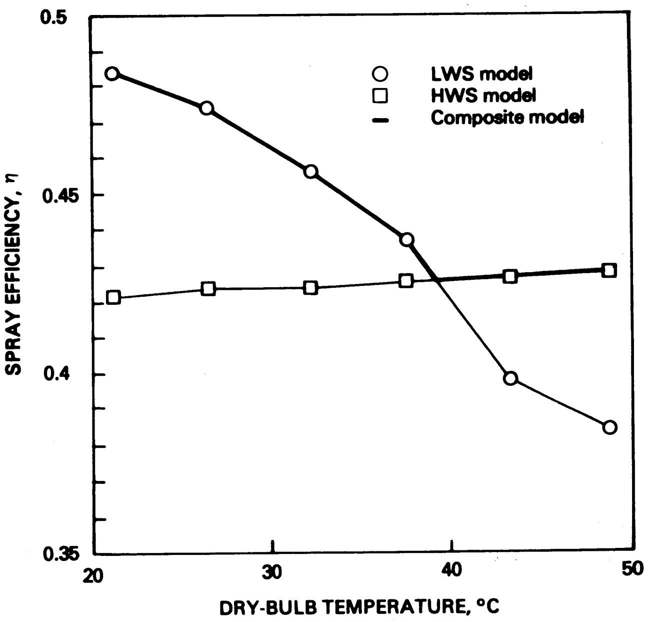

Figure 5.3 Dependence of η on dry-bulb temperature

Figure 5.4 demonstrates the dependence of η on dry-bulb temperature T_A. The HWS model shows a small positive, nearly linear dependence on T_A. The LWS model shows a much larger, negative dependence with an apparent inflection.

Figure 5.5 demonstrates the dependence of η on windspeed w. Since windspeed is not one of the independent variables in the LWS model, η is a constant for that model. The HWS model shows a decreasing slope with increasing windspeed.

It is possible to guess a form for the equations (with as-yet-undetermined coefficients), which would predict the performance of the HWS and LWS models over a wide range of variations of the independent variables T_A, T_W, T_{HOT}, and w. The proposed equation for the efficiency of the HWS model would be:

$$\eta_{HWS} = a_1 + b_1 T_A + c_1 T_W + d_1 T_{HOT} + e_1 w + f_1 \sqrt{w} \qquad (5.9)$$

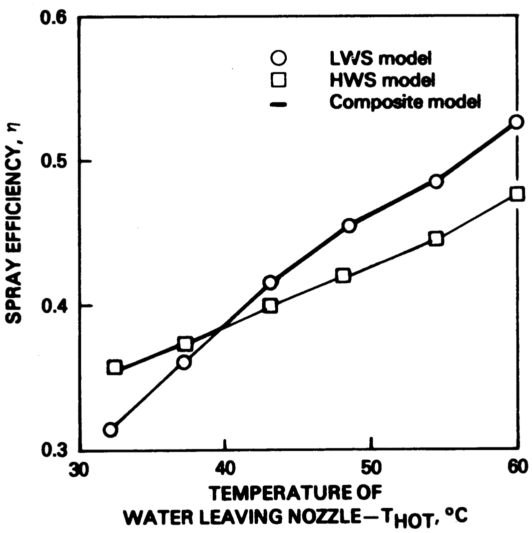

Figure 5.4 Spray efficiency vs sprayed temperature

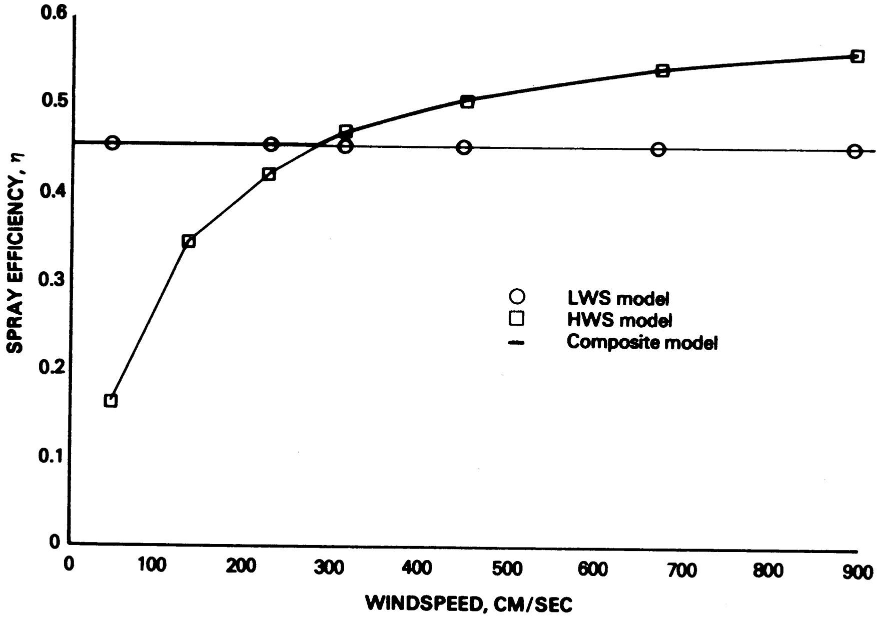

Figure 5.5 Spray efficiency vs windspeed

For the LWS model, the regression equation for efficiency would be:

$$\eta_{LWS} = a_2 + b_2T_A + c_2T_A^2 + D_2T_A^3 + e_2T_W + f_2T_{HOT} + g_2T_{HOT}^2 \quad (5.10)$$

The evaporation rate Q is correlated in exactly the same fashion:

$$Q_{HWS} = a_3 + b_3T_A + c_3T_W + d_3T_{HOT} + e_3w + f_3\sqrt{w} \quad (5.11)$$

and

$$Q_{LWS} = a_4 + b_4T_A + c_4T_A^2 + d_4T_A^3 + e_4T_W + f_4T_{HOT} + g_4T_{HOT}^2 \quad (5.12)$$

The coefficients a through g are determined by a least-squares multiple-linear-regression analysis of η and Q over a wide range of the independent variables T_A, T_W, T_{HOT}, and w for the spray pond under investigation. Program SPRCO generates random values of the independent variables in given ranges, runs the HWS and LWS models to generate η and Q, performs the multiple-linear regressions, and presents the correlations of the curve-fitted η and Q versus the calculated η and Q in terms of the coefficient of determination r^2 and a graphical x-y scattergram. The coefficients for Eqs. 5.9 through 5.12 are punched for subsequent use in programs SPSCAN, SPRPND and COMET2. Correlations of the regression equations with the HWS and LWS models are generally excellent.

6 ONSITE-OFFSITE CORRELATION

Long-term meteorological records at the site itself are not usually available and current NRC practice requires only limited onsite data collection. Furthermore, the meteorological data collected onsite may be incomplete for the purposes of spray-pond analysis.

The meteorological data for UHS performance must be obtained from offsite weather stations (such as airports) for which long-term records, including solar radiation or cloud cover, are available. The site meteorology may be significantly different from that of the offsite station, however, because of such reasons as orographic features or altitude differences. Thus, it is necessary to determine if serious discrepancies exist between the two sites. We are only interested, however, in long-term differences between the meteorology of the onsite and offsite data, and not the short-term, local variations, such as thunderstorms.

The assumption is made that we can calculate an "average" pond temperature or water loss based on monthly (or some other period) averages of the important meteorological parameters for the onsite and offsite data. By comparing the monthly average pond temperatures or water loss using the onsite data with the pond temperature or water loss using the offsite data, we can estimate the bias that would be introduced by using the offsite data in the temperature calculations. The biases estimated by the above procedure can be used as correction factors for the water losses and peak temperatures calculated using the long-term offsite data. Experimentation with the models has shown that the proposed correction factors reliably account for the differences between the onsite and offsite data sets and are conservative.

The biases in pond temperature and evaporation can further be related to differences in each meteorological parameter separately. For example, if the meteorological parameters of the model are T_A, T_W, $\dot{H}_S$, and w:

$$\Delta E \cong \Delta E)_{T_A,w,\dot{H}_{SN}} + \Delta E)_{T_W,w,\dot{H}_{SN}} + \Delta E)_{T_A,T_W,\dot{H}_{SN}} + \Delta E)_{T_A,T_W,w} \qquad (6.1)$$

where

ΔE = overall bias in pond temperature between the two data sets, °F

T_W = wet bulb temperature, °F

and

$\Delta E)_{T_A,w,\dot{H}_{SN}}$ = bias attributable only to the variation in T_W between the data sets, °F

$\Delta E)_{T_W,w,\dot{H}_{SN}}$ = bias attributable only to the variation in T_A between the data sets, °F

$\Delta E)_{T_A,T_W,\dot{H}_{SN}}$ = bias attributable only to the variation in w between the data sets, °F

$\Delta E)_{T_A,T_W,w}$ = bias attributable only to the variation in $\dot{H}_{SN}$ between the data sets, °F

Equation 6.1 is extremely useful because it allows a comparison between onsite and offsite data sets, even if one or more parameters are missing. For example, solar radiation is not usually collected on site. The biases attributable to the other variations can be estimated, bearing in mind that no contribution of the solar radiation difference is included.

A brief computer program, COMET2 (COmpare METeorology), has been written which evaluates the differences in steady-state temperatures between two data sets and their sensitivity to differences in the averages of wet bulb, air temperature, windspeed, and solar radiation between the two sets of data.

This program also calculates the correction factor, in cubic feet of water, for the differences in evaporation and drift between two sites based on the 30-day average meteorology.

Resultant steady-state temperatures and water-loss rates between the two data sets are correlated and the coefficients of correlation, r^2, and the standard error, σ, are calculated.

7 DESCRIPTION OF COMPUTER PROGRAMS

Five separate computer programs are described that are used for several facets of the spray-cooling-pond analysis:

(1) Program SPRCO simulates the high- and low-windspeed versions of the spray-pond-cooling model and generates regression equations based on these models for use in subsequent programs.

(2) Program DRIFT calculates a table of drift water loss versus windspeed for the spray pond.

(3) Program SPSCAN scans a weather-record tape to predict the likely periods of lowest cooling performance and highest evaporation and drift losses. Programs DRIFT and SPRCO generate necessary inputs on the pond performance for this code.

(4) Program COMET2 compares the limited quantity of onsite meteorological data with summaries of offsite data provided by program SPSCAN to determine if there are significant differences between the two which might lead to differences in predicted pond performance, and suggests correction factors.

(5) Program SPRPND calculates the most pessimistic cooling-pond temperature for a design-basis accident using the abbreviated data provided by program SPSCAN.

The complicated manner in which these programs are used to determine design-basis temperature and heat loads is shown in Figure 7.1 and described below.

7.1 Program SPRCO

This program generates the coefficients of a set of multiple-linear regression equations which represent the cooling performance and evaporative water loss

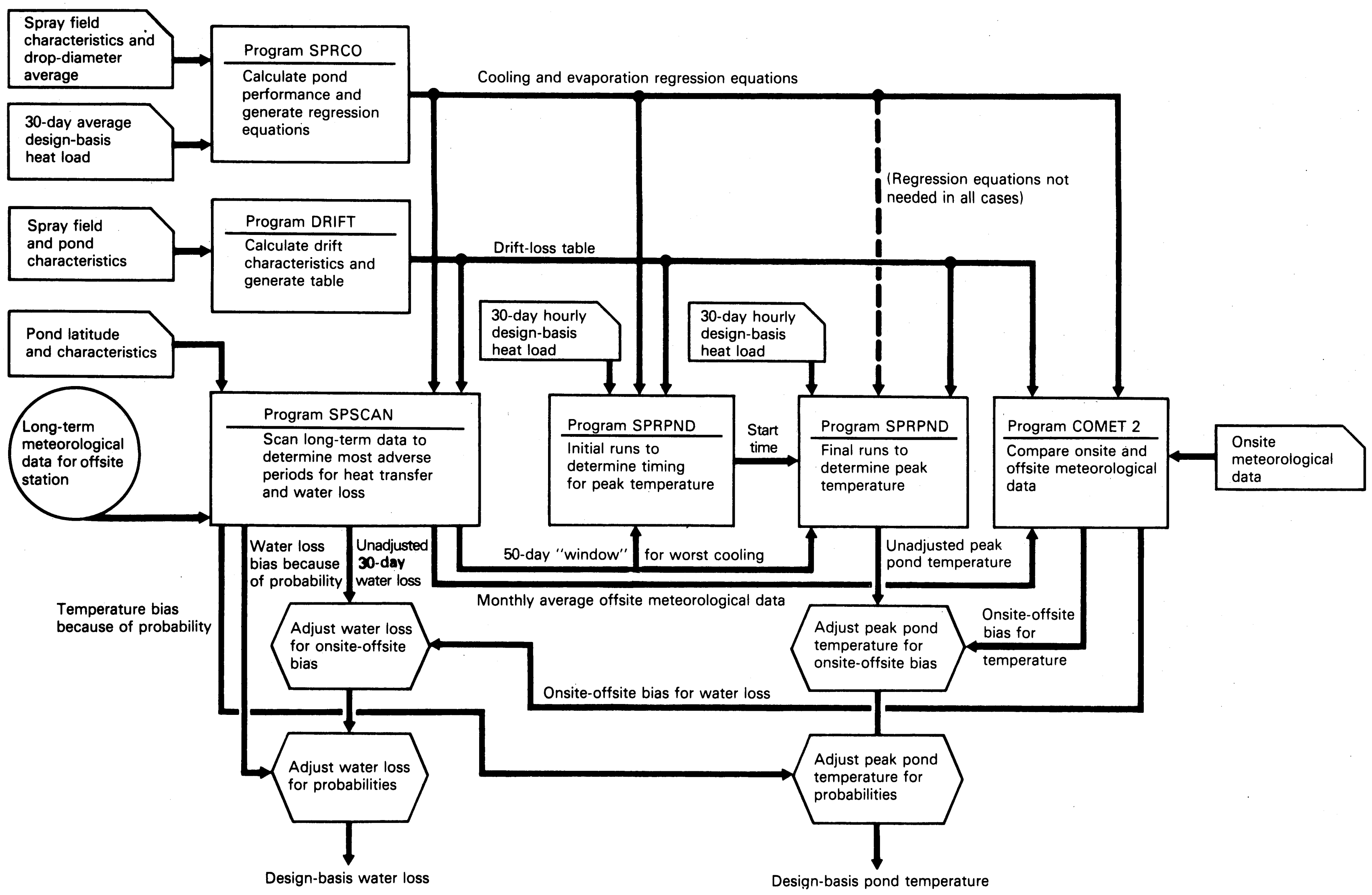

Figure 7.1 Flowchart for design-basis water loss and temperature determination

of a spray field. The regression equations are subsequently used in programs SPSCAN, SPRPND and COMET2 because they are much less time consuming than the direct use of the HWS and LWS models.

7.1.1 Operation of Program

Program SPRCO runs the HWS and LWS for a large number of cases, typically 200. Each case has the meteorological inputs of wet-bulb temperature T_W, dry-bulb temperature T_A, windspeed w, and sprayed-water temperature T_{HOT}, chosen from a specified range by a pseudorandom-number routine. The resulting cooling performance and evaporation for the HWS and LWS models are recorded and are subsequently fitted to multiple-regression equations whose independent variables are T_A, T_W, w, and T_{HOT}, or powers thereof. Goodness of the fit is tested by calculating the estimated efficiency and evaporation from the four regression equations and comparing these to the results of the HWS and LWS models directly. The standard errors and coefficient of correlation are also calculated.

7.1.2 Program Inputs

Inputs to program SPRCO are of two types:

(1) Variables which describe the basic characteristics of the spray field.

(2) The ranges of meteorological conditions from which each case is randomly chosen.

All inputs are specified in a namelist called INPUT, which is described in Table 7.1. Default values are given where possible, which are typical of Spraco 1751 nozzles with the manufacturer's recommended setup. Only those variables different from the default values need to be read in.

Table 7.1 Namelist INPUT--Inputs to Program SPRCO

Variable name	Description and units	Default value
NPNTS	Number of randomly chosen cases in set	200
VELØ	Initial velocity of drops leaving the spray nozzle, ft/sec	-
HT	Height of spray field from water surface to highest point attained by drop, ft	-
ALEN	Length of the spray field, ft (longer dimension)	-
WID	Width of the spray field, ft (shorter dimension)	-
THETA	Angle of spray to horizontal, degrees	71
YØ	Height of spray nozzles from water surfaces, ft	-
R	Mean drop radius, cm (see text)	0.104
PB	Atmospheric pressure, in. Hg	29.92
Q	Flowrate of water sprayed, ft^3/sec	-
PHI	Heading of wind with respect to long axis, degrees	90
TWETØ	The lower limit of T_W, °F	50
RTW	Range of T_W, °F	30
DTDRYØ	The lower limit of ΔT_A $\left(\text{which is added to the value of } T_W\text{, since } T_W \geq T_A\text{; i.e., } T_A = T_W + \Delta T_A\right)$, °F	20
RTD	Range of ΔT_A, °F	30
WINDØ	The lower limit of w, mph	0.1
RW	Range of w, mph	20
THOTØ	The lower limit of T_{HOT}, °F	90
RTH	Range of T_{HOT}, °F	30

Ø = zero

7.1.3 Program Outputs

The following outputs are generated:

(1) The random meteorological inputs and results of the HWS and LWS models for each case.

(2) The regression equations in terms of the coefficient a_1 through g_4:

(a) HWS efficiency (approach to wet bulb):

$$\eta_{HWS} = a_1 + b_1T_A + C_1T_A + d_1T_{HOT} + e_1w + f_1\sqrt{w}$$

(b) HWS evaporation (fraction sprayed evaporated):

$$EVAP_{HWS} = a_2 + b_2T_A + c_2T_W + d_2T_{HOT} + e_2w + f_2\sqrt{w}$$

(c) LWS efficiency:

$$\eta_{LWS} = a_3 + b_3T_A + c_3T_A^2 + d_3T_A^3 + e_3T_W + f_3T_{HOT} + g_3T_{HOT}^2$$

(d) LWS evaporation:

$$EVAP_{LWS} = a_4 + b_4T_A + C_4T_A^2 + d_4T_A^3 + e_4T_W + f_4T_{HOT} + g_4T_{HOT}^2.$$

(3) Goodness of fit of the regression equations versus the HWS and LWS model outputs:

(a) Coefficient of determination r^2.
(b) Standard error σ.
(c) x-y scattergrams.

7.2 Program DRIFT

The computer program DRIFT computes the drift loss from a spray pond in terms of a fraction of the total amount of water sprayed. The program requires the input of the spray-field geometry and outputs the drift-loss fraction for various windspeeds between 0 and 50 mph. The default drop-diameter distribution in the program is for the Spraco 1751A nozzle under standard operating conditons. Other distributions may be entered.

The spray-field geometry is described by specifying the distances downwind from a group of sprays to the edge of the pond surface and the fraction of the total flow of the spray field represented by that group. When concerned with finding the worst-case drift loss, the direction of the wind is assumed to be the direction that minimizes the distance between the sprays and the edge of the pond surface.

The description of the spray geometry is fairly straightforward when rows of sprays are set parallel to the edge of the pond, as each row can be considered a group of sprays. Irregularly shaped ponds or complex spray arrangements may require an arbitrary grouping of sprays. Figure 3.3 shows how this can be done for a complicated geometry.

To begin the calculation of drift loss from a spray pond, it is first necessary to choose a worst-case wind direction. For simple ponds, this may be done by inspection; more-complex ponds may require that several likely wind directions be modeled before the worst-case wind direction can be determined. Second, the spray field is divided into groups of sprays which are roughly equidistant from the downwind edge of the pond. For conservatism, all of the sprays in the group may be assumed to lie on the boundary of each segment nearest the pond's edge. The fraction of sprays in each group is then calculated.

The final step in the calculations is to prepare the input for DRIFT and run the program. Table 7.2 shows the input format for program DRIFT.

These cards form a repeatable data set. Several runs may be made in a single execution of the program enabling, for example, different pond geometries to be tested.

7.3 Meteorological Data Screening Program SPSCAN

Program SPSCAN is used to scan long-term weather records to determine the period of lowest cooling performance and highest water loss for spray cooling ponds in UHS service. A simple mixed-tank hydraulic model is employed in a running

Table 7.2 Input Variables for Program DRIFT

Card no.	Format	Variables	Comments
1	80A1	TITLE	Columns 2-80 are used to input a message which will be printed at the beginning of the output
2	namelist DROPSZ	DIAM(I), PROPOR(I)	Table for optional drop-diameter distribution. DIAM(I) = drop diameter, cm. PROPOR(I) = corresponding fraction by mass of that diameter. Up to 21 values in table.
3	I2	NUM	Number of cards used in the description of the spray geometry
4 to (3 + NUM)	2F10.0	SPRAY (N,1) SPRAY (N,2)	Distance between a group of sprays and the downwind edge of the pond (ft) and the location of the sprays in the group. There should be NUM cards of this type, one for each group of sprays
(4 + NUM)	80A1	TITLE	The letter "s" is entered in the first column of the last card in the data deck to stop the program

simulation for the entire length of the weather record. Heat and water losses from the sprays are estimated from regression equations generated from program SPRCO and the drift-loss table generated from program DRIFT. The time of maximum ambient pond temperature and the 30-day period giving maximum water loss are determined from the simulation. Annual event statistics are generated for water loss and temperature maxima.

7.3.1 Program Operation

The program first reads and screens meteorological data from National Weather Service Tape Data Family-14 (TDF-14) magnetic tapes. Hourly or three-hourly values of up to 48 meteorological variables are stored on these tapes in a compact alphanumeric code. The program interprets the code and extracts the values of windspeed, dry-bulb temperature, wet-bulb temperature, dewpoint temperature, cloud cover, and atmospheric pressure.

The stored data are checked for missing or inconsistent values. If one or two consecutive observations of a meteorological parameter are missing, they will be replaced by interpolated values. If, however, more than two consecutive observations are missing or in error, the entire day of data is skipped and an informative message to this effect is printed.

The program synthesizes solar radiation needed for subsequent calculations from the cloud cover, date, and latitude, since no direct observations of solar radiation are contained in the TDF-14 tapes. This procedure is discussed in Section 5.2. Direct observations of solar radiation would be most desirable if available from other sources, but no provisions for their input are presently incorporated in the program.

The program then calculates the ambient pond temperature and evaporative loss with the mixed-tank model using the meteorological variables generated in subroutine SUB1. It is necessary to specify a base heat load, which should be the 30-day average design-basis heat load, because the spray performance models are highly nonlinear and sensitive to heat input. The yearly maximum pond temperature and yearly maximum 30-day evaporative and driftwater loss are determined along with their dates of occurrence.

The program statistically treats the data base consisting of the annual maximum pond temperatures and 30-day evaporations. The recurrence interval of the maximum water loss and temperature can be determined from this analysis.

7.3.2 Program Outputs

The program provides the following information, depending in some cases on the options selected:

(1) An informative message is printed if bad data are encountered, so that it is clear that the record for that day has been skipped.

(2) A table of hourly values of windspeed, dry-bulb temperature, wet-bulb temperature, solar radiation, atmospheric pressure, and dewpoint temperature is printed and/or punched (or stored in some other fashion) for the

20 days preceding the time of maximum ambient temperature and 30 days following. This table may subsequently be used in a more rigorous computation of thermally loaded pond temperature with program SPRPND or some other dynamic temperature model.

(3) The dates and quantity of the yearly worst-30-day-water-loss period for the spray pond with steady heat load is outputted. Since the 30-day-average design-basis heat load is used in this program, the water loss calculated in SPSCAN approximately adequately reflects the design-basis loss (other than seepage) without the need for subsequent modeling.

(4) Monthly averages of meteorological parameters for all specified years of the record are printed for the purpose of comparing offsite data with limited quantities of onsite data using program COMET2 which will be described later.

(5) The maximum annual pond temperatures and 30-day water losses for all years on the tape are printed, ranked from highest to lowest magnitude. Approximate probabilities are calculated so that the ranked outputs can be plotted on an arithmetic-probability scale. The mean and standard deviation of the data are also printed. Maximum likelihood and confidence limit curves are generated for the statistical adjustment of the design-basis water loss and temperature, as discussed in Appendix A.

7.3.3 Program Inputs

The following input data are necessary to run program SPSCAN:

(1) Pond surface area
(2) Pond volume
(3) Base heat load
(4) Latitude
(5) A TDF-14 weather tape from a representative station near the site

The TDF-14 weather tapes can be obtained for U.S. weather stations from the National Climatic Center, Federal Building, Asheville, North Carolina 28801.

Computer and peripheral requirements to run program SPSCAN on the Brookhaven National Laboratory CDC 7600 computer are one magnetic tape drive, two disk files and about 12,000 (decimal) words.

The data deck required to operate program SPSCAN consists of four types of data cards: the regression coefficient cards, the pond data card, the monthly average card, and the end card.

The regression coefficients for the spray performance equations are inputted in exactly the format in which they are punched by program SPRCO. There are 26 variables, read in format 4E15.8 on 7 cards.

The pond data, monthly average, and end cards are read in a namelist format called INPUT. The variables in this namelist are described in Tables 7.3 and 7.4.

7.3.4 Pond Data Card

This card specifies the pond parameters for the mixed-tank models and specifies certain printing options as shown in Table 7.3.

Table 7.3 Namelist INPUT--Pond Data Card for Program SPSCAN

Variable name	Value	Type and description
N	1-99	Integer--card number used to identify the card as a "pond data" card and to identify the results in the output
A	≥ 0	Real--pond surface area in square feet
	< 0	In acres
V	≥ 0	Real--pond volume in cubic feet
	< 0	In acre feet
LAT	25-50	Real--latitude of pond in decimal degrees north latitude
IPRNT		Integer--print option
	0	Prints and punches hourly meteorological data
	1	Printed output only
	-1	Punched output only
HEAT		Real--base-heat load, Btu/hr

7.3.5 Monthly Average Card

This card specifies the year and month to start computing monthly meteorological summaries to be used for comparison with onsite meteorological data in program COMET2, as shown in Table 7.4.

Table 7.4 Namelist INPUT--Monthly Average Card for Program SPSCAN

Variable name	Value	Type and description
N	Greater than 99	Integer--identifies this card as a "monthly average" card
YRMODY(1)	-	Real--the year of the beginning date for the computation of monthly averages of meteorological data
YRMODY(2)	5-9	Real--the month of the beginning date for the computation of monthly averages
LAT	25-50	Real--the latitude in decimal degrees north if different from that previously specified

7.3.6 End Card

By specifying N = 0, the program terminates.

One set of output is generated from each pond data card or monthly average card. These cards are unrelated and may be inserted in any order.

If a second pond data or monthly average card is used, say, to test the sensitivity to a variation in a pond parameter, only the variable changed needs to be inputted on the namelist card.

7.4 Program COMET2

Program COMET2 (COmpare METeorology) compares steady-state temperature, drift and evaporation rates computed from monthly average values of solar radiation, dry-bulb temperature, wet-bulb temperature, rms windspeed, and barometric pressure for two data sets.

Program SPSCAN computes the monthly averages of the meteorological parameters from the offsite weather station record provided on the National Climatic Center tape. The other data set would be taken from limited onsite measurements.

If onsite data are not complete (for example, if solar radiation is not available), the offsite data can be substituted for the missing parameters. The program calculates the steady-state temperature and 30-day water loss for each data set, the difference in calculated values of pond temperature, and the apparent differences in pond temperature due to differences between each of the meteorological parameters. Therefore, if one of the meteorological parameters for the site is unknown, the apparent differences due to only the other three parameters can still be determined.

The output values of onsite and offsite equilibrium temperature and evaporation rates are correlated for as many months as available to determine if there is a significant difference between the locations. The coefficient of determination r^2 is computed for pond temperatures and water losses for both onsite and offsite locations. A coefficient of determination of 0.9 would indicate that 90% of the variance in one data set is accounted for by variation of the other data set, and that 10% of the variation is unexplained.

The average equilibrium temperature difference and water loss rate difference between the two data sets are the <u>biases</u>. The biases may be used cautiously as correction factors to the peak thermally loaded-pond temperature and 30-day evaporation loss. The coefficient of determination r^2 should be high. Lower values may indicate poor quality data or real orographic differences between the sites. Because the data bases are generally small and may be incomplete, it is suggested that the biases be used only in the conservative sense; that is, if onsite values for pond temperatures or water losses are greater than corresponding offsite values, the difference should be added to the peak loaded-pond temperature or water loss as a correction. If the opposite is the case, no corrections should be made.

7.4.1 Program Inputs

Program COMET2 requires recording of monthly averages of dry-bulb temperature, wet-bulb temperature, solar radiation, rms windspeed, and barometric pressure for each site. The first card specifies the number of months of data (I), and is read in I5 format. The next I cards contain the information shown in Table 7.5.

Table 7.5 Meteorological Data Input for Program COMET2

Field	Variable name	Description
1	TW1	Wet-bulb temperature, °F, data set 1
2	TA1	Dry-bulb temperature, °F, data set 1
3	W1	Rms windspeed, mph, data set 1
4	H1	Solar radiation, Btu/(ft^2 day), data set 1
5	PB1	Atmospheric pressure, in. Hg, data set 1
6	TW2	Wet-bulb temperature, °F, data set 2
7	TA2	Dry-bulb temperature, °F, data set 2
8	W2	Rms windspeed, mph, data set 2
9	H2	Solar radiation, Btu/(ft^2 day), data set 2
10	PB2	Atmospheric pressure, in. Hg, data set 2

7.5 Program SPRPND

Program SPRPND calculates the temperature in the UHS pond under the combined influence of the meteorology and the external plant heat load. Hourly meteorological data are provided on cards, disk, or tape from program SPSCAN. The pond is represented by a simplified mixed-tank model used in the screening program SPSCAN. Maximum temperature is determined and the time of the occurrence of the maximum is printed.

7.5.1 Input to Program

Necessary input data for this program include a title card, the external heat input, meteorological conditions, volume and surface area, makeup, blowdown, leakage, circulation flowrate of the pond, height, length, and width of the spray field, and other parameters that describe the sprays.

The first data set consists of the spray performance and evaporation coefficients for the regression equations, punched directly from program SPRCO. There are 26 numbers, read in 4E15.8 format on 7 cards. The spray-pond performance can be calculated from either the regression equations or the self-contained HWS and LWS models, but these seven cards, or seven blank cards, must be read in.

The input data pertaining to the spray field itself are next read in from namelist PARAM, which is defined in Table 7.6.

Table 7.6 Namelist PARAM, Spray-Field Data for Program SPRPND

Parameter	Default value	Description
NDRIFT	-	Number of points in drift-loss table
WDR0	-	Lowest windspeed in drift-loss table, mph
DWDR	-	Windspeed increment of table, mph
FDRIFT	-	Array of drift-loss fractional values
CEMAX	0.1	Maximum allowed evaporation fraction
CEMIN	0.0	Minimum allowed evaporation fraction
CMAX	0.8	Maximum allowed spray efficiency
CMIN	0.2	Minimum allowed spray efficiency
VEL0	22.5	Initial velocity of drop leaving nozzle, ft/sec*
THETA	71.0	Initial angle with respect to horizon of drop leaving nozzle, degrees*
R	0.104	Average drop radius, cm*
HT	-	Height of spray field, ft*
WID	-	Width of spray field, ft (short dimension)*
ALEN	-	Length of spray field, ft (long dimension)*
Y0	5.0	Height of sprays above water surface*, ft
PHI	80.0	Angle of wind direction with respect to long axis, degrees*
ISPRAY	2	If ISPRAY = 1, use regression model for spray performance If ISPRAY = 2, use rigorous model

- = no default value
* = these variables need to be read in only for rigorous model, i.e., ISPRAY=2
0 = zero

The meteorological data are inputted next. Meteorological data are generally provided directly from program SPSCAN. The first card in the meteorological deck specifies the number of time periods in the table and is read in I5 format. The subsequent cards are read two time periods (usually 1 hr each) per card in the format shown in Table 7.7 as punched by program SPSCAN. (Typically, the meteorological table itself would be stored on a disk or tape file rather than on punched cards. In the present version of the program, this table is read from logical file number 8.)

Table 7.7 Meteorological Input for Program SPRPND
[Format (I3, 3F5.0, F6.0, F7.0, F7.0,
3F5.0, F6.0, F7.0, F7.0)]

Field	Variable	Description
1	ISEQ	Sequence number--not used
2	W(I)	Windspeed, mph
3	TA(I)	Dry-bulb temperature, °F
4	TD(I)	Dewpoint temperature, °F
5	HS(I)	Solar radiation Btu/(ft^2 day)
6	TW(I)	Wet-bulb temperature, °F
7	PRESS(I)	Atmospheric pressure, psia
8	W(I+1)	Windspeed, mph
9	TA(I+1)	Dry-bulb temperature, °F
10	TD(I+1)	Dewpoint temperature, °F
11	HS(I+1)	Solar radiation, Btu/(ft^2 day)
12	TW(I+1)	Wet-bulb temperature, °F
13	PRESS(I+1)	Atmospheric pressure, psia

The heat-and-flowrate table is inputted next. The plant-heat rejection and UHS flowrate during the design accident should be plotted on a log-linear scale, with heat and flowrate on the linear scale and time on the logarithmic scale. A table of heat and flowrate to the pond versus time should then be created from a straight line approximation of the graph. This procedure must be followed because a log-linear interpolation of the heat and flowrate table is used in the program. Also, plant-heat rejection is often provided directly in this graphical form.

Heat and flowrate are inputted in a namelist format named HFT as shown in Table 7.8.

Table 7.8 Namelist HFT for Program SPRPND

Variable name	Description
HEAT	An array of values of the heat load on the pond, Btu/hr
FLOW	An array of values of the flowrate through the sprays, ft^3/hr
TH	The array of values of time corresponding to the element of the HEAT and FLOW arrays, hr
NH	The number of entries in the table (maximum of 20)

It should be noted that the start of the heat and flowrate table does not necessarily have to correspond to the start of the meteorological input table. The time for the start of the heat-and-flowrate table is delayed by a variable TSKIP(hr) to be described.

Pond parameters and constants are read next in a namelist format called INLIST. The variables in INLIST are described in Table 7.9.

Multiple runs may be made by inserting several title and INLIST cards in succession. Only the variables that are different from the previous namelist card read are changed. A blank title card terminates the program.

7.5.2 Usage of Program SPRPND

Program SPRPND is usually employed to determine maximum pond temperature in the following manner:

(1) Two initial pond simulations should be performed (in the same run):

   (a) The first run simulates the pond ambient temperature resulting only from meteorological inputs with a constant base heat load H1 and flowrate F1 specified.

Table 7.9 Namelist INLIST for Program SPRPND

Variable name	Default value	Description
VZERO	0.0	Pond volumes, ft^3--if zero, terminates program
BLOW	0.0	Blowdown flowout, ft^3/hr
A	0.0	Pond surface area, ft^2
NSTEPS	100	Number of timesteps to be performed
NPRINT	10	Printouts of pond temperature and volume every NPRINT steps
DT	0.2	Integration timestep, hr
TZERO	80	Initial pond temperature, °F
TSKIP	0	Time after start of program that corresponds to start of heat-and-flow table. Shifts this table relative to meteorology table which starts at time zero. For time less than TSKIP, evaporation is suppressed so that the pond volume does not decrease
QBASE	0	Bias to be added to all **heat** in heat-flow table, Btu/hr
FBASE	0	Bias to be added to all flowrate in heat-flow table, ft^3/hr
Q1	0	Heat load for time less than TSKIP, Btu/hr
F1	1	Flow through sprays for time less than TSKIP, ft^3/hr
HEAT FLOW NH	Same as specified by previous input in namelist HFT	Heat-flow table if different from that specified by previous input in namelist HFT
ISPRAY	2	If ISPRAY = 1, uses regression equations for spray performance If ISPRAY = 2, uses HWS and LWS performance models directly
IMET	0	If IMET = 0, regular meteorological table used If IMET = 1, constant values TA, TW, W, TD, HS, and PB are used for dry-bulb temperature, wet-bulb temperature, windspeed, dewpoint, solar radiation, and atmospheric pressure as defined in this namelist
TA	90	Constant dry-bulb temperature, °F
TD	60	Constant dewpoint temperature, °F
TW	70	Constant wet-bulb temperature, °F
W	3	Constant windspeed, mph
HS	1500	Constant solar radiation, $Btu/hr/ft^2$
IEVAP	1	If IEVAP = 0, water level in pond remains constant If IEVAP = 1, normal water loss allowed
TSPRON	0	Delay turning on sprays TSPRON hours. Also maintains full pond until sprays are turned on
NITER	0	Repeat run NITER times, incrementing the value of TSKIP and TSPRON by the value DTITER. Used in procedure 2 to determine maximum pond temperature (see paragraph 8.6.2)
DTITER	5	Increment for iterative procedure above, hr

    (b) The second simulation determines the peak pond temperature from the effects of external heat input only. This is done by specifying constant values of the meteorological variables.

(2) A second run is prepared so that peak ambient pond temperature determined from the first simulation will roughly coincide with the peak excess temperature caused by plant input alone:

    (a) By inspection of the two previous simulations the times of peak temperature for each are chosen.

    (b) The approximate time to delay the start of the heat input TSKIP and TSPRON is then defined:

TSKIP = (time of peak ambient temperature) - (time of peak excess temperature).

    (c) The peak pond temperature should occur at approximately the same time as the peak temperature determined for the steady heat load.

Because of nonlinearities in the pond models, the time to the peak temperature may be shifted. An alternative procedure which increments values of the TSKIP and TSPRON for multiple runs may be preferred for determining peak temperature. (See paragraph 8.6.2.) The difference in the final peak temperatures determined will generally be minor.

Either the regression equations (ISPRAY = 1) or the HWS/LWS performance models (ISPRAY = 2) may be used. The latter option has higher accuracy, but the computations are much more time consuming, and may be prohibitive for more than several runs. The regression equations generally give adequate results.

An example run of all programs from start to finish will be covered in the next section.

8 SAMPLE PROBLEM

8.1 Introduction

A complete study of a hypothetical UHS spray pond was undertaken in order to demonstrate the procedure for evaluating the design-basis performance. Details of pond design and meteorology are taken from no plant in particular, but represent eastern U.S. sites and environments. It would be useful to follow the flowchart in Figure 7.1 as an aid in understanding the procedures used.

A plan view of the pond is shown in Figure 8.1. The design-basis heat load is shown in Figure 8.2. Other parameters characterizing the pond are given in Table 8.1.

The spray nozzles are assumed to be of a type similar to the Spraco 1751A, operating at standard pressure and arranged in accordance with the manufacturer's recommendations but with a somewhat different drop-diameter distribution. The drop-diameter distribution for this nozzle is available in only 10 ranges, and given in Table 8.2.

The 28-year tape record (1948-1975) from Harrisburg, Pennsylvania was ordered from the National Climatic Center, Asheville, North Carolina 28801 in TDF-14 format. The spray pond was assumed to be located at the site of the Susquehanna Nuclear Generating Station, although the pond design and heat loads used are not those of this plant, and should not be directly compared. Approximately 15 months of May-October onsite meteorological data were available from the site for a direct side-by-side comparison with the Harrisburg data.

The design-basis evaluation consists of running five programs sequentially as shown in Figure 7.1:

(1) Program SPRCO estimates the regression equations for spray performance for subsequent use in other programs;

(2) Program DRIFT estimates the drift loss for the sprays in the pond configuration as a tabular function of windspeed;

(3) Program SPSCAN scans the TDF-14 meterology tape to determine the periods of most adverse performances and their recurrence intervals;

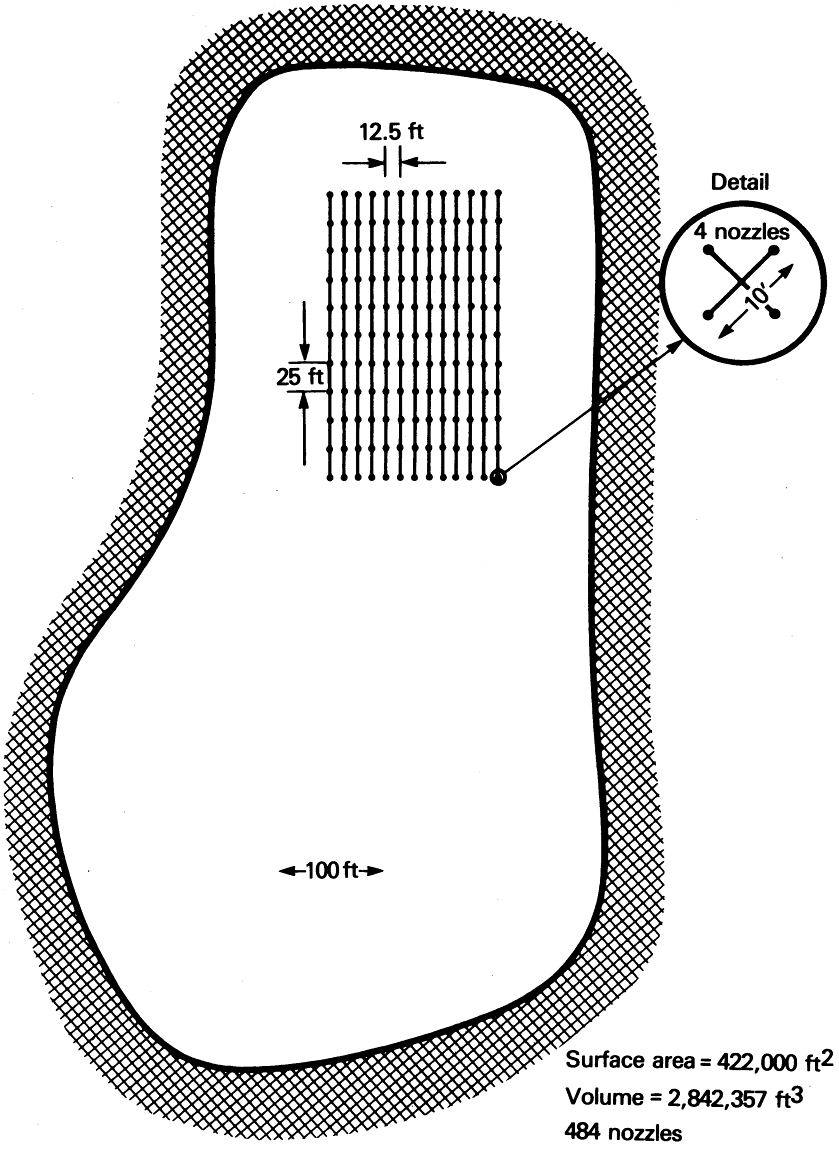

Figure 8.1 Hypothetical spray-cooling pond

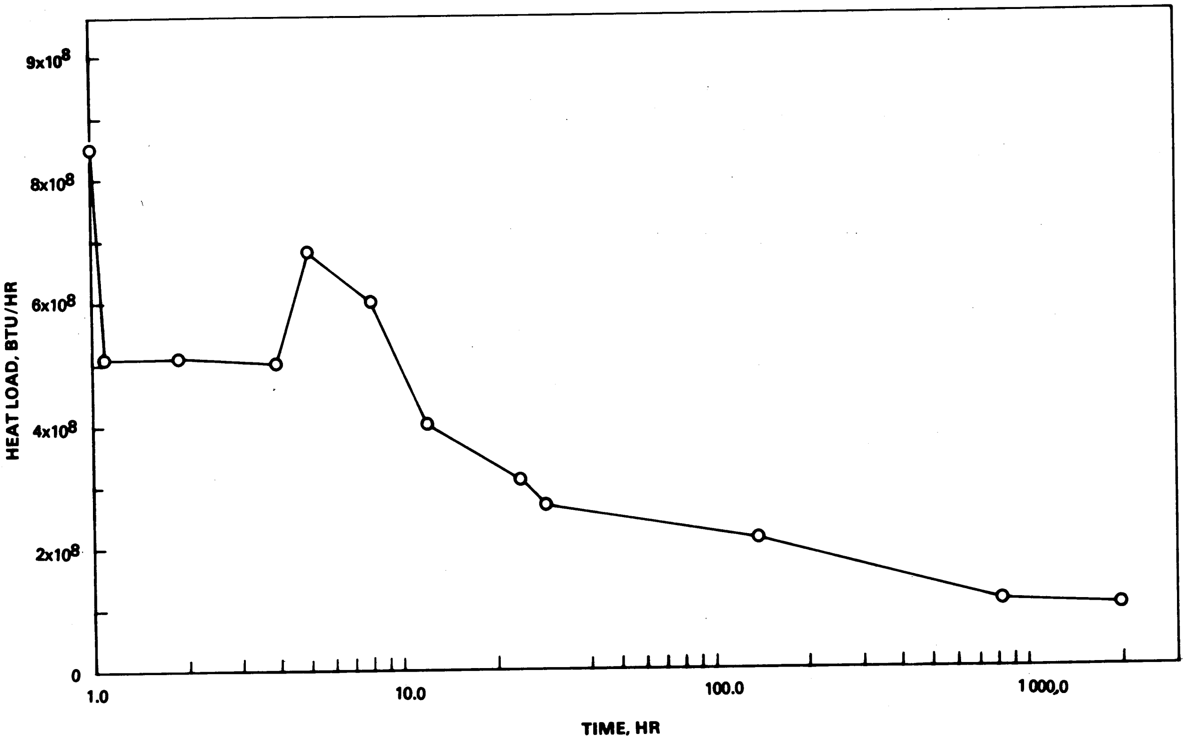

Figure 8.2 Example of design-basis heat load

Table 8.1 Parameters of Spray-Pond Example

Variable	Quantity
Initial pond volume	2,942,357 ft^3
Pond surface area	422,000 ft^2
Flowrate through sprays	57 cfs
Number of nozzles	484
Nozzle pressure	7 psig
Width of spray field	183 ft
Length of spray field	283 ft
Height of nozzles above initial surface	5 ft
Height attained by spray, above nozzles	7 ft

Table 8.2 Drop-Diameter Spectrum for Spray Nozzle

Diameter, Cm	Volume fraction, %
0.067	10
0.108	10
0.135	10
0.166	10
0.198	10
0.220	10
0.243	10
0.279	10
0.324	10
0.405	10

(4) Program COMET2 compares onsite versus offsite meteorology to predict correction factors for pond temperature and evaporation;

(5) Program SPRPND predicts the uncorrected design-basis pond temperature.

The step-by-step analysis of this spray pond is demonstrated below.

8.2 Determining Characteristics of Spray Field

The first step in the analysis is to determine the inputs for the spray performance model.

8.2.1 Dimensions of Sprayed Region

The average angle of the droplets leaving the spray nozzle can be determined from photographs of sprays operating at the design pressure, or from promotional literature from the spray-nozzle manufacturers. The literature indicated that the spray from the nozzles will reach a height of about 7 ft above the nozzles at a pressure of 7 psig. The heaviest accumulation of water will occur at a radius of about 13 ft. If friction between the drop and the air is neglected, simple ballistics indicates that the initial drop velocity should be about 22.47 ft/sec and the initial angle of the drop trajectory with the horizon should be about 71°.

8.2.2 Average Drop Diameter

The drop-diameter distribution for the nozzle is presented in Table 8.2. Since the distribution is given as tabular values in 10 equal divisions, the discrete summation form of Eq. 2.52 is used for the mean diameter:

$$D_{\frac{1}{2}} = \frac{\sum_{i=1}^{10} \sqrt{D_i}}{\sum_{i=1}^{10} \frac{1}{\sqrt{D_i}}}$$

The mean diameter calculated from the above equation is about 0.19 cm.

8.2.3 Length and Width of Spray Field

The arrangement of sprays is shown in Figure 8.1. The center of each cluster of four nozzles (inset, Figure 8.1) is on 12.5-ft spacing in one direction and 25-ft spacing in the other direction. The overall distance between nozzles is, therefore, 257.1 ft in the long direction and 157.1 ft in the short direction. The actual width of the spray field extends about 13 ft further on each side, which is the radius of the spray umbrella from each nozzle. The length and width of the spray field are, therefore, 283 ft and 183 ft, respectively.

8.3 Spray-Field Performance Regression Equations--Program SPRCO

Program SPRCO generates the coefficients of several regression equations which are used to represent the spray performance models in subsequent programs SPSCAN, COMET2, and SPRPND. Figure 8.3 shows the input cards for program SPRCO set up in accordance with Section 7.1.

Ranges of meteorological variables were chosen to bound those of the site. Other climates might dictate different ranges. The sprayed temperature chosen is rather high, which places emphasis on the performance of the pond under high-heat-load conditions.

```
$INPUT NPNTS=200,HT=12,ALEN=283,WID=183,VELO=22.47,THETA=71,YO=5,R=.095,
PB=29.92,Q=57,PHI=90,TWETO=50,DTDRYO=20,WINDO=0.1,THOTO=90,RTW=30,RW=20,RTH=30,
RTD=30$
```

Figure 8.3 Input deck for program SPRCO

The output from program SPRCO is shown in Figure 8.4. The high coefficients of determination and relatively small scatter indicate that the regression equations for cooling and evaporative loss should be consistent predictors of the basic performance models. The regression coefficients are outputted on punched cards for subsequent use.

8.4 Determining Drift-Loss Table--Program DRIFT

A table of drift loss versus windspeed is necessary for subsequent use in programs SPSCAN, COMET2, and SPRPND. The arrangement of the spray field with respect to the most critical direction for drift loss is shown in Figure 8.1. Data inputs to program DRIFT are given in Figure 8.5. Although the drop-diameter distribution of Table 8.2 is somewhat different from the Spraco 1751A distribution, only the default distribution is used. Drift is generally only a small contribution to total water loss, and the difference in this case was judged insignificant. If the correct distribution were to be used, a finer division of the scale, especially toward the smaller drop diameters, would be necessary. The output from program DRIFT for the default distribution is shown in Figure 8.6.

```
                    COEFFICIENTS FOR EFFICIENCY AND EVAPORATION
FROM A SPRAY FIELD


                    INPUT VARIABLES


         NUMBER OF RANDOM POINTS,NPNTS =   200
         INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO =      22.47 FT/SEC
         INITIAL ANFLE OF DROPS TO HOR., THETA =     71.000 DEGREES
         GEOMETRIC MEAN RADIUS OF DROPS, R =      .0950 CM
         ATMOSPHERIC PRESSURE, PB =      29.92 INCHES HG
         HEIGHT OF SPRAY FIELD, HT =      12.00 FT
         WIDTH OF SPRAY FIELD, WID =      183.0 FT
         LENGTH OF SPRAY FIELD, ALEN =      283.0 FT
         HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, YO =       5.0 FT
         FLOWRATE OF WATER SPRAYED, Q =      57.00 CU.FT./SEC
         HEADING OF WIND W.R.T.LONG AXIS, PHI =      90.00 DEGREES


                              RANGES OF METEOROLOGICAL PARAMETERS
         WET BULB TEMPERATURE =      50.000 TO    80.000 DEG.F
         DRY BULB TEMPERATURE =      70.000 TO   130.000 DEG.F
         WIND SPEED =       .100 TO    20.100 MPH
         SPRAYED TEMPERATURE =     90.000 TO   120.000 DEG.F

PT NO.   TWET      TDRY      THOT      WIND        HUMID     ETA       ETA       EVAP.        EVAP.
          F         F         F        MPH                  LWS       HWS       LWS          HWS

    1  67.4034  115.9188   98.9286  15.8274      .0033  *******     .5380   *********      .020377
    2  63.6110   83.7989   99.1695   5.6147      .0079    .4149     .3835     .013030      .011946
    3  70.6730  102.1529  114.9557   2.7581      .0088    .4544     .3241     .019007      .012913
    4  67.4894   90.4482  108.6134   5.6310      .0091    .4553     .4208     .016761      .015325
    5  79.3804  120.1969   96.3628  18.7895      .0122  *******     .6291   *********      .015147
    6  72.9555  121.2013  107.5499   5.8861      .0063  *******     .4503   *********      .016922
    7  77.0908  123.6912  101.8945  10.0333      .0093  *******     .5444   *********      .016790
    8  76.1547  124.0878   96.2884  12.0097      .0084  *******     .5596   *********      .015672
    9  76.6438  110.5680  103.4017  12.6606      .0119  *******     .5640   *********      .016678
   10  63.7355   90.7825  107.7358  15.3719      .0064    .4359     .5209     .017421      .021192
   11  63.3150   98.1664   96.3034  18.5362      .0045  *******     .5156   *********      .018110
   12  74.9604   99.5406  110.3361  17.0259      .0130    .4561     .5875     .015159      .019981
   13  77.7856  108.6317   98.4362   5.1585      .0134  *******     .4255   *********      .009660
   14  61.3496   84.1540  109.9794   6.3540      .0064    .4549     .4196     .019059      .017558
   15  69.5134  104.8221  101.5942   3.7755      .0073  *******     .3436   *********      .010932
   16  71.3049  112.9713   90.4744  12.9280      .0069  *******     .5263   *********      .013812
   17  62.6886   94.3131  116.9105  12.1842      .0049    .4635     .5176     .022789      .025712
   18  77.2425  114.4053  113.5303   2.5335      .0116  *******     .3211   *********      .011077
   19  67.6711   96.0390   96.9980   9.1525      .0080    .3888     .4640     .011624      .013746
   20  68.7162  112.8469  105.4877   2.8467      .0049  *******     .2978   *********      .010872
   21  69.0083  111.2167  105.2128  14.1406      .0055  *******     .5422   *********      .021321
   22  72.4562  109.3174  104.5630   6.2623      .0086  *******     .4498   *********      .014952
   23  75.6357  121.2607  105.0449  13.8731      .0086  *******     .5792   *********      .020161
   24  56.0361   81.5676  115.7457   6.0561      .0037    .4605     .4097     .023309      .020749
   25  53.6464   80.2143  118.6083  16.3569      .0027    .4632     .5072     .025324      .028258
   26  66.0732  103.3842  100.8678  14.7033      .0052  *******     .5201   *********      .019210
   27  69.3244  104.5041  101.5334  17.8440      .0073  *******     .5537   *********      .019146
   28  72.9292  119.3568   92.2437   2.6840      .0067  *******     .2651   *********      .006386
   29  72.9469  120.4440  105.2067  15.3963      .0065  *******     .5756   *********      .021750
   30  65.6499  114.2279  117.5436  19.2457      .0024    .4336     .5784     .022758      .031003
   31  72.5336  102.1859  117.3421  16.1745      .0103    .4762     .5876     .019962      .025103
   32  75.0965  105.6050  103.7690  16.1169      .0117  *******     .5771   *********      .017556
   33  66.2869  112.3171   98.8206   6.9498      .0033  *******     .4295   *********      .015601
   34  71.0051   92.4416   91.9975   3.8862      .0113  *******     .3307   *********      .006774
   35  65.8917  100.6496  101.1688   2.2234      .0056    .3897     .2368     .014099      .007846
   36  51.0901   76.6584  110.8489  18.4939      .0022    .4355     .4878     .021699      .024855
   37  68.6926  117.0634  107.8917  19.2171      .0040  *******     .5762   *********      .025237
   38  65.7140   95.8163  107.6715   4.8479      .0066    .4219     .3894     .016621      .014989
   39  68.8206  101.2450  110.1299   9.0038      .0076    .4174     .4965     .016510      .019756
   40  55.7223   93.8110  108.1511  10.5547      .0008    .3989     .4583     .019600      .022675
   41  54.4359   89.5847  101.3530   6.2148      .0010    .3737     .3744     .016444      .016277
   42  55.4213   83.3247   99.0454  16.4184      .0030    .3893     .4719     .015290      .018918
   43  79.4392   99.5306   91.5599   5.9521      .0171  *******     .4445   *********      .006209
   44  56.5438   92.2766  106.1011   2.1938      .0016    .3966     .2287     .018364      .010011
   45  67.7047  110.1276   91.9911   1.0133      .0048  *******     .1055   *********      .002781
   46  52.2689   84.5510  113.8613   8.9372      .0010    .4367     .4401     .023504      .023800
   47  62.1334  104.9040  103.1690   8.3484      .0022  *******     .4465   *********      .018832
   48  53.5962   90.3111  109.6218  12.3392      .0004    .4116     .4681     .021101      .024257
```

Figure 8.4 Output from program SPRCO

```
 49   71.8194   97.8476  100.4904   18.8526    .0107     .4079    .5624      .011680      .016444
 50   58.3695   91.8028   95.6111   13.6956    .0028     .3502    .4651      .012886      .017369
 51   78.6444  102.3428   90.7101    8.5383    .0156  ********    .5035   **********      .007661
 52   70.3325   91.3590  107.4342    5.5791    .0110     .4555    .4267      .015186      .014074
 53   54.9284   92.8665  114.2647    4.2193    .0006     .4291    .3511      .023300      .018558
 54   60.1730   90.6156   91.8128    1.4641    .0042     .3554    .1432      .011434      .004185
 55   56.1549   80.2818   97.6986   16.4833    .0041     .3950    .4703      .014412      .017541
 56   59.4876   87.2057   91.8161    1.1705    .0045     .3226    .1154      .010026      .003352
 57   69.0714  113.9063  110.7897    6.2578    .0049  ********    .4510   **********      .019149
 58   65.6746  113.0471   99.5546   15.6650    .0027  ********    .5278   **********      .020772
 59   63.5147  101.1542  102.4783    6.5767    .0039     .3891    .4166      .015448      .016132
 60   67.0307   88.2855  105.7960    1.7116    .0093     .4471    .2081      .015401      .006861
 61   69.6083  109.1265  108.2640   19.0745    .0064  ********    .5753   **********      .023480
 62   78.2613  125.4515  111.8672   12.6241    .0100  ********    .5945   **********      .022694
 63   59.9315  106.1264   96.2880    7.9430    .0005  ********    .4171   **********      .016579
 64   67.5132  100.1693   99.9405   17.1177    .0069  ********    .5360   **********      .018191
 65   58.9288   95.9033  100.0849    7.3330    .0022     .3621    .4091      .014747      .016489
 66   78.1897  113.7561  101.3892   12.5969    .0126  ********    .5717   **********      .015552
 67   66.6298   94.3767   95.9493    5.7640    .0076     .3723    .3919      .011011      .011268
 68   64.2434  113.7548   90.9821   10.5420    .0016  ********    .4648   **********      .015929
 69   59.8068   93.0472  109.0746    6.1812    .0034     .4207    .4095      .019166      .018429
 70   74.3182   96.6462   99.0229   10.4864    .0131     .4120    .5135      .010155      .012674
 71   61.0001  105.2545  105.0803    2.8782    .0014  ********    .2795   **********      .011768
 72   58.0411   82.6889   94.1253    5.4050    .0046     .3732    .3484      .012279      .011297
 73   64.3971  110.8943   92.2571    6.5829    .0023  ********    .3999   **********      .013257
 74   66.9483   96.0381  116.1524   15.1604    .0074     .4713    .5530      .021153      .025213
 75   77.3562  102.1617  104.8187    6.5793    .0145     .4364    .4766      .011977      .012820
 76   72.9537  113.9999  111.9333    5.9842    .0080  ********    .4618   **********      .018170
 77   76.9588  111.5965  118.5848    1.5527    .0119     .4717    .2396      .019282      .009035
 78   79.0883  100.3738  111.8250   17.4999    .0165     .4787    .6117      .014600      .019093
 79   51.1801   83.2446   99.6720   20.0928    .0007     .3790    .4716      .016631      .021198
 80   79.9590  100.7945   95.4169    9.8881    .0173  ********    .5322   **********      .009141
 81   72.7173  122.5141  104.2142   11.6365    .0058  ********    .5434   **********      .020278
 82   70.1080  100.6791   91.4884   12.1836    .0087  ********    .5025   **********      .012442
 83   61.4963   86.2209  106.0671   13.9953    .0060     .4347    .4985      .017156      .019997
 84   61.9210   97.4075  106.4095   19.1029    .0037     .3876    .5310      .016492      .023274
 85   63.8127  100.0225  103.3220    3.4352    .0044     .3901    .3142      .015424      .011732
 86   72.4654  121.6405  114.1130   13.4156    .0058  ********    .5744   **********      .025972
 87   52.4328   86.9093  117.0768   18.4850    .0006     .4441    .5105      .025293      .029624
 88   58.0944  100.7889  104.3526    4.5358    .0006     .3755    .3466      .017402      .015413
 89   68.6256   90.5076  113.9251   11.0905    .0099     .4833    .5234      .019258      .021075
 90   63.5293  105.6638   91.2158   10.2672    .0029  ********    .4545   **********      .014903
 91   57.9937   85.4488   95.7425     .4734    .0040     .3703    .0473      .012977      .001380
 92   57.9713   96.7101  118.1942    9.9329    .0015     .4457    .4832      .024748      .026921
 93   65.2281   97.4012   99.3172   19.5465    .0059     .3896    .5329      .013442      .018720
 94   72.7199  104.0671  106.0756    6.0870    .0100     .4297    .4485      .014514      .014718
 95   68.5792  113.9043   98.8573    6.9392    .0046  ********    .4391   **********      .015092
 96   63.4203   98.3815   95.7829   13.8597    .0045  ********    .4906   **********      .016865
 97   56.7413   92.3483  112.4770   19.1774    .0017     .4289    .5211      .021870      .027121
 98   79.9125  120.6913   98.2020    4.4492    .0126  ********    .4083   **********      .009232
 99   78.8285  127.2704   93.1343   18.1476    .0101  ********    .6387   **********      .015174
100   64.8418   92.5447   92.9948   10.5771    .0068     .3692    .4599      .010652      .013219
101   64.7569   95.1750   90.5651   19.7177    .0061  ********    .5148   **********      .014690
102   70.3287  111.6158  108.0073    4.7942    .0064  ********    .4049   **********      .015339
103   79.8324  122.5774  101.1812   13.7402    .0121  ********    .5999   **********      .016546
104   50.2843   84.3593  111.8900    4.1588    .0000     .4237    .3312      .022954      .017607
105   67.6379  105.7145  104.8616    4.3632    .0057  ********    .3714   **********      .013595
106   76.5129   97.4769   93.7958    3.8063    .0148  ********    .3503   **********      .006151
107   50.2871   75.6865  100.6088   13.8789    .0020     .3996    .4415      .017028      .019177
108   61.1566   94.0369   94.6069   13.5144    .0040     .3622    .4740      .012411      .016340
109   61.6523   92.7169  100.8256   19.4719    .0046     .3774    .5171      .014091      .019873
110   68.7779   96.4446   90.5561   10.0251    .0087  ********    .4686   **********      .011255
111   69.2385   89.9574  114.4638   13.8699    .0105     .4891    .5480      .019320      .021985
112   79.2581  128.2571  118.6875    2.8362    .0102  ********    .3623   **********      .014153
113   51.0051   79.0942   99.0560     .6522    .0016     .3881    .0671      .016336      .002695
114   61.0026   87.8337  113.3350   17.5152    .0053     .4585    .5307      .021103      .024898
115   71.1008  105.0568  104.6273   12.2713    .0085  ********    .5325   **********      .018511
116   72.2442   93.8480  112.2074   15.0614    .0120     .4800    .5651      .017231      .020637
117   53.6169   79.2727  113.8384   11.5373    .0029     .4496    .4683      .022772      .024064
118   58.6711   83.3907  103.7567    7.1649    .0049     .4223    .4115      .016708      .016269
119   64.5140  105.3610   93.9220    2.3925    .0036  ********    .2284   **********      .006941
120   57.2807   91.5981   96.8422   16.0434    .0022     .3258    .4767      .012430      .018808
121   64.1858   93.1116  103.4380    8.3820    .0062     .4029    .4521      .014877      .016711
122   79.2938  107.4412  109.2870    3.8628    .0151     .4594    .4012      .013957      .011532
123   66.6769  116.0519  100.5806   17.3038    .0027  ********    .5451   **********      .021838
124   69.1430  103.5153  113.7618     .5781    .0074     .4301    .0842      .018342      .003336
125   56.3752   84.8528   99.7334   18.1018    .0032     .3890    .4846      .015302      .019508
126   61.9749   88.3719  107.5155   10.3578    .0058     .4367    .4758      .017814      .019565
127   79.0554  103.2812   99.1784   11.1396    .0158  ********    .5493   **********      .011949
128   68.7923   98.1392  116.8077   15.5832    .0083     .4741    .5653      .020929      .025380
129   73.2131  108.5415  113.5956   17.6234    .0094     .4494    .5946      .018027      .024338
130   55.4639   82.9496   99.7177   14.8472    .0031     .3939    .4656      .015593      .018775
```

Figure 8.4 (Continued)

```
 131   61.3000   88.8576  114.7576   11.8224     .0053     .4627     .5029     .021826     .023983
 132   74.4032  114.3866  105.0155    4.1364     .0091   *******     .3858   *********     .012270
 133   51.5690   84.2426  109.8430   13.8297     .0007     .4206     .4693     .021596     .024458
 134   50.5931   70.6975  116.9882   11.2832     .0032     .4588     .4612     .024244     .024867
 135   52.2620   78.0522  116.2913   11.9360     .0025     .4544     .4720     .024269     .025602
 136   61.6710   83.1307   99.7283   19.2615     .0068     .4126     .5079     .013825     .017451
 137   73.8796  113.5426  101.2148   13.5128     .0088   *******     .5563   *********     .017638
 138   51.1270   72.2501  116.4497   17.3699     .0032     .4580     .4947     .024042     .026575
 139   72.7124  107.6576  101.4917    5.8419     .0092   *******     .4323   *********     .013030
 140   78.6340  115.3275   93.9846   16.2058     .0126   *******     .6036   *********     .013078
 141   56.7777   95.2767   94.6560   15.5823     .0011   *******     .4699   *********     .018627
 142   64.6105  109.8044  119.4119   13.4093     .0027     .4098     .5453     .021677     .029597
 143   71.3983   95.3890  110.7226   18.1067     .0110     .4620     .5743     .016628     .021133
 144   77.9664  126.3154  100.1681    9.9117     .0095   *******     .5477   *********     .015976
 145   78.5490   99.8391  105.1210    8.7062     .0161     .4142     .5223     .010540     .013434
 146   57.5637   89.1638  116.5244   11.9659     .0029     .4553     .4944     .023809     .026122
 147   73.2727  121.2378  109.8102    3.1316     .0066   *******     .3398   *********     .012620
 148   64.6853   93.5201  105.9272   15.9243     .0064     .4181     .5253     .016070     .020609
 149   68.2226   94.7813   99.4242    8.8357     .0087     .3580     .4662     .010750     .014201
 150   74.6831  109.0938  107.2351    1.6844     .0105   *******     .2199   *********     .006741
 151   66.0542   89.9826   97.0707   15.1379     .0082     .3784     .5066     .011097     .015212
 152   74.1215  117.6612  105.9791    7.8658     .0081   *******     .4977   *********     .017477
 153   76.7173  123.7331  109.4219   18.9267     .0089   *******     .6226   *********     .023748
 154   57.0949   90.9050  106.2536   10.2591     .0022     .4047     .4551     .018393     .020819
 155   58.1275   93.6501  108.8546   13.7410     .0022     .4115     .4935     .019437     .023661
 156   54.3402   87.3218  113.2785    7.4716     .0015     .4362     .4255     .022818     .022219
 157   71.7842  106.3771   97.3862    3.8282     .0087   *******     .3435   *********     .009226
 158   75.5373  122.6951  110.5109    2.5525     .0081   *******     .3079   *********     .010840
 159   57.2252   98.2442  106.6623   15.8426     .0007     .3685     .4992     .017543     .024399
 160   56.5473   77.6957   92.6084    8.9358     .0049     .3786     .4036     .011930     .012831
 161   64.4577  111.0088  110.1480    7.9576     .0023   *******     .4659   *********     .021685
 162   56.7155   99.4639  117.3073   13.4489     .0001     .4283     .5069     .024351     .029193
 163   72.0759  114.8235  107.5444   16.5400     .0071   *******     .5777   *********     .022581
 164   55.6898   90.2117  109.4029   19.4244     .0016     .4179     .5103     .020478     .025549
 165   62.3659   83.1844   99.3503   13.3041     .0072     .4132     .4812     .013454     .015951
 166   62.9510   94.7213   99.7866   17.8437     .0050     .3612     .5154     .012931     .019018
 167   66.6190   93.2614  106.3580    4.1365     .0078     .4287     .3628     .015763     .012969
 168   79.4957  114.5755  113.9865   11.4705     .0136   *******     .5863   *********     .020950
 169   68.7722  114.9594   93.8845    5.8484     .0045   *******     .4023   *********     .012248
 170   64.3319  111.0137   99.7700   12.3209     .0022   *******     .4969   *********     .019850
 171   79.3533  120.9988  119.5969   14.4833     .0120   *******     .6239   *********     .026386
 172   56.9720   79.0464   93.8202    7.5818     .0040     .3814     .3890     .012376     .012655
 173   58.3138   83.2309  110.1849   10.7160     .0047     .4466     .4704     .019965     .021265
 174   51.4455   81.6802  117.7597    2.7979     .0012     .4513     .2883     .025553     .016039
 175   58.3238   89.4820  101.8941    8.8074     .0033     .3899     .4324     .015794     .017560
 176   75.5881  108.8309   97.5416   13.8105     .0114   *******     .5593   *********     .014463
 177   63.6032  105.1123  119.6778   12.2361     .0031     .4419     .5313     .023583     .028708
 178   65.6732  105.6303  113.1837    2.8961     .0044     .4075     .3138     .018837     .013769
 179   65.6493  112.4201  115.5197   13.7300     .0028     .4289     .5450     .021643     .027777
 180   58.2750   95.1571  107.5181   18.3230     .0020     .3975     .5146     .018483     .024504
 181   60.1580   85.6616  118.8807    1.4109     .0053     .4788     .1974     .024169     .009711
 182   76.9950  126.6796  116.0926   12.2467     .0085   *******     .5920   *********     .025492
 183   69.9647   90.4464  118.5879   10.7991     .0110     .5063     .5361     .021362     .022856
 184   57.5646   92.8684  112.1333   11.1285     .0021     .4287     .4788     .021467     .024164
 185   72.1245  108.8369  101.4905   17.7975     .0085   *******     .5705   *********     .018733
 186   61.5944   85.8952   95.7620   18.2366     .0061     .3805     .4975     .012027     .016129
 187   63.1549   93.7709  119.5039   15.5678     .0053     .4767     .5461     .024117     .028055
 188   65.6625  101.4808  116.4901   17.9258     .0053     .4479     .5645     .021445     .027625
 189   72.8020  109.5644  118.9666   13.6729     .0088     .4428     .5808     .019693     .026450
 190   57.7963   78.7206  110.3588   10.2728     .0054     .4534     .4634     .019846     .020570
 191   65.9348   93.1745  114.5765   17.8526     .0074     .4688     .5569     .020537     .024871
 192   72.4141  105.4053   93.4107   11.3346     .0095   *******     .5121   *********     .012790
 193   70.1000   99.7839  102.0029    5.7930     .0089     .4015     .4203     .012879     .013113
 194   50.9828   75.4225  105.9585   13.8405     .0024     .4210     .4556     .019275     .021263
 195   69.4827  118.2645   90.2725    4.7112     .0043   *******     .3598   *********     .009863
 196   71.4134  101.5811  110.0976   16.1022     .0096     .4270     .5680     .015822     .021580
 197   73.5714  104.0047   94.4088    5.3200     .0108   *******     .4040   *********     .009282
 198   64.4607  111.3646  108.5826    7.7821     .0023   *******     .4595   *********     .020863
 199   71.0673  102.9614  106.7075   14.1714     .0090     .4231     .5495     .015025     .019772
 200   59.9966  108.3595  118.1041   11.9669     .0001     .3947     .5128     .022150     .029395
NUMBER OF POINTS GENERATED =   200
NUMBER OF POINTS PLOTTED =   117

 FOR HWS EFFICIENCY,CONSTANT AND COEFF OF T,TWET,THOT,
WIND AND WIND**.5 ARE
 -.60637276E+00
  .40195127E-03
  .38449863E-02
  .18230236E-02
 -.34078270E-01
  .30138737E+00
```

Figure 8.4 (Continued)

```
FOR HWS EVAPORATION,CONSTANT AND COEFICIENT OF T,  TWET,THOT,WIND AND WIND**.5 ARE
 -.41450389E-01
  .14646531E-03
 -.33234415E-03
  .41560445E-03
 -.12268707E-02
  .11416664E-01


FOR LWS EFFICIENCY,CONSTANT AND COEFF OF T,T**2,  T**3,TWET,THOT AND THOT**2 ARE
 -.25690451E+01
  .65576685E-01
 -.73791051E-03
  .26319278E-05
  .35669730E-02
  .12911864E-01
 -.39275022E-04


FOR LWS EVAPORATION,CONSTANT AND COEFF OF T,T**2,  T**3,TWET,THOT AND THOT**2 ARE
 -.86122112E-01
  .28767122E-02
 -.29725976E-04
  .10168749E-06
 -.27394599E-03
  .28406611E-04
  .22034012E-05
```

```
    CORRELATION OF EVAPORATION FRACTION
   CORRELATION COEFF R**2 =     .9895
   STANDARD ERROR =       .0005
   MIN AND MAX OF PLOT SCALES =     .100256E-01    .310034E-01
*I*********I*********I*********I*********I*********I*********I*********
*                                                                      *
*                                                                      *
*                                                                      *
*                                                                      *
*                                                                1    1*
*                                                               11     *
*                                                            1   1     *
*                                                             1        *
*                                                      1    1          *
*                                                       11 2           *
*                                                                      *
*                                                1  2 11               *
*                                               1   2                  *
*                                              2  12                   *
*                                              22 3                    *
*                                           1 211                      *
*                                         112                          *
*                                          1                           *
*                                    1  1  1                           *
*                                    211                               *
*                                  111                                 *
*                                2 2 1                                 *
*                              112                                     *
*                            2312                                      *
*                            221                                       *
*                        1  2                                          *
*                        2                                             *
*                        1                                             *
*                   11   1                                             *
*                   125                                                *
*                1 111                                                 *
*                11                                                    *
*                 1                                                    *
*               1                                                      *
*             1                                                        *
*          2111                                                        *
*        22                                                            *
*       121                                                            *
*                                                                      *
*                                                                      *
*1   1                                                                 *
*   1                                                                  *
*I*********I*********I*********I*********I*********I*********I*********

PLOTTED CHARACTERS ARE NUMBER OF POINTS FALLING AT THAT POSITION
```

Figure 8.4 (Continued)

```
     CORRELATION OF SPRAY EFFICIENCY
    CORRELATION COEFF R**2 =    .9906
    STANDARD ERROR =      .0057
    MIN AND MAX OF PLOT SCALES =     .322636E+00    .611726E+00
*I*********I*********I*********I*********I*********I*********I*********
*                                                                      *
*                                                                     1*
*                                                                      *
*                                                               1 1    *
*                                                              11      *
*                                                                      *
*                                                          3 11        *
*                                                          1           *
*                                                      2111            *
*                                                     3                *
*                                                                      *
*                                                1111                  *
*                                               1111                   *
*                                              22                      *
*                                            331                       *
*                                         1213                         *
*                                        1                             *
*                                     11  3                            *
*                                    2  1                              *
*                                 1 2121                               *
*                                  241                                 *
*                                2221                                  *
*                              1211                                    *
*                            1 14                                      *
*                             2  1                                     *
*                         1 1                                          *
*                         12                                           *
*                       2 1                                            *
*                    1  3                                              *
*                     11                                               *
*                   11                                                 *
*                 1                                                    *
*                1                                                     *
*               2                                                      *
*            1  2                                                      *
*           2                                                          *
*            1                                                         *
*                                                                      *
*1                                                                     *
*       1                                                              *
*                                                                      *
*                                                                      *
*I*********I*********I*********I*********I*********I*********I*********
PLOTTED CHARACTERS ARE NUMBER OF POINTS FALLING AT THAT POSITION
```

Figure 8.4 (Continued)

8.5 Scanning Weather Record--Program SPSCAN

The periods of most-adverse meteorology with respect to cooling performance and water loss were determined from the tape meteorological record using program SPSCAN and the output from programs SPRCO and DRIFT. The inputs to program SPSCAN were developed according to Section 7.4, and are shown in Figure 8.7. There is one pond data card, one monthly average card, and one end card.

```
 DRIFT TABLE FOR HYPOTHETICAL SPRAY POND
 $DROPSZ$
13
     120.0 .07692308
   132.5   .07692308
   145.0   .07692308
   157.5   .07692308
   170.0   .07692308
   182.5   .07692308
   195.0   .07692308
   207.5   .07692308
   220.0   .07692308
   232.5   .07692308
   245.0   .07692308
   257.5   .07692308
   270.0   .07692308
$
```

Figure 8.5 Input deck for program DRIFT

The base heat load HEAT on the pond data card is taken to be the 30-day average excess heat load from the plant, so that the 30-day evaporative loss calculated in this program could be used directly, since evaporation is approximately proportional to the cumulative heat load.

Partial printed output is shown in Figure 8.8. In addition to the printed output, the hourly record of the 20-day period before and the 30-day period after the time of most-adverse cooling performance was either punched or (preferably) stored on a permanent file for further use in program SPRPND. This output is also shown in Figure 8.8.

8.6 Determining the Uncorrected Design-Basis Temperature--Program SPRPND

Once the period of most-adverse meteorology for cooling has been determined by program SPSCAN, program SPRPND is run to simulate the pond temperature under tne actual design-basis heat loads. One of two procedures may be followed to make this determination.

```
TITLE: DRIFT TABLE FOR HYPOTHETICAL SPRAY POND

SPRAY GEOMETRY (13 POINTS)

   FEET FROM EDGE     FRAC. OF SPRAYS

     120.000000          .076923

     132.500000          .076923

     145.000000          .076923

     157.500000          .076923

     170.000000          .076923

     182.500000          .076923

     195.000000          .076923

     207.500000          .076923

     220.000000          .076923

     232.500000          .076923

     245.000000          .076923

     257.500000          .076923

     270.000000          .076923

DRIFT LOSS FRACTION

         WIND SPEED     LOSS FRAC.

              0.000    .00050000

              2.500    .00050000

              5.000    .00050000

              7.500    .00050000

             10.000    .00058047

             12.500    .00075946

             15.000    .00106712

             17.500    .00145037

             20.000    .00191420

             22.500    .00237861

             25.000    .00296085

             30.000    .00434594

             35.000    .00590310

             40.000    .00789034

             45.000    .01086714

             50.000    .01432954
```

Figure 8.6 Output from program DRIFT

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$INPUT N=1,A=422000.,V=2942357.,LAT=41.2,HEAT=2.3E8,IPRNT=0,WDR0=0,
   NDRIFT =6,DWDR=10,FDRIFT=.0005,.00058,.001914,.004346,.007890,.014330$
$INPUT N=100,YRMODY(1)=73,YRMODY(2)=5$
$INPUT N=0$
```

Figure 8.7 Input deck for program SPSCAN

8.6.1 Procedure 1

(1) Make two runs of program SPRPND; first to determine the pond temperature for the ambient meteorology (but with a steady heat load), and second, to determine the pond response to the design-basis heat load, but with constant meteorological parameters.

(2) Make a third run combining the time-varying meteorology and heat load, with the timing adjusted so that the two temperature peaks determined in the step above are approximately superimposed.

The inputs to program SPRPND for the first run are shown in Figure 8.9. The parameter IMET = 0 specifies that the tabular meteorological data is used for meteorology. ISPRAY = 1 specifies that the regression model is used for spray-heat and mass transfer. TSKIP = 5000 effectively eliminates the use of the design-basis heat-and-flowrate table. Parameter Q1 = 0.23E9 specifies the steady heat load for this run. IEVAP = 0 forces the pond to remain full for the run. TSPRON = 0 specifies that the sprays are turned on at the beginning of the run.

The output of run 1 is shown printed in Figure 8.10 and plotted in Figure 8.11.

```
U.S. NUCLEAR REGULATORY COMMISSION- ULTIMATE HEAT SINK SPRAY   POND METEOROLOGICAL SCANNING MODEL



          ********** SUBROUTINE SUB1 HAS BEEN CALLED FOR LATITUDE = 41.20 DEG. NORTH *****

                         DISCONTINUITY IN DATA CAUSED  6/11/71 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  9/25/71 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  5/ 5/72 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  5/ 6/72 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  5/ 7/72 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  5/ 8/72 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  8/ 7/72 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  7/11/73 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  7/15/73 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  7/16/73 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  7/17/73 TO BE SKIPPED
                         DISCONTINUITY IN DATA CAUSED  5/ 1/75 TO BE SKIPPED



          ***w******* POND NUMBER  1 HAS THE FOLLOWING PARAMETERS *************************

                         SURFACE AREA      422000.00 FT**2 (      9.69 ACRES)

                         VOLUME           2942357.00 FT**3 (     67.55 ACRE-FT)

                         ISRCH =  1                    IPRNT =  0



          ********** POND NUMBER  1 HAS BEEN MODELLED TO DETERMINE THE WORST *************
                              PERIODS FOR COOLING AND EVAPORATIVE WATER LOSS


          **********SPRAY PARAMETERS
                        BASE HEAT LOAD =       .23E+09 BTU/HR
                        MINIMUM EVAPORATIVE LOSS FRACTION =   0.000000
                        MAXIMUM EVAPORATIVE LOSS FRACTION =    .050000
                        MINIMUM SPRAY EFFICIENCY =      .1000
                        MAXIMUM SPRAY EFFICIENCY =      .8000

          **********DRIFT LOSS TABLE

                  WIND SPEED - MPH               DRIFT LOSS FRACTION

                         0.00                           .000500

                        10.00                           .000580

                        20.00                           .001914

                        30.00                           .004346

                        40.00                           .007890

                        50.00                           .014330
```

Figure 8.8 Output from program SPSCAN

```
**********THE SAMPLE OF YEARLY MAXIMUM POND TEMPERATURES AND 30 DAY **********
           EVAPORATIVE LOSSES GENERATED BY THIS MODEL IS DESCRIBED BELOW.

           ..........TEMPERATURE...................EVAPORATIVE LOSS..........
           *EXCEEDED                 DATE    *EXCEEDED                 DATE    *
           */100 YR*  (DEG.F)  *(YR.MO.DY.)*/100 YR*   FT**3    *(YR.MO.DY.)*
           ..................................................................
           *  2.45 *   92.74   * 72. 7.22. *  2.45 * 2462822.8 * 66. 7.20. *
           *  5.97 *   92.02   * 75. 8. 2. *  5.97 * 2409377.5 * 55. 8. 9. *
           *  9.49 *   91.55   * 59. 6.30. *  9.49 * 2352520.5 * 63. 7.30. *
           * 13.01 *   91.11   * 68. 7.18. * 13.01 * 2337086.9 * 74. 7.30. *
           * 16.54 *   91.04   * 73. 8.31. * 16.54 * 2332290.8 * 57. 7.15. *
           * 20.06 *   91.00   * 48. 8.27. * 20.06 * 2330110.7 * 52. 7.24. *
           * 23.58 *   90.98   * 57. 6.18. * 23.58 * 2329511.1 * 71. 7.20. *
           * 27.10 *   90.48   * 52. 7.22. * 27.10 * 2326817.8 * 68. 8.11. *
           * 30.63 *   90.39   * 65. 8.17. * 30.63 * 2323800.6 * 65. 7.20. *
           * 34.15 *   90.35   * 49. 7.29. * 34.15 * 2309946.7 * 64. 7. 8. *
           * 37.67 *   90.34   * 53. 9. 2. * 37.67 * 2306465.0 * 54. 8.12. *
           * 41.19 *   90.01   * 62. 7. 8. * 41.19 * 2302173.2 * 53. 7.20. *
           * 44.72 *   90.01   * 66. 8.22. * 44.72 * 2302154.9 * 49. 7. 5. *
           * 48.24 *   89.97   * 63. 7. 1. * 48.24 * 2288803.4 * 62. 7.27. *
           * 51.76 *   89.57   * 55. 7. 4. * 51.76 * 2287736.5 * 59. 7. 5. *
           * 55.28 *   89.54   * 64. 7.20. * 55.28 * 2286469.7 * 72. 7.26. *
           * 58.81 *   89.39   * 70. 8. 1. * 58.81 * 2283665.6 * 73. 8. 6. *
           * 62.33 *   89.27   * 69. 6.28. * 62.33 * 2270155.6 * 51. 8. 2. *
           * 65.85 *   89.23   * 60. 8.29. * 65.85 * 2268953.0 * 75. 8.15. *
           * 69.37 *   89.07   * 61. 7.23. * 69.37 * 2267994.3 * 67. 7. 4. *
           * 72.90 *   88.73   * 71. 6.28. * 72.90 * 2265241.7 * 70. 8.31. *
           * 76.42 *   88.65   * 74. 7. 4. * 76.42 * 2261924.0 * 69. 7.24. *
           * 79.94 *   88.10   * 67. 6.17. * 79.94 * 2251452.1 * 56. 7.10. *
           * 83.46 *   88.09   * 51. 8.10. * 83.46 * 2245862.8 * 48. 7.24. *
           * 86.99 *   87.95   * 58. 7.27. * 86.99 * 2242686.2 * 61. 7.28. *
           * 90.51 *   87.79   * 56. 8.31. * 90.51 * 2226405.1 * 60. 7.24. *
           * 94.03 *   87.62   * 50. 8. 1. * 94.03 * 2215186.3 * 58. 7.30. *
           * 97.55 *   87.49   * 54. 9. 6. * 97.55 * 2202979.8 * 50. 7.21. *
           ..................................................................

          MEAN         89.73                           2296092.7

 STANDARD DEV.          1.380                            55542.68

          SKEW           .154                                1.010
```

Figure 8.8 (Continued)

```
            PREDICTED VALUES AND CONFIDENCE LIMITS ON
            PEAK TEMPERATURE, DEG.F

  EXCEEDED          PREDICTED          5 PERCENT          95 PERCENT
 PER 100 YR           VALUE           CONFIDENCE          CONFIDENCE

      .100           94.451             93.288              95.613
      .500           93.554             92.577              94.530
     1.000           93.142             92.248              94.037
     2.000           92.708             91.898              93.518
     5.000           92.081             91.386              92.776
    10.000           91.544             90.937              92.150
    20.000           90.911             90.392              91.430
    30.000           90.463             89.989              90.938
    40.000           90.084             89.633              90.535
    60.000           89.378             88.927              89.830
    70.000           88.999             88.525              89.473
    80.000           88.551             88.033              89.070
    90.000           87.919             87.313              88.525
    95.000           87.381             86.686              88.077
    98.000           86.754             85.944              87.564
    99.000           86.320             85.425              87.214
    99.500           85.909             84.932              86.886
    99.900           85.012             83.849              86.174


            PREDICTED VALUES AND CONFIDENCE LIMITS ON
            30 DAY EVAPORATION, FT**3

  EXCEEDED          PREDICTED          5 PERCENT          95 PERCENT
 PER 100 YR           VALUE           CONFIDENCE          CONFIDENCE

      .100        2486106.070        2439307.091        2532905.048
      .500        2449983.821        2410657.411        2489310.231
     1.000        2433430.819        2397419.438        2469442.200
     2.000        2415944.033        2383327.751        2448560.315
     5.000        2390697.864        2362709.866        2418685.863
    10.000        2369059.240        2344656.889        2393461.591
    20.000        2343589.274        2322696.192        2364482.356
    30.000        2325566.328        2306470.449        2344662.207
    40.000        2310303.682        2292134.736        2328472.628
    60.000        2281881.643        2263712.697        2300050.589
    70.000        2266618.996        2247523.118        2285714.875
    80.000        2248596.051        2227702.969        2269489.132



    90.000        2223126.085        2198723.734        2247528.435
    95.000        2201487.460        2173499.462        2229475.459
    98.000        2176241.292        2143625.010        2208857.573
    99.000        2158754.506        2122743.125        2194765.887
    99.500        2142201.504        2102875.094        2181527.914
    99.900        2106079.255        2059280.276        2152878.233
```

Figure 8.8 (Continued)

```
********** METEOROLOGY FOR  7/ 3/72*********************************************

.................................................................
,  HOUR    , WIND SP.,DRY BULB ,DEWPOINT ,SOLAR RAD WET BULB ,ATM.PRESS,
,          ,  (MPH)  , (DEG.F) , (DEG.F) ,BTU/FT2/D, (DEG.F) ,  PSIA    ,
.................................................................
,    0.    ,   5.0   ,   74.0  ,   65.7  ,      0.0 ,  68.67  ,  29.59   ,
,    1.    ,   3.5   ,   72.0  ,   66.0  ,      0.0 ,  68.00  ,  29.58   ,
,    2.    ,   4.2   ,   72.0  ,   66.0  ,      0.0 ,  68.00  ,  29.57   ,
,    3.    ,   5.0   ,   72.0  ,   66.0  ,      0.0 ,  68.00  ,  29.57   ,
,    4.    ,   5.8   ,   72.0  ,   66.0  ,      0.0 ,  68.00  ,  29.56   ,
,    5.    ,   5.4   ,   73.3  ,   66.7  ,    247.5 ,  69.00  ,  29.56   ,
,    6.    ,   5.0   ,   74.7  ,   67.3  ,    947.6 ,  70.00  ,  29.56   ,
,    7.    ,   4.6   ,   76.0  ,   68.0  ,   1788.6 ,  71.00  ,  29.56   ,
,    8.    ,   4.6   ,   78.3  ,   69.3  ,   2296.4 ,  72.33  ,  29.55   ,
,    9.    ,   4.6   ,   80.7  ,   70.7  ,   2556.1 ,  73.67  ,  29.55   ,
,   10.    ,   4.6   ,   83.0  ,   72.0  ,   2522.9 ,  75.00  ,  29.54   ,
,   11.    ,   7.7   ,   84.7  ,   71.3  ,   2725.0 ,  75.33  ,  29.53   ,
,   12.    ,  10.7   ,   86.3  ,   70.7  ,   2794.0 ,  75.67  ,  29.52   ,
,   13.    ,  13.8   ,   88.0  ,   70.0  ,   2725.0 ,  76.00  ,  29.51   ,
,   14.    ,  11.9   ,   85.0  ,   69.3  ,   2287.7 ,  74.67  ,  29.51   ,
,   15.    ,  10.0   ,   82.0  ,   68.7  ,   1772.2 ,  73.33  ,  29.52   ,
,   16.    ,   8.1   ,   79.0  ,   68.0  ,   1238.5 ,  72.00  ,  29.52   ,
,   17.    ,  10.0   ,   79.3  ,   67.7  ,   1042.2 ,  71.67  ,  29.53   ,
,   18.    ,  11.9   ,   79.7  ,   67.3  ,    699.2 ,  71.33  ,  29.54   ,
,   19.    ,  13.8   ,   80.0  ,   67.0  ,    247.6 ,  71.00  ,  29.55   ,
,   20.    ,  13.8   ,   78.3  ,   66.0  ,      0.0 ,  70.00  ,  29.58   ,
,   21.    ,  13.8   ,   76.7  ,   65.0  ,      0.0 ,  69.00  ,  29.60   ,
,   22.    ,  13.8   ,   75.0  ,   64.0  ,      0.0 ,  68.00  ,  29.63   ,
,   23.    ,  10.4   ,   73.0  ,   62.0  ,      0.0 ,  66.00  ,  29.65   ,
.................................................................

********** METEOROLOGY FOR  7/ 4/72*********************************************

.................................................................
,  HOUR    , WIND SP.,DRY BULB ,DEWPOINT ,SOLAR RAD WET BULB ,ATM.PRESS,
,          ,  (MPH)  , (DEG.F) , (DEG.F) ,BTU/FT2/D, (DEG.F) ,  PSIA    ,
.................................................................
,    0.    ,   6.9   ,   71.0  ,   60.0  ,      0.0 ,  64.00  ,  29.66   ,
,    1.    ,   3.5   ,   69.0  ,   58.0  ,      0.0 ,  62.00  ,  29.68   ,
,    2.    ,   6.1   ,   68.7  ,   57.0  ,      0.0 ,  61.33  ,  29.70   ,
,    3.    ,   8.8   ,   68.3  ,   56.0  ,      0.0 ,  60.67  ,  29.71   ,
,    4.    ,  11.5   ,   68.0  ,   55.0  ,      0.0 ,  60.00  ,  29.73   ,
,    5.    ,  10.0   ,   67.7  ,   55.0  ,    264.8 ,  60.00  ,  29.75   ,
,    6.    ,   8.4   ,   67.3  ,   55.0  ,    800.7 ,  60.00  ,  29.77   ,
,    7.    ,   6.9   ,   67.0  ,   55.0  ,   1290.6 ,  60.00  ,  29.79   ,
,    8.    ,   8.4   ,   69.3  ,   55.3  ,   1998.7 ,  61.00  ,  29.80   ,
,    9.    ,  10.0   ,   71.7  ,   55.7  ,   2699.8 ,  62.00  ,  29.80   ,
,   10.    ,  11.5   ,   74.0  ,   56.0  ,   3310.8 ,  63.00  ,  29.81   ,
,   11.    ,  10.0   ,   74.7  ,   55.7  ,   3253.5 ,  63.00  ,  29.81   ,
,   12.    ,   8.4   ,   75.3  ,   55.3  ,   2910.2 ,  63.00  ,  29.81   ,
,   13.    ,   6.9   ,   76.0  ,   55.0  ,   2331.0 ,  63.00  ,  29.81   ,
,   14.    ,   7.3   ,   77.0  ,   54.7  ,   2627.5 ,  63.33  ,  29.80   ,
,   15.    ,   7.7   ,   78.0  ,   54.3  ,   2627.6 ,  63.67  ,  29.80   ,
,   16.    ,   8.1   ,   79.0  ,   54.0  ,   2337.9 ,  64.00  ,  29.79   ,
,   17.    ,   6.9   ,   78.0  ,   53.7  ,   1586.1 ,  63.33  ,  29.79   ,
,   18.    ,   5.8   ,   77.0  ,   53.3  ,    862.5 ,  62.67  ,  29.78   ,
,   19.    ,   4.6   ,   76.0  ,   53.0  ,    244.1 ,  62.00  ,  29.78   ,
,   20.    ,   4.2   ,   74.7  ,   55.0  ,      0.0 ,  62.67  ,  29.78   ,
,   21.    ,   3.8   ,   73.3  ,   57.0  ,      0.0 ,  63.33  ,  29.79   ,
,   22.    ,   3.5   ,   72.0  ,   59.0  ,      0.0 ,  64.00  ,  29.79   ,
,   23.    ,   4.6   ,   71.0  ,   57.3  ,      0.0 ,  62.67  ,  29.79   ,
.................................................................
```

Figure 8.8 (Continued)

NOTE: Output for dates 7/5/72 through 8/19/72 not shown because of its length.

```
********** METEOROLOGY FOR  8/20/72********************************************

.................................................................................
,  HOUR   , WIND SP.,DRY BULB ,DEWPOINT ,SOLAR RAD WET BULB ,ATM.PRESS,
,         , (MPH)   , (DEG.F) , (DEG.F) ,BTU/FT2/D, (DEG.F) ,  PSIA   ,
.................................................................................
,   0.    ,   1.5   ,   63.7  ,   58.7  ,     0.0 ,  61.00  ,  29.71  ,
,   1.    ,   0.0   ,   62.0  ,   58.0  ,     0.0 ,  60.00  ,  29.72  ,
,   2.    ,   1.9   ,   61.3  ,   57.7  ,     0.0 ,  59.33  ,  29.72  ,
,   3.    ,   3.8   ,   60.7  ,   57.3  ,     0.0 ,  58.67  ,  29.73  ,
,   4.    ,   5.8   ,   60.0  ,   57.0  ,     0.0 ,  58.00  ,  29.73  ,
,   5.    ,   5.4   ,   61.0  ,   57.7  ,     0.0 ,  59.00  ,  29.74  ,
,   6.    ,   5.0   ,   62.0  ,   58.3  ,   537.2 ,  60.00  ,  29.76  ,
,   7.    ,   4.6   ,   63.0  ,   59.0  ,  1296.6 ,  61.00  ,  29.77  ,
,   8.    ,   4.6   ,   67.3  ,   58.3  ,  2004.3 ,  62.00  ,  29.77  ,
,   9.    ,   4.6   ,   71.7  ,   57.7  ,  2612.0 ,  63.00  ,  29.78  ,
,  10.    ,   4.6   ,   76.0  ,   57.0  ,  3078.4 ,  64.00  ,  29.78  ,
,  11.    ,   6.9   ,   78.0  ,   57.0  ,  3371.5 ,  65.00  ,  29.77  ,
,  12.    ,   9.2   ,   80.0  ,   57.0  ,  3471.5 ,  66.00  ,  29.75  ,
,  13.    ,  11.5   ,   82.0  ,   57.0  ,  3371.5 ,  67.00  ,  29.74  ,
,  14.    ,  10.0   ,   82.7  ,   55.7  ,  3078.4 ,  66.33  ,  29.74  ,
,  15.    ,   8.4   ,   83.3  ,   54.3  ,  2612.0 ,  65.67  ,  29.73  ,
,  16.    ,   6.9   ,   84.0  ,   53.0  ,  2004.3 ,  65.00  ,  29.73  ,
,  17.    ,   6.1   ,   82.3  ,   53.0  ,  1296.6 ,  64.67  ,  29.73  ,
,  18.    ,   5.4   ,   80.7  ,   53.0  ,   537.2 ,  64.33  ,  29.74  ,
,  19.    ,   4.6   ,   79.0  ,   53.0  ,     0.0 ,  64.00  ,  29.74  ,
,  20.    ,   3.1   ,   74.3  ,   54.0  ,     0.0 ,  62.67  ,  29.74  ,
,  21.    ,   1.5   ,   69.7  ,   55.0  ,     0.0 ,  61.33  ,  29.75  ,
,  22.    ,   0.0   ,   65.0  ,   56.0  ,     0.0 ,  60.00  ,  29.75  ,
,  23.    ,   0.0   ,   64.0  ,   55.7  ,     0.0 ,  59.33  ,  29.76  ,
.................................................................................
```

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********** METEOROLOGY FOR  8/21/72********************************************

.................................................................................
,  HOUR   , WIND SP.,DRY BULB ,DEWPOINT ,SOLAR RAD WET BULB ,ATM.PRESS,
,         , (MPH)   , (DEG.F) , (DEG.F) ,BTU/FT2/D, (DEG.F) ,  PSIA   ,
.................................................................................
,   0.    ,   0.0   ,   63.0  ,   55.3  ,     0.0 ,  58.67  ,  29.76  ,
,   1.    ,   0.0   ,   62.0  ,   55.0  ,     0.0 ,  58.00  ,  29.77  ,
,   2.    ,   0.0   ,   61.0  ,   54.7  ,     0.0 ,  57.33  ,  29.77  ,
,   3.    ,   0.0   ,   60.0  ,   54.3  ,     0.0 ,  56.67  ,  29.77  ,
,   4.    ,   0.0   ,   59.0  ,   54.0  ,     0.0 ,  56.00  ,  29.77  ,
,   5.    ,   0.0   ,   59.7  ,   55.0  ,     0.0 ,  57.00  ,  29.78  ,
,   6.    ,   0.0   ,   60.3  ,   56.0  ,   521.7 ,  58.00  ,  29.79  ,
,   7.    ,   0.0   ,   61.0  ,   57.0  ,  1280.5 ,  59.00  ,  29.80  ,
,   8.    ,   1.9   ,   65.7  ,   58.7  ,  1987.5 ,  61.67  ,  29.79  ,
,   9.    ,   3.8   ,   70.3  ,   60.3  ,  2594.6 ,  64.33  ,  29.79  ,
,  10.    ,   5.8   ,   75.0  ,   62.0  ,  3060.5 ,  67.00  ,  29.78  ,
,  11.    ,   5.0   ,   77.7  ,   60.7  ,  3353.4 ,  67.00  ,  29.77  ,
,  12.    ,   4.2   ,   80.3  ,   59.3  ,  3453.3 ,  67.00  ,  29.76  ,
,  13.    ,   3.5   ,   83.0  ,   58.0  ,  3353.4 ,  67.00  ,  29.75  ,
,  14.    ,   4.6   ,   83.3  ,   58.3  ,  3025.2 ,  67.33  ,  29.73  ,
,  15.    ,   5.8   ,   83.7  ,   58.7  ,  2474.7 ,  67.67  ,  29.72  ,
,  16.    ,   6.9   ,   84.0  ,   59.0  ,  1780.8 ,  68.00  ,  29.70  ,
,  17.    ,   6.5   ,   81.7  ,   60.0  ,  1188.0 ,  67.67  ,  29.69  ,
,  18.    ,   6.1   ,   79.3  ,   61.0  ,   497.6 ,  67.33  ,  29.68  ,
,  19.    ,   5.8   ,   77.0  ,   62.0  ,     0.0 ,  67.00  ,  29.67  ,
,  20.    ,   6.5   ,   76.0  ,   61.7  ,     0.0 ,  66.67  ,  29.67  ,
,  21.    ,   7.3   ,   75.0  ,   61.3  ,     0.0 ,  66.33  ,  29.67  ,
,  22.    ,   8.1   ,   74.0  ,   61.0  ,     0.0 ,  66.00  ,  29.67  ,
,  23.    ,   6.9   ,   72.3  ,   60.7  ,     0.0 ,  65.00  ,  29.67  ,
.................................................................................
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Figure 8.8 (Continued)

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***********NUMBER OF CARDS PUNCHED = 588 *******************************************

********** THE MONTHLY AVERAGE VALUES FROM 5/ 1/73 TO END OF DATA *************


          .............................................................
          *RMS WIND *DRY BULB *DEWPOINT *  SOLAR   *WET BULB *ATM.PRESS*
          *  SPEED  * (DEG.F) * (DEG.F) *RADIATION* (DEG.F) *   PSIG  *
1973      .............................................................
          *         *         *         *         *         *         *
MAY       *   8.91  *  57.38  *  47.16  * 1378.4  * 52.03   * 29.54   *
          *         *         *         *         *         *         *
JUNE      *   6.12  *  72.79  *  62.67  * 1662.2  * 66.35   * 29.64   *
          *         *         *         *         *         *         *
JULY      *   6.43  *  76.14  *  63.78  * 1884.9  * 68.19   * 29.63   *
          *         *         *         *         *         *         *
AUGUST    *   5.90  *  75.38  *  64.59  * 1539.1  * 68.37   * 29.67   *
          *         *         *         *         *         *         *
SEPTEMBER *   7.37  *  67.87  *  55.93  * 1291.5  * 60.89   * 29.71   *
          *         *         *         *         *         *         *
1974      .............................................................
          *         *         *         *         *         *         *
MAY       *   8.61  *  63.47  *  46.71  * 1648.8  * 54.71   * 29.58   *
          *         *         *         *         *         *         *
JUNE      *   7.59  *  70.60  *  57.27  * 1686.6  * 62.61   * 29.60   *
          *         *         *         *         *         *         *
JULY      *   7.54  *  77.27  *  59.89  * 1763.9  * 66.46   * 29.64   *
          *         *         *         *         *         *         *
AUGUST    *   5.74  *  76.47  *  63.89  * 1377.3  * 68.34   * 29.71   *
          *         *         *         *         *         *         *
SEPTEMBER *   7.46  *  64.24  *  55.62  * 1182.6  * 59.29   * 29.70   *
          *         *         *         *         *         *         *
1975      .............................................................
          *         *         *         *         *         *         *
MAY       *   6.65  *  64.74  *  55.96  * 1559.6  * 59.57   * 29.61   *
          *         *         *         *         *         *         *
JUNE      *   7.61  *  70.57  *  62.24  * 1636.9  * 65.36   * 29.67   *
          *         *         *         *         *         *         *
JULY      *   6.84  *  75.01  *  66.34  * 1746.9  * 69.36   * 29.65   *
          *         *         *         *         *         *         *
AUGUST    *   6.75  *  75.12  *  66.77  * 1507.4  * 69.63   * 29.70   *
          *         *         *         *         *         *         *
SEPTEMBER *   7.31  *  62.82  *  56.25  * 1157.0  * 58.99   * 29.76   *
          *         *         *         *         *         *         *
          .............................................................
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Figure 8.8 (Continued)

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** APPROXIMATELY 50 DAYS OF MET. DATA FOLLOW. DATA AREPUNCHED 2 HOURS TO A
**** CARD BEGINNING WITH HOUR 0 ON 7. 3.72.  THE FORMAT FOR THE DATA IS I3,2(
****3F5.1,F6.1,F4.2,F4 .0)WHERE FIELD 1 IS THE CARD NUMBER AND THE FOLLOWING
****VA  RIABLE SEQUENCE IS REPEATED:WIND SPEED,DRY BULB,DEWPOINT,SOLAR RA D-
****IATION,CLOUD COVER,AND RELATIVE HUMIDITY.
  1  5.0 74.0 65.7    0.0  68.67   29.59  3.5 72.0 66.0    0.0  68.00   29.58
  2  4.2 72.0 66.0    0.0  68.00   29.57  5.0 72.0 66.0    0.0  68.00   29.57
  3  5.8 72.0 66.0    0.0  68.00   29.56  5.4 73.3 66.7 247.5  69.00   29.56
  4  5.0 74.7 67.3 947.6  70.00   29.56  4.6 76.0 68.01788.6  71.00   29.56
  5  4.6 78.3 69.32296.4  72.33   29.55  4.6 80.7 70.72556.1  73.67   29.55
  6  4.6 83.0 72.02522.9  75.00   29.54  7.7 84.7 71.32725.0  75.33   29.53
  7 10.7 86.3 70.72794.0  75.67   29.52 13.8 88.0 70.02725.0  76.00   29.51
  8 11.9 85.0 69.32287.7  74.67   29.51 10.0 82.0 68.71772.2  73.33   29.52
  9  8.1 79.0 68.01238.5  72.00   29.52 10.0 79.3 67.71042.2  71.67   29.53
 10 11.9 79.7 67.3 699.2  71.33   29.54 13.8 80.0 67.0 247.6  71.00   29.55
 11 13.8 78.3 66.0    0.0  70.00   29.58 13.8 76.7 65.0    0.0  69.00   29.60
 12 13.8 75.0 64.0    0.0  68.00   29.63 10.4 73.0 62.0    0.0  66.00   29.65
 13  6.9 71.0 60.0    0.0  64.00   29.66  3.5 69.0 58.0    0.0  62.00   29.68
 14  6.1 68.7 57.0    0.0  61.33   29.70  8.8 68.3 56.0    0.0  60.67   29.71
 15 11.5 68.0 55.0    0.0  60.00   29.73 10.0 67.7 55.0 264.8  60.00   29.75
 16  8.4 67.3 55.0 800.7  60.00   29.77  6.9 67.0 55.01290.6  60.00   29.79
 17  8.4 69.3 55.31998.7  61.00   29.80 10.0 71.7 55.72699.8  62.00   29.80
 18 11.5 74.0 56.03310.8  63.00   29.81 10.0 74.7 55.73253.5  63.00   29.81
 19  8.4 75.3 55.32910.2  63.00   29.81  6.9 76.0 55.02331.0  63.00   29.81
 20  7.3 77.0 54.72627.5  63.33   29.80  7.7 78.0 54.32627.6  63.67   29.80
 21  8.1 79.0 54.02337.9  64.00   29.79  6.9 78.0 53.71586.1  63.33   29.79
 22  5.8 77.0 53.3 862.5  62.67   29.78  4.6 76.0 53.0 244.1  62.00   29.78
 23  4.2 74.7 55.0    0.0  62.67   29.78  3.8 73.3 57.0    0.0  63.33   29.79
 24  3.5 72.0 59.0    0.0  64.00   29.79  4.6 71.0 57.3    0.0  62.67   29.79
 25  5.8 70.0 55.7    0.0  61.33   29.79  6.9 69.0 54.0    0.0  60.00   29.79
 26  5.8 66.3 54.0    0.0  59.00   29.79  4.6 63.7 54.0    0.0  58.00   29.79
 27  3.5 61.0 54.0    0.0  57.00   29.79  5.4 60.3 53.0 123.6  56.33   29.80
 28  7.3 59.7 52.0 392.2  55.67   29.81  9.2 59.0 51.0 660.7  55.00   29.82
 29 10.4 59.3 52.0 910.9  55.67   29.82 11.5 59.7 53.01125.8  56.33   29.81
 30 12.7 60.0 54.01290.7  57.00   29.81 11.9 60.0 54.01394.4  57.00   29.80
 31 11.1 60.0 54.01429.7  57.00   29.80 10.4 60.0 54.01394.4  57.00   29.79
 32  8.8 61.7 54.71290.7  58.00   29.78  7.3 63.3 55.31125.8  59.00   29.77
 33  5.8 65.0 56.0 910.9  60.00   29.76  7.7 65.7 56.3 660.7  60.33   29.76
 34  9.6 66.3 56.7 392.2  60.67   29.76 11.5 67.0 57.0 123.6  61.00   29.76
 35 11.1 66.3 57.0    0.0  60.67   29.76 10.7 65.7 57.0    0.0  60.33   29.77
 36 10.4 65.0 57.0    0.0  60.00   29.77  9.2 64.7 56.3    0.0  59.67   29.77
 37  8.1 64.3 55.7    0.0  59.33   29.77  6.9 64.0 55.0    0.0  59.00   29.77
 38  6.5 63.7 55.0    0.0  58.67   29.77  6.1 63.3 55.0    0.0  58.33   29.77
 39  5.8 63.0 55.0    0.0  58.00   29.77  5.8 63.0 54.7 121.8  58.00   29.78
 40  5.8 63.0 54.3 390.2  58.00   29.80  5.8 63.0 54.0 658.5  58.00   29.81
 41  5.8 63.3 54.3 908.6  58.33   29.82  5.8 63.7 54.71123.3  58.67   29.83
 42  5.8 64.0 55.01288.1  59.00   29.84  5.8 65.3 54.71391.7  59.33   29.84
 43  5.8 66.7 54.31427.0  59.67   29.84  5.8 68.0 54.01391.7  60.00   29.84
 44  5.4 69.0 54.01596.4  60.33   29.83  5.0 70.0 54.01642.6  60.67   29.83
 45  4.6 71.0 54.01516.0  61.00   29.82  4.6 70.3 55.71162.7  61.67   29.82
 46  4.6 69.7 57.3 725.1  62.33   29.82  4.6 69.0 59.0 237.2  63.00   29.82
 47  4.2 67.3 58.0    0.0  61.67   29.83  3.8 65.7 57.0    0.0  60.33   29.84
 48  3.5 64.0 56.0    0.0  59.00   29.85  3.5 63.3 56.3    0.0  59.00   29.85
 49  3.5 62.7 56.7    0.0  59.00   29.85  3.5 62.0 57.0    0.0  59.00   29.85
 50  3.5 61.0 56.0    0.0  58.00   29.85  3.5 60.0 55.0    0.0  57.00   29.86
 51  3.5 59.0 54.0    0.0  56.00   29.86  4.6 59.7 54.7 294.5  56.67   29.87
 52  5.8 60.3 55.3 721.4  57.33   29.89  6.9 61.0 56.0 656.3  58.00   29.90
 53  6.9 64.0 57.31512.0  60.00   29.90  6.9 67.0 58.72452.9  62.00   29.91
 54  6.9 70.0 60.03290.5  64.00   29.91  6.1 72.0 59.03234.5  64.00   29.90
 55  5.4 74.0 58.02893.5  64.00   29.88  4.6 76.0 57.02317.4  64.00   29.87
 56  4.6 76.3 56.32269.4  64.00   29.86  4.6 76.7 55.72082.8  64.00   29.85
 57  4.6 77.0 55.01764.5  64.00   29.84  5.0 76.0 56.01277.9  64.00   29.84
```

Figure 8.8 (Continued)

```
 58   5.4 75.0 57.0 755.9   64.00   29.85   5.8 74.0 58.0 233.8   64.00   29.85
 59   3.8 71.7 57.7   0.0   63.00   29.85   1.9 69.3 57.3   0.0   62.00   29.85
 60   0.0 67.0 57.0   0.0   61.00   29.85   1.2 66.3 57.0   0.0   60.67   29.85
 61   2.3 65.7 57.0   0.0   60.33   29.86   3.5 65.0 57.0   0.0   60.00   29.86
 62   3.5 63.7 56.3   0.0   59.33   29.86   3.5 62.3 55.7   0.0   58.67   29.87
 63   3.5 61.0 55.0   0.0   58.00   29.87   3.8 62.0 56.3 337.0   59.00   29.88
 64   4.2 63.0 57.71090.6   60.00   29.88   4.6 64.0 59.01820.2   61.00   29.89
 65   4.6 65.3 59.32356.4   61.67   29.89   4.6 66.7 59.72603.8   62.33   29.89
 66   4.6 68.0 60.02497.3   63.00   29.89   4.6 70.7 59.02575.7   63.33   29.88
 67   4.6 73.3 58.02509.3   63.67   29.86   4.6 76.0 57.02312.6   64.00   29.85
 68   7.3 74.0 58.02140.0   64.00   29.85  10.0 72.0 59.01865.6   64.00   29.86
 69  12.7 70.0 60.01507.9   64.00   29.86  10.7 70.0 59.71215.5   63.67   29.86
 70   8.8 70.0 59.3 784.6   63.33   29.86   6.9 70.0 59.0 258.9   63.00   29.86
 71   5.8 68.3 59.0   0.0   62.33   29.87   4.6 66.7 59.0   0.0   61.67   29.88
 72   3.5 65.0 59.0   0.0   61.00   29.89   2.3 64.0 58.0   0.0   60.00   29.89
 73   1.2 63.0 57.0   0.0   59.00   29.90   0.0 62.0 56.0   0.0   58.00   29.90
 74   1.5 61.7 56.3   0.0   58.33   29.89   3.1 61.3 56.7   0.0   58.67   29.89
 75   4.6 61.0 57.0   0.0   59.00   29.88   4.6 61.3 57.3 116.5   59.33   29.89
 76   4.6 61.7 57.7 384.1   59.67   29.90   4.6 62.0 58.0 651.8   60.00   29.91
 77   5.0 64.0 59.3 901.2   61.33   29.91   5.4 66.0 60.71115.3   62.67   29.92
 78   5.8 68.0 62.01279.7   64.00   29.92   8.1 70.7 63.71714.0   66.00   29.91
 79  10.4 73.3 65.32073.8   68.00   29.89  12.7 76.0 67.02307.6   70.00   29.88
 80  12.3 77.7 67.01871.2   70.67   29.87  11.9 79.3 67.01382.3   71.33   29.85
 81  11.5 81.0 67.0 901.2   72.00   29.84  10.7 80.0 65.3 881.7   70.67   29.83
 82  10.0 79.0 63.7 641.0   69.33   29.83   9.2 78.0 62.0 226.8   68.00   29.82
 83  10.0 76.7 63.3   0.0   68.33   29.83  10.7 75.3 64.7   0.0   68.67   29.83
 84  11.5 74.0 66.0   0.0   69.00   29.84  10.0 73.7 65.7   0.0   68.67   29.84
 85   8.4 73.3 65.3   0.0   68.33   29.84   6.9 73.0 65.0   0.0   68.00   29.84
 86   4.6 72.3 64.7   0.0   67.67   29.84   2.3 71.7 64.3   0.0   67.33   29.83
 87   0.0 71.0 64.0   0.0   67.00   29.83   3.1 71.3 63.7 304.0   66.67   29.83
 88   6.1 71.7 63.31071.9   66.33   29.83   9.2 72.0 63.01855.5   66.00   29.83
 89  10.7 74.3 63.72567.4   67.33   29.83  12.3 76.7 64.33178.6   68.67   29.84
 90  13.8 79.0 65.03647.7   70.00   29.84  13.8 81.3 65.73760.4   71.00   29.84
 91  13.8 83.7 66.33295.5   72.00   29.83  13.8 86.0 67.02302.5   73.00   29.83
 92  13.0 85.0 66.71866.8   72.67   29.82  12.3 84.0 66.31378.8   72.33   29.81
 93  11.5 83.0 66.0 898.6   72.00   29.80  11.9 81.7 66.0 649.4   71.33   29.81
 94  12.3 80.3 66.0 382.1   70.67   29.81  12.7 79.0 66.0 114.7   70.00   29.82
 95  11.5 78.7 65.7   0.0   70.00   29.83  10.4 78.3 65.3   0.0   70.00   29.85
 96   9.2 78.0 65.0   0.0   70.00   29.86  10.0 77.3 64.7   0.0   69.33   29.87
 97  10.7 76.7 64.3   0.0   68.67   29.87  11.5 76.0 64.0   0.0   68.00   29.88
 98   7.7 74.7 63.7   0.0   67.33   29.88   3.8 73.3 63.3   0.0   66.67   29.88
 99   0.0 72.0 63.0   0.0   66.00   29.88   0.0 73.0 64.0 322.5   67.00   29.89
100   0.0 74.0 65.01085.6   68.00   29.91   0.0 75.0 66.01848.7   69.00   29.92
101   1.9 77.3 67.32559.8   70.67   29.92   3.8 79.7 68.73170.4   72.33   29.92
102   5.8 82.0 70.03639.0   74.00   29.92   6.5 84.0 69.33888.1   74.00   29.92
103   7.3 86.0 68.73847.5   74.00   29.91   8.1 88.0 68.03524.4   74.00   29.91
104   8.4 88.7 68.73123.9   74.67   29.90   8.8 89.3 69.32584.2   75.33   29.89
105   9.2 90.0 70.01960.8   76.00   29.88   8.1 89.0 70.31506.9   76.00   29.88
106   6.9 88.0 70.7 931.9   76.00   29.87   5.8 87.0 71.0 289.0   76.00   29.87
107   6.1 85.3 67.3   0.0   73.33   29.88   6.5 83.7 63.7   0.0   70.67   29.89
108   6.9 82.0 60.0   0.0   68.00   29.90   6.1 80.0 62.7   0.0   69.00   29.90
109   5.4 78.0 65.3   0.0   70.00   29.91   4.6 76.0 68.0   0.0   71.00   29.91
110   5.0 75.3 67.3   0.0   70.33   29.90   5.4 74.7 66.7   0.0   69.67   29.90
111   5.8 74.0 66.0   0.0   69.00   29.89   5.0 74.3 66.7 315.3   69.33   29.89
112   4.2 74.7 67.31051.5   69.67   29.90   3.5 75.0 68.01734.0   70.00   29.90
113   4.2 76.7 69.02240.6   71.33   29.90   5.0 78.3 70.02502.0   72.67   29.89
114   5.8 80.0 71.02473.8   74.00   29.89   5.4 81.3 70.72552.5   74.00   29.88
115   5.0 82.7 70.32486.9   74.00   29.86   4.6 84.0 70.02291.7   74.00   29.85
116   5.4 84.3 69.31857.8   73.67   29.83   6.1 84.7 68.71371.6   73.33   29.81
117   6.9 85.0 68.0 893.2   73.00   29.79   6.9 84.0 68.3 798.9   73.00   29.78
118   6.9 83.0 68.7 552.5   73.00   29.78   6.9 82.0 69.0 185.3   73.00   29.77
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Figure 8.8 (Continued)

NOTE: Cards 119 to 427 not shown because of length of output.

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428 11.1 79.3 58.32422.5   66.33    29.49 11.9 80.7 57.72221.6   66.67    29.49
429 12.7 82.0 57.01839.1   67.00    29.49  8.4 79.3 59.01329.4   67.00    29.48
430  4.2 76.7 61.0 677.3   67.00    29.48  0.0 74.0 63.0    0.0   67.00    29.47
431  2.3 74.0 62.7    0.0   66.67    29.48  4.6 74.0 62.3    0.0   66.33    29.49
432  6.9 74.0 62.0    0.0   66.00    29.50  4.6 72.7 62.3    0.0   66.00    29.50
433  2.3 71.3 62.7    0.0   66.00    29.49  0.0 70.0 63.0    0.0   66.00    29.49
434  0.0 68.7 62.7    0.0   65.00    29.48  0.0 67.3 62.3    0.0   64.00    29.47
435  0.0 66.0 62.0    0.0   63.00    29.46  0.0 67.0 63.0    0.0   64.00    29.47
436  0.0 68.0 64.0 500.9   65.00    29.48  0.0 69.0 65.0 695.4   66.00    29.49
437  2.7 72.7 65.71196.3   67.67    29.49  5.4 76.3 66.31725.3   69.33    29.49
438  8.1 80.0 67.02222.5   71.00    29.49 10.7 81.7 66.02197.5   71.00    29.49
439 13.4 83.3 65.02006.1   71.00    29.48 16.1 85.0 64.01683.8   71.00    29.48
440 15.3 84.0 62.31904.5   70.00    29.49 14.6 83.0 60.71902.8   69.00    29.51
441 13.8 82.0 59.01670.3   68.00    29.52 13.0 78.7 56.71162.0   65.33    29.55
442 12.3 75.3 54.3 574.2   62.67    29.58 11.5 72.0 52.0    0.0   60.00    29.61
443 10.7 69.3 52.3    0.0   59.33    29.64 10.0 66.7 52.7    0.0   58.67    29.67
444  9.2 64.0 53.0    0.0   58.00    29.70  6.1 63.0 52.7    0.0   57.33    29.71
445  3.1 62.0 52.3    0.0   56.67    29.73  0.0 61.0 52.0    0.0   56.00    29.74
446  2.7 60.7 51.7    0.0   55.67    29.75  5.4 60.3 51.3    0.0   55.33    29.76
447  8.1 60.0 51.0    0.0   55.00    29.77  8.4 60.3 51.0    0.0   55.00    29.79
448  8.8 60.7 51.0 687.4   55.00    29.80  9.2 61.0 51.01443.9   55.00    29.82
449 10.0 63.0 50.02151.1   55.67    29.83 10.7 65.0 49.02758.4   56.33    29.84
450 11.5 67.0 48.03224.3   57.00    29.85 11.5 68.7 47.33448.3   57.33    29.85
451 11.5 70.3 46.73427.9   57.67    29.84 11.5 72.0 46.03172.1   58.00    29.84
452 11.5 72.7 46.02849.3   58.33    29.84 11.5 73.3 46.02383.4   58.67    29.84
453 11.5 74.0 46.01813.3   59.00    29.84  8.8 73.0 47.01348.3   59.00    29.84
454  6.1 72.0 48.0 677.0   59.00    29.84  3.5 71.0 49.0    0.0   59.00    29.84
455  2.3 67.0 49.3    0.0   57.33    29.85  1.2 63.0 49.7    0.0   55.67    29.87
456  0.0 59.0 50.0    0.0   54.00    29.88  0.0 58.0 49.7    0.0   53.33    29.89
457  0.0 57.0 49.3    0.0   52.67    29.90  0.0 56.0 49.0    0.0   52.00    29.91
458  0.0 54.7 48.3    0.0   51.00    29.91  0.0 53.3 47.7    0.0   50.00    29.91
459  0.0 52.0 47.0    0.0   49.00    29.91  1.5 53.0 48.3    0.0   50.33    29.92
460  3.1 54.0 49.7 604.2   51.67    29.94  4.6 55.0 51.01101.5   53.00    29.95
461  4.2 59.0 52.01926.0   55.00    29.94  3.8 63.0 53.02688.8   57.00    29.94
462  3.5 67.0 54.03229.5   59.00    29.93  5.0 70.0 53.33483.5   60.00    29.91
463  6.5 73.0 52.73457.2   61.00    29.88  8.1 76.0 52.03157.7   62.00    29.86
464  8.1 76.7 53.02893.6   62.67    29.84  8.1 77.3 54.02473.5   63.33    29.83
465  8.1 78.0 55.01926.0   64.00    29.81  8.8 76.3 55.31353.8   63.67    29.80
466  9.6 74.7 55.7 656.8   63.33    29.79 10.4 73.0 56.0    0.0   63.00    29.78
467 10.0 72.0 56.3    0.0   62.67    29.78  9.6 71.0 56.7    0.0   62.33    29.78
468  9.2 70.0 57.0    0.0   62.00    29.78  6.1 69.0 57.0    0.0   61.67    29.78
469  3.1 68.0 57.0    0.0   61.33    29.78  0.0 67.0 57.0    0.0   61.00    29.78
470  0.0 66.7 57.3    0.0   61.00    29.77  0.0 66.3 57.7    0.0   61.00    29.75
471  0.0 66.0 58.0    0.0   61.00    29.74  0.0 66.0 58.3    0.0   61.33    29.75
472  0.0 66.0 58.7 407.3   61.67    29.75  0.0 66.0 59.0 497.9   62.00    29.76
473  0.0 66.0 59.7 746.9   62.33    29.76  0.0 66.0 60.3 960.6   62.67    29.77
474  0.0 66.0 61.01124.7   63.00    29.77  1.5 68.7 62.31521.7   64.67    29.76
475  3.1 71.3 63.71846.8   66.33    29.75  4.6 74.0 65.02048.7   68.00    29.74
476  5.0 75.7 66.31762.9   69.33    29.72  5.4 77.3 67.71404.7   70.67    29.70
477  5.8 79.0 69.01010.4   72.00    29.68  3.8 79.0 68.3 673.6   71.67    29.67
478  1.9 79.0 67.7 312.1   71.33    29.67  0.0 79.0 67.0    0.0   71.00    29.66
479  1.9 77.7 67.3    0.0   70.67    29.68  3.8 76.3 67.7    0.0   70.33    29.70
480  5.8 75.0 68.0    0.0   70.00    29.72  3.8 74.0 67.7    0.0   69.67    29.71
481  1.9 73.0 67.3    0.0   69.33    29.71  0.0 72.0 67.0    0.0   69.00    29.70
482  0.0 71.7 67.0    0.0   68.67    29.70  0.0 71.3 67.0    0.0   68.33    29.70
483  0.0 71.0 67.0    0.0   68.00    29.70  0.0 71.0 67.0    0.0   68.00    29.71
484  0.0 71.0 67.0 225.4   68.00    29.71  0.0 71.0 67.0 492.5   68.00    29.72
485  1.2 72.3 67.01236.9   68.67    29.72  2.3 73.7 67.02090.1   69.33    29.73
486  3.5 75.0 67.02864.6   70.00    29.73  4.6 77.3 67.32924.2   71.00    29.73
487  5.8 79.7 67.72751.5   72.00    29.72  6.9 82.0 68.02379.5   73.00    29.72
488  7.7 83.0 66.72529.7   72.33    29.71  8.4 84.0 65.32395.6   71.67    29.70
489  9.2 85.0 64.01994.1   71.00    29.69  7.7 83.7 62.71370.5   70.00    29.69
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Figure 8.8 (Continued)

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490  6.1 82.3 61.3 639.9   69.00   29.69  4.6 81.0 60.0   0.0   68.00   29.69
491  4.2 77.0 61.0   0.0   67.00   29.70  3.8 73.0 62.0   0.0   66.00   29.72
492  3.5 69.0 63.0   0.0   65.00   29.73  2.3 68.3 62.7   0.0   64.67   29.73
493  1.2 67.7 62.3   0.0   64.33   29.73  0.0 67.0 62.0   0.0   64.00   29.73
494  1.5 67.0 62.7   0.0   64.33   29.72  3.1 67.0 63.3   0.0   64.67   29.72
495  4.6 67.0 64.0   0.0   65.00   29.71  5.4 67.0 64.3   0.0   65.33   29.72
496  6.1 67.0 64.7 628.9   65.67   29.72  6.9 67.0 65.01391.5   66.00   29.73
497  6.9 71.3 65.72088.5   67.67   29.73  6.9 75.7 66.32641.8   69.33   29.73
498  6.9 80.0 67.02994.5   71.00   29.73  6.9 82.7 66.32983.1   71.67   29.71
499  6.9 85.3 65.72643.1   72.33   29.70  6.9 88.0 65.02029.4   73.00   29.68
500  8.4 88.7 64.72516.7   73.00   29.67 10.0 89.3 64.32516.5   73.00   29.65
501 11.5 90.0 64.02088.5   73.00   29.64  9.2 87.3 64.01291.0   72.00   29.63
502  6.9 84.7 64.0 497.6   71.00   29.63  4.6 82.0 64.0   0.0   70.00   29.62
503  6.1 80.0 64.3   0.0   69.67   29.62  7.7 78.0 64.7   0.0   69.33   29.61
504  9.2 76.0 65.0   0.0   69.00   29.61  8.4 75.3 64.3   0.0   68.33   29.61
505  7.7 74.7 63.7   0.0   67.67   29.62  6.9 74.0 63.0   0.0   67.00   29.62
506  7.7 74.3 63.7   0.0   67.67   29.62  8.4 74.7 64.3   0.0   68.33   29.63
507  9.2 75.0 65.0   0.0   69.00   29.63 10.0 72.7 62.0   0.0   66.33   29.67
508 10.7 70.3 59.0 266.2   63.67   29.71 11.5 68.0 56.0 651.5   61.00   29.75
509 12.3 70.0 55.01483.4   61.33   29.77 13.0 72.0 54.02367.0   61.67   29.79
510 13.8 74.0 53.03081.7   62.00   29.81 13.8 75.7 52.73395.7   62.33   29.81
511 13.8 77.3 52.33517.4   62.67   29.82 13.8 79.0 52.03435.7   63.00   29.82
512 13.0 78.3 52.03017.8   62.67   29.82 12.3 77.7 52.02366.9   62.33   29.83
513 11.5 77.0 52.01598.0   62.00   29.83 10.0 75.0 51.31053.9   61.00   29.84
514  8.4 73.0 50.7 470.1   60.00   29.86  6.9 71.0 50.0   0.0   59.00   29.87
515  4.6 68.0 51.0   0.0   58.33   29.88  2.3 65.0 52.0   0.0   57.67   29.89
516  0.0 62.0 53.0   0.0   57.00   29.90  0.0 61.3 53.0   0.0   56.67   29.91
517  0.0 60.7 53.0   0.0   56.33   29.91  0.0 60.0 53.0   0.0   56.00   29.92
518  0.0 59.7 53.0   0.0   56.00   29.92  0.0 59.3 53.0   0.0   56.00   29.93
519  0.0 59.0 53.0   0.0   56.00   29.93  0.0 60.0 54.0   0.0   56.67   29.94
520  0.0 61.0 55.0 582.9   57.33   29.96  0.0 62.0 56.01280.6   58.00   29.97
521  2.7 64.7 56.01889.1   59.33   29.96  5.4 67.3 56.02352.4   60.67   29.96
522  8.1 70.0 56.02635.8   62.00   29.95  7.7 70.7 54.02636.0   61.33   29.93
523  7.3 71.3 52.02413.5   60.67   29.91  6.9 72.0 50.02009.7   60.00   29.89
524  8.1 73.3 50.31838.0   60.33   29.87  9.2 74.7 50.71564.8   60.67   29.84
525 10.4 76.0 51.01208.9   61.00   29.82  9.2 74.0 51.0 794.3   60.33   29.81
526  8.1 72.0 51.0 349.5   59.67   29.80  6.9 70.0 51.0   0.0   59.00   29.79
527  7.7 69.3 51.0   0.0   58.67   29.80  8.4 68.7 51.0   0.0   58.33   29.80
528  9.2 68.0 51.0   0.0   58.00   29.81  9.2 67.0 52.3   0.0   58.33   29.79
529  9.2 66.0 53.7   0.0   58.67   29.76  9.2 65.0 55.0   0.0   59.00   29.74
530  8.4 64.3 55.7   0.0   59.00   29.72  7.7 63.7 56.3   0.0   59.00   29.71
531  6.9 63.0 57.0   0.0   59.00   29.69  4.6 63.3 57.7   0.0   59.67   29.69
532  2.3 63.7 58.3 204.1   60.33   29.68  0.0 64.0 59.0 470.5   61.00   29.68
533  2.3 64.3 59.3 718.8   61.33   29.68  4.6 64.7 59.7 932.0   61.67   29.67
534  6.9 65.0 60.01095.6   62.00   29.67  4.6 65.3 61.01198.4   62.67   29.66
535  2.3 65.7 62.01233.5   63.33   29.65  0.0 66.0 63.01198.4   64.00   29.64
536  0.0 66.7 63.01095.6   64.33   29.63  0.0 67.3 63.0 932.0   64.67   29.61
537  0.0 68.0 63.0 718.8   65.00   29.60  1.9 67.3 63.3 470.5   65.00   29.60
538  3.8 66.7 63.7 204.1   65.00   29.60  5.8 66.0 64.0   0.0   65.00   29.60
539  6.1 65.7 63.7   0.0   64.67   29.60  6.5 65.3 63.3   0.0   64.33   29.60
540  6.9 65.0 63.0   0.0   64.00   29.60  4.6 65.0 62.7   0.0   63.67   29.60
541  2.3 65.0 62.3   0.0   63.33   29.60  0.0 65.0 62.0   0.0   63.00   29.60
542  0.0 65.0 62.0   0.0   63.00   29.59  0.0 65.0 62.0   0.0   63.00   29.59
543  0.0 65.0 62.0   0.0   63.00   29.58  0.0 65.3 62.3   0.0   63.33   29.59
544  0.0 65.7 62.7 198.7   63.67   29.59  0.0 66.0 63.0 465.0   64.00   29.60
545  0.0 67.7 63.7 713.1   65.00   29.60  0.0 69.3 64.3 926.1   66.00   29.61
546  0.0 71.0 65.01089.6   67.00   29.61  2.3 74.3 66.72105.1   69.00   29.59
547  4.6 77.7 68.32858.5   71.00   29.58  6.9 81.0 70.03207.4   73.00   29.56
548  8.1 83.3 70.73032.2   74.33   29.54  9.2 85.7 71.32628.8   75.67   29.52
549 10.4 88.0 72.02037.4   77.00   29.50  8.8 86.3 72.01313.2   76.33   29.50
550  7.3 84.7 72.0 541.6   75.67   29.51  5.8 83.0 72.0   0.0   75.00   29.51
551  5.4 81.3 71.0   0.0   74.00   29.52  5.0 79.7 70.0   0.0   73.00   29.52
```

Figure 8.8 (Continued)

```
552  4.6 78.0 69.0   0.0  72.00  29.53  4.6 76.3 68.3   0.0  71.00  29.54
553  4.6 74.7 67.7   0.0  70.00  29.55  4.6 73.0 67.0   0.0  69.00  29.56
554  3.1 70.3 65.3   0.0  67.00  29.57  1.5 67.7 63.7   0.0  65.00  29.57
555  0.0 65.0 62.0   0.0  63.00  29.58  2.7 67.7 62.7   0.0  64.33  29.60
556  5.4 70.3 63.3 546.1  65.67  29.62  8.1 73.0 64.01278.5  67.00  29.64
557  7.7 75.3 64.01927.5  68.00  29.65  7.3 77.7 64.02439.2  69.00  29.66
558  6.9 80.0 64.02773.9  70.00  29.67  7.7 80.7 62.32681.8  69.33  29.66
559  8.4 81.3 60.72269.5  68.67  29.66  9.2 82.0 59.01604.8  68.00  29.65
560  7.3 83.0 60.31807.9  69.00  29.64  5.4 84.0 61.71791.8  70.00  29.62
561  3.5 85.0 63.01548.0  71.00  29.61  3.8 83.3 61.31176.1  69.33  29.62
562  4.2 81.7 59.7 538.1  67.67  29.62  4.6 80.0 58.0   0.0  66.00  29.63
563  4.6 75.7 58.7   0.0  65.00  29.65  4.6 71.3 59.3   0.0  64.00  29.67
564  4.6 67.0 60.0   0.0  63.00  29.69  3.1 65.3 59.3   0.0  62.00  29.70
565  1.5 63.7 58.7   0.0  61.00  29.71  0.0 62.0 58.0   0.0  60.00  29.72
566  1.9 61.3 57.7   0.0  59.33  29.72  3.8 60.7 57.3   0.0  58.67  29.73
567  5.8 60.0 57.0   0.0  58.00  29.73  5.4 61.0 57.7   0.0  59.00  29.74
568  5.0 62.0 58.3 537.2  60.00  29.76  4.6 63.0 59.01296.6  61.00  29.77
569  4.6 67.3 58.32004.3  62.00  29.77  4.6 71.7 57.72612.0  63.00  29.78
570  4.6 76.0 57.03078.4  64.00  29.78  6.9 78.0 57.03371.5  65.00  29.77
571  9.2 80.0 57.03471.5  66.00  29.75 11.5 82.0 57.03371.5  67.00  29.74
572 10.0 82.7 55.73078.4  66.33  29.74  8.4 83.3 54.32612.0  65.67  29.73
573  6.9 84.0 53.02004.3  65.00  29.73  6.1 82.3 53.01296.6  64.67  29.73
574  5.4 80.7 53.0 537.2  64.33  29.74  4.6 79.0 53.0   0.0  64.00  29.74
575  3.1 74.3 54.0   0.0  62.67  29.74  1.5 69.7 55.0   0.0  61.33  29.75
576  0.0 65.0 56.0   0.0  60.00  29.75  0.0 64.0 55.7   0.0  59.33  29.76
577  0.0 63.0 55.3   0.0  58.67  29.76  0.0 62.0 55.0   0.0  58.00  29.77
578  0.0 61.0 54.7   0.0  57.33  29.77  0.0 60.0 54.3   0.0  56.67  29.77
579  0.0 59.0 54.0   0.0  56.00  29.77  0.0 59.7 55.0   0.0  57.00  29.78
580  0.0 60.3 56.0 521.7  58.00  29.79  0.0 61.0 57.01280.5  59.00  29.80
581  1.9 65.7 58.71987.5  61.67  29.79  3.8 70.3 60.32594.6  64.33  29.79
582  5.8 75.0 62.03060.5  67.00  29.78  5.0 77.7 60.73353.4  67.00  29.77
583  4.2 80.3 59.33453.3  67.00  29.76  3.5 83.0 58.03353.4  67.00  29.75
584  4.6 83.3 58.33025.2  67.33  29.73  5.8 83.7 58.72474.7  67.67  29.72
585  6.9 84.0 59.01780.8  68.00  29.70  6.5 81.7 60.01188.0  67.67  29.69
586  6.1 79.3 61.0 497.6  67.33  29.68  5.8 77.0 62.0   0.0  67.00  29.67
587  6.5 76.0 61.7   0.0  66.67  29.67  7.3 75.0 61.3   0.0  66.33  29.67
588  8.1 74.0 61.0   0.0  66.00  29.67  6.9 72.3 60.7   0.0  65.00  29.67
```

Figure 8.8 (Continued)

The input for run 2 is also shown in Figure 8.9. The parameter IMET = 1 specifies that the fixed values are used for meteorology for the run, namely TA ± 90, TW = 70, TD = 60.1, W = 3, and HS = 1500. The parameter ISPRAY = 1 specifies the regression model. IEVAP = 0 specifies that the pond remains full during the run. The parameter TSPRON = 200 specifies that the sprays are off until 200 hr into the run. Essentially, this allows the pond temperature to reach equilibrium before the effects of the sprays are felt, allowing a more-accurate prediction of the peak temperature attributable to heat load alone.

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$PARAM WID=183,ALEN=283,HT=12.0,THETA=71.0,VELO=22.47,R=.095,
  Y0=5.0,WDR0=0,NDRIFT=6,DWDR=10,FDRIFT=.0005,.00058,.001914,.004346,
 .00789,.014330$
1176
$HFT NH=14.,TH=0.,.01,1.,1.1,1.9,3.9,5.,8.,12.,24.,29.,140.,840.,2000.,
  HEAT(1)=0.,0.,.85E9,2*.51E9,.5E9,.68E9,.6E9,.4E9,.31E9,.27E9,
   .21E9,.18E9,.1E9,FLOW=14*205200.0$
  EFFECTS OF DESIGN BASIS METEOROLOGY WITH STEADY HEAT LOAD-SPRAYS ON
$INLIST VZERO=2942357,A=422000,NSTEPS=2000,NPRINT=10,TZERO=80,
   IMET=0,ISPRAY=1,TSKIP=5000,Q1=0.23E9,F1=2.052E5,TSPRON=0.0,IEVAP=0$
  EFFECTS OF DESIGN BASIS HEAT LOAD ONLY
$INLIST VZERO=2942357.,A=422000.,NSTEPS=2000,NPRINT=10,TZERO=90,IMET=1,
   TSKIP=200,DT=.5,TA=90,TW=70,TD=60.1,W=0,HS=1500,ISPRAY=1,IEVAP=0,
  TSPRON=200,Q1=0,F1=1$
```

Figure 8.9 Input deck for program SPRND, procedure 1

The output from run 2 is shown printed in Figure 8.12 and plotted in Figure 8.13.

Run 3 would be set up after inspection of runs 1 and 2. The peak temperature for ambient meteorology and steady heat load occurred at 451.0 hr. The peak temperature for the design-basis heat load alone occurred at 213.0 hr, or 15.0 hr after the sprays were turned on. The parameter TSKIP should, therefore, be 451.0 hr - 13.0 hr = 438.0 hr.

The data input for run 3 is shown in Figure 8.14. The parameter TSPRON = 438.0 hr delays the sprays 438.0 hr. The parameters Q1 = 0.0 and F1 = 1.0 specify that the heat load and flowrate to the pond are 0 Btu/hr and 1 ft^3/hr for times less than 438.0 hr. The parameter IMET = 0 specifies that the meteorological table is used for input. IEVAP = 1 specifies that the pond volume is allowed to change in response to water loss for times greater than 438.0 hr. The parameter ISPRAY = 2 specifies that the rigorous spray model is used.

```
 EFFECTS OF DESIGN BASIS METEOROLOGY WITH STEADY HEAT LOAD-SPRAYS ON


SPRAY FIELD PARAMETERS
****************************************
INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO =      684.89 CM/SEC
INITIAL ANGLE OF DROPS TO HOR., THETA =      1.239 RADIANS
GEOMETRIC MEAN RADIUS OF DROPS, R =      .0950 CM
HEIGHT OF SPRAY FIELD, HT =      365.76 CM
WIDTH OF SPRAY FIELD, WID =      5577.8 CM
LENGTH OF SPRAY FIELD, ALEN =      8625.8 CM
HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, YO =      152.4
HEADING OF WIND W.R.T.LONG AXIS, PHI =      90.00 DEGREES


POND PARAMETERS
****************************************
INITIAL POND VOLUME,VZERO =      2942357.0 CU.FT.
POND SURFACE AREA,A =      422000.0 SQ.FT.
BLOWDOWN AND LEAKAGE,BLOW =      0.00 CU.FT./HR.
NUMBER OF INTEGRATION STEPS,NSTEPS =  2000
PRINT INTERVAL,NPRINT =    10
INTEGRATION TIMESTEP,DT =        .50 HOURS
INITIAL POND TEMPERATURE,TZERO =      80.00 DEG.F
DELAY FOR HEAT TABLE,TSKIP =    5000.00 HRS
BASE HEAT LOAD ADDED TO TABLE,QBASE =      0.00 HRS
BASE FLOW RATE ADDED TO TABLE ,FBASE =    0.          CU.FT./HR.



                    .....................................
                    : HEAT IN   : TIME FROM : FLOW IN   :
                    :  BTU/HR   :   START   : FT**3/HR  :
                    .....................................
                    :0.         :      0.00 : .205E+06  :
                    :0.         :       .01 : .205E+06  :
                    : .850E+09  :      1.00 : .205E+06  :
                    : .510E+09  :      1.10 : .205E+06  :
                    : .510E+09  :      1.90 : .205E+06  :
                    : .500E+09  :      3.90 : .205E+06  :
                    : .680E+09  :      5.00 : .205E+06  :
                    : .600E+09  :      8.00 : .205E+06  :
                    : .400E+09  :     12.00 : .205E+06  :
                    : .310E+09  :     24.00 : .205E+06  :
                    : .270E+09  :     29.00 : .205E+06  :
                    : .210E+09  :    140.00 : .205E+06  :
                    : .180E+09  :    840.00 : .205E+06  :
                    : .100E+09  :   2000.00 : .205E+06  :

      FOR TIME LESS THAN TSKIP
      Q1 =      .230E+09 BTU/HR
      F1 =      .205E+06 FT**3/HR
```

Figure 8.10 Output from program SPRPND, effect of ambient meteorology and steady heat load

```
METEOROLOGICAL TABLE USED AS INPUT

REGRESSION EQUATIONS USED FOR SPRAY MODEL

SPRAYS WILL BE DELAYED      0.00 HOURS

                              ..................................



                            ************* MODEL RESULTS *************

                         ..TIME.......TEMPERATURE (F)........VOLUME...,
                         :  HR                              :     FT**3    :
                         ...............................................
                             5.00                80.58          .29423570E+07
                            10.00                82.48          .29423570E+07
                            15.00                84.21          .29423570E+07
                            20.00                83.76          .29423570E+07
                            25.00                82.27          .29423570E+07
                            30.00                80.57          .29423570E+07
                            35.00                80.35          .29423570E+07
                            40.00                81.02          .29423570E+07
                            45.00                80.92          .29423570E+07
                            50.00                80.29          .29423570E+07
                            55.00                79.26          .29423570E+07
                            60.00                77.43          .29423570E+07
                            65.00                77.21          .29423570E+07
                            70.00                76.45          .29423570E+07
                            75.00                76.27          .29423570E+07
                            80.00                76.53          .29423570E+07
                            85.00                77.21          .29423570E+07
                            90.00                78.04          .29423570E+07
                            95.00                78.22          .29423570E+07
                           100.00                78.14          .29423570E+07
                           105.00                78.26          .29423570E+07
                           110.00                79.78          .29423570E+07
                           115.00                80.45          .29423570E+07
                           120.00                80.28          .29423570E+07
                           125.00                79.77          .29423570E+07
                           130.00                80.28          .29423570E+07
                           135.00                81.01          .29423570E+07
                           140.00                80.31          .29423570E+07
                           145.00                79.97          .29423570E+07
                           150.00                79.59          .29423570E+07
                           155.00                79.82          .29423570E+07
                           160.00                80.66          .29423570E+07
                           165.00                80.78          .29423570E+07
                           170.00                80.71          .29423570E+07
                           175.00                81.15          .29423570E+07
                           180.00                81.95          .29423570E+07
                           185.00                82.56          .29423570E+07
```

Figure 8.10 (Continued)

```
   190.00          82.05        .29423570E+07
   195.00          81.58        .29423570E+07
   200.00          82.49        .29423570E+07
   205.00          84.93        .29423570E+07
   210.00          86.44        .29423570E+07
   215.00          86.17        .29423570E+07
   220.00          85.40        .29423570E+07
   225.00          85.54        .29423570E+07
   230.00          86.79        .29423570E+07
   235.00          86.92        .29423570E+07
   240.00          86.13        .29423570E+07
   245.00          85.28        .29423570E+07
   250.00          84.92        .29423570E+07
   255.00          85.88        .29423570E+07
   260.00          84.09        .29423570E+07
   265.00          82.87        .29423570E+07
   270.00          82.51        .29423570E+07
   275.00          84.23        .29423570E+07
   280.00          85.54        .29423570E+07
   285.00          85.72        .29423570E+07
   290.00          85.18        .29423570E+07
   295.00          84.90        .29423570E+07
   300.00          86.40        .29423570E+07
   305.00          87.24        .29423570E+07
   310.00          86.33        .29423570E+07
   315.00          85.60        .29423570E+07
   320.00          85.85        .29423570E+07
   325.00          87.22        .29423570E+07
   330.00          87.17        .29423570E+07
   335.00          86.62        .29423570E+07
   340.00          86.13        .29423570E+07
   345.00          85.78        .29423570E+07
   350.00          87.40        .29423570E+07
   355.00          87.78        .29423570E+07
   360.00          87.33        .29423570E+07
   365.00          86.63        .29423570E+07
   370.00          87.05        .29423570E+07
   375.00          88.70        .29423570E+07
   380.00          89.38        .29423570E+07
   385.00          88.90        .29423570E+07
   390.00          88.23        .29423570E+07
   395.00          89.42        .29423570E+07
   400.00          91.39        .29423570E+07
   405.00          91.36        .29423570E+07
   410.00          90.52        .29423570E+07
   415.00          89.55        .29423570E+07
   420.00          90.57        .29423570E+07
   425.00          90.99        .29423570E+07
   430.00          90.98        .29423570E+07
   435.00          90.05        .29423570E+07
   440.00          89.91        .29423570E+07
   445.00          91.29        .29423570E+07
   450.00          92.12        .29423570E+07
   455.00          91.68        .29423570E+07
   460.00          90.33        .29423570E+07
```

Figure 8.10 (Continued)

```
465.00          89.66          .29423570E+07
470.00          90.70          .29423570E+07
475.00          92.11          .29423570E+07
480.00          91.39          .29423570E+07
485.00          90.05          .29423570E+07
490.00          90.31          .29423570E+07
495.00          91.18          .29423570E+07
500.00          91.07          .29423570E+07
505.00          89.51          .29423570E+07
510.00          88.44          .29423570E+07
515.00          88.74          .29423570E+07
520.00          88.99          .29423570E+07
525.00          88.08          .29423570E+07
530.00          87.27          .29423570E+07
535.00          86.77          .29423570E+07
540.00          86.70          .29423570E+07
545.00          86.32          .29423570E+07
550.00          84.34          .29423570E+07
555.00          81.94          .29423570E+07
560.00          80.57          .29423570E+07
565.00          80.21          .29423570E+07
570.00          79.80          .29423570E+07
575.00          79.82          .29423570E+07
580.00          80.08          .29423570E+07
585.00          80.51          .29423570E+07
590.00          81.21          .29423570E+07
595.00          81.62          .29423570E+07
600.00          81.66          .29423570E+07
605.00          81.38          .29423570E+07
610.00          81.90          .29423570E+07
615.00          82.72          .29423570E+07
620.00          81.93          .29423570E+07
625.00          81.32          .29423570E+07
630.00          80.46          .29423570E+07
635.00          80.39          .29423570E+07
640.00          81.45          .29423570E+07
645.00          81.81          .29423570E+07
650.00          81.58          .29423570E+07
655.00          81.16          .29423570E+07
660.00          81.41          .29423570E+07
665.00          81.71          .29423570E+07
670.00          81.85          .29423570E+07
675.00          81.38          .29423570E+07
680.00          81.41          .29423570E+07
685.00          81.94          .29423570E+07
690.00          82.67          .29423570E+07
695.00          82.95          .29423570E+07
700.00          82.48          .29423570E+07
705.00          82.36          .29423570E+07
710.00          83.71          .29423570E+07
715.00          84.40          .29423570E+07
720.00          84.23          .29423570E+07
725.00          83.79          .29423570E+07
730.00          84.51          .29423570E+07
735.00          85.48          .29423570E+07
```

Figure 8.10 (Continued)

```
         740.00                 85.28            .29423570E+07
         745.00                 84.68            .29423570E+07
         750.00                 84.30            .29423570E+07
         755.00                 84.74            .29423570E+07
         760.00                 86.18            .29423570E+07
         765.00                 86.39            .29423570E+07
         770.00                 85.88            .29423570E+07
         775.00                 85.05            .29423570E+07
         780.00                 84.19            .29423570E+07
         785.00                 82.30            .29423570E+07
         790.00                 80.78            .29423570E+07
         795.00                 80.07            .29423570E+07
         800.00                 79.65            .29423570E+07
         805.00                 80.32            .29423570E+07
         810.00                 81.21            .29423570E+07
         815.00                 80.95            .29423570E+07
         820.00                 80.53            .29423570E+07
         825.00                 80.48            .29423570E+07
         830.00                 81.46            .29423570E+07
         835.00                 82.01            .29423570E+07
         840.00                 81.72            .29423570E+07
         845.00                 81.19            .29423570E+07
         850.00                 81.28            .29423570E+07
         855.00                 81.34            .29423570E+07
         860.00                 81.57            .29423570E+07
         865.00                 81.53            .29423570E+07
         870.00                 81.60            .29423570E+07
         875.00                 82.51            .29423570E+07
         880.00                 82.31            .29423570E+07
         885.00                 80.35            .29423570E+07
         890.00                 79.35            .29423570E+07
         895.00                 78.06            .29423570E+07
         900.00                 77.47            .29423570E+07
         905.00                 77.17            .29423570E+07
         910.00                 77.32            .29423570E+07
         915.00                 77.63            .29423570E+07
         920.00                 78.00            .29423570E+07
         925.00                 79.18            .29423570E+07
         930.00                 79.76            .29423570E+07
         935.00                 78.91            .29423570E+07
         940.00                 79.11            .29423570E+07
         945.00                 79.64            .29423570E+07
         950.00                 80.83            .29423570E+07
         955.00                 82.21            .29423570E+07
         960.00                 82.68            .29423570E+07
         965.00                 82.98            .29423570E+07
         970.00                 83.65            .29423570E+07
         975.00                 85.00            .29423570E+07
         980.00                 84.90            .29423570E+07
         985.00                 83.97            .29423570E+07
         990.00                 83.14            .29423570E+07
         995.00                 83.81            .29423570E+07
        1000.00                 85.17            .29423570E+07

TSKIP =   5000.0 HOURS     MAX MODELED TEMPERATURE =     92.17 AT  451.00 HOURS
```

Figure 8.10 (Continued)

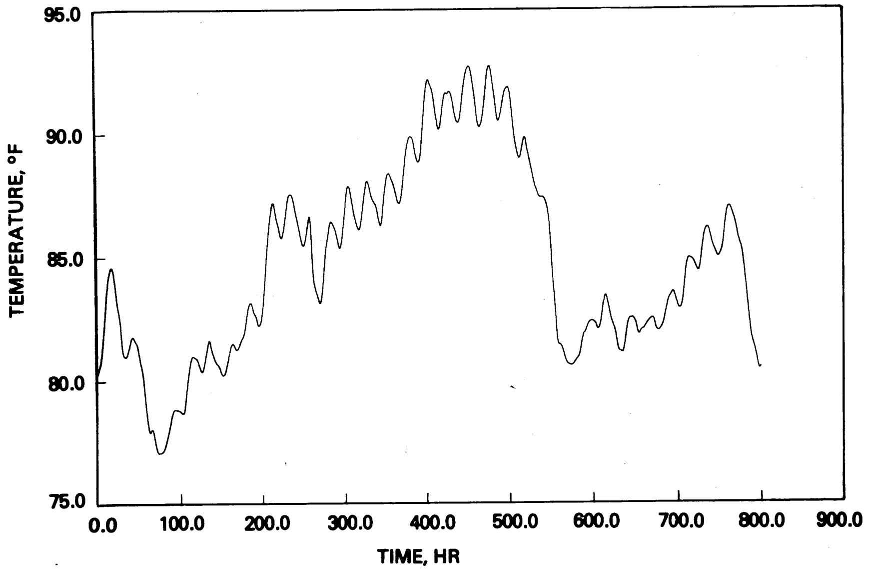

Figure 8.11 Pond temperature in response to a steady heat load and ambient meteorology

The reliability of this estimate of the parameter ISKIP is questionable however, because of nonlinearities in the models that make the use of linear superposition strictly invalid. Therefore, a series of runs should be made varying TSTART over a range of 1 or 2 days. The results of this run will, therefore, not be shown, in favor of procedure 2 below.

8.6.2 Procedure 2

An alternative procedure for determining TSKIP is simply to vary this parameter over a wide range in a repetitive manner within the 50-day period of data and pick the value giving the highest pond temperature. This "brute force" approach is not particularly wasteful of computer time if the regression spray model is used for pond performance. The rigorous spray model may then be run for the value of TSKIP determined to give the highest pond temperature.

The input for the first run in procedure 2 is shown in Figure 8.15. The parameters IEVAP = 1 and IMET = 0 specify normal water loss and meteorological

```
  EFFECTS OF DESIGN BASIS HEAT LOAD ONLY


 SPRAY FIELD PARAMETERS
 ****************************************
 INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO =      684.89 CM/SEC
 INITIAL ANGLE OF DROPS TO HOR., THETA =      1.239 RADIANS
 GEOMETRIC MEAN RADIUS OF DROPS, R =      .0950 CM
 HEIGHT OF SPRAY FIELD, HT =     365.76 CM
 WIDTH OF SPRAY FIELD, WID =     5577.8 CM
 LENGTH OF SPRAY FIELD, ALEN =     8625.8 CM
 HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, YO =      152.4
 HEADING OF WIND W.R.T.LONG AXIS, PHI =      90.00 DEGREES



 POND PARAMETERS
 ****************************************
 INITIAL POND VOLUME,VZERO =     2942357.0 CU.FT.
 POND SURFACE AREA,A =     422000.0 SQ.FT.
 BLOWDOWN AND LEAKAGE,BLOW =      0.00 CU.FT./HR.
 NUMBER OF INTEGRATION STEPS,NSTEPS =  1600
 PRINT INTERVAL,NPRINT =    10
 INTEGRATION TIMESTEP,DT =      .50 HOURS
 INITIAL POND TEMPERATURE,TZERO =      90.00 DEG.F
 DELAY FOR HEAT TABLE,TSKIP =    200.00 HRS
 BASE HEAT LOAD ADDED TO TABLE,QBASE =      0.00 HRS
 BASE FLOW RATE ADDED TO TABLE ,FBASE =    0.           CU.FT./HR.


                          ....................................
                          : HEAT IN   : TIME FROM : FLOW IN   :
                          :  BTU/HR   :   START   : FT**3/HR  :
                          ....................................
                          :0.         :      0.00 : .205E+06  :
                          :0.         :       .01 : .205E+06  :
                          : .850E+09  :      1.00 : .205E+06  :
                          : .510E+09  :      1.10 : .205E+06  :
                          : .510E+09  :      1.90 : .205E+06  :
                          : .500E+09  :      3.90 : .205E+06  :
                          : .680E+09  :      5.00 : .205E+06  :
                          : .600E+09  :      8.00 : .205E+06  :
                          : .400E+09  :     12.00 : .205E+06  :
                          : .310E+09  :     24.00 : .205E+06  :
                          : .270E+09  :     29.00 : .205E+06  :
                          : .210E+09  :    140.00 : .205E+06  :
                          : .180E+09  :    840.00 : .205E+06  :
                          : .100E+09  :   2000.00 : .205E+06  :
```

Figure 8.12 Output from program SPRND, effect of design-basis heat load and steady meteorology

```
        FOR TIME LESS THAN TSKIP
        Q1 =     0.         BTU/HR
        F1 =      .100E+01 FT**3/HR


 FIXED METEOROLOGICAL VALUES USED AS INPUT


 DRY BULB TEMPERATURE,TA =       90.00 DEG. F
 WET BULB TEMPERATURE,TW =       70.00 DEG. F
 WIND SPEED,W =         0.00MPH
 DEW POINT TEMPERATURE,TD =       60.10 DEG. F
 SOLAR RADIATION,HS =    1500.00 BTU/SQ.FT./DAY
 3AROMETRIC PRESSURE,PB =       29.92 IN.HG.

 REGRESSION EQUATIONS USED FOR SPRAY MODEL


 SPRAYS WILL BE DELAYED    200.00 HOURS

                         ..................................



                       ************* MODEL RESULTS *************


                    ..TIME.......TEMPERATURE (F)........VOLUME....
                    :  HR                              :    FT**3   :

                    .............................................
                       5.00           90.04         .29423570E+07
                      10.00           90.07         .29423570E+07
                      15.00           90.11         .29423570E+07
                      20.00           90.14         .29423570E+07
                      25.00           90.16         .29423570E+07
                      30.00           90.19         .29423570E+07
                      35.00           90.21         .29423570E+07
                      40.00           90.24         .29423570E+07
                      45.00           90.26         .29423570E+07
                      50.00           90.28         .29423570E+07
                      55.00           90.30         .29423570E+07
                      60.00           90.31         .29423570E+07
                      65.00           90.33         .29423570E+07
                      70.00           90.34         .29423570E+07
                      75.00           90.36         .29423570E+07
                      80.00           90.37         .29423570E+07
                      85.00           90.38         .29423570E+07
                      90.00           90.39         .29423570E+07
                      95.00           90.40         .29423570E+07
                     100.00           90.41         .29423570E+07
                     105.00           90.42         .29423570E+07
                     110.00           90.43         .29423570E+07
                     115.00           90.44         .29423570E+07
                     120.00           90.44         .29423570E+07
                     125.00           90.45         .29423570E+07
```

Figure 8.12 (Continued)

```
130.00          90.46          .29423570E+07
135.00          90.46          .29423570E+07
140.00          90.47          .29423570E+07
145.00          90.47          .29423570E+07
150.00          90.48          .29423570E+07
155.00          90.48          .29423570E+07
160.00          90.49          .29423570E+07
165.00          90.49          .29423570E+07
170.00          90.49          .29423570E+07
175.00          90.50          .29423570E+07
180.00          90.50          .29423570E+07
185.00          90.50          .29423570E+07
190.00          90.50          .29423570E+07
195.00          90.51          .29423570E+07
200.00          90.38          .29423570E+07
205.00          92.89          .29423570E+07
210.00          95.00          .29423570E+07
215.00          95.21          .29423570E+07
220.00          94.96          .29423570E+07
225.00          94.55          .29423570E+07
230.00          93.96          .29423570E+07
235.00          93.42          .29423570E+07
240.00          92.97          .29423570E+07
245.00          92.60          .29423570E+07
250.00          92.29          .29423570E+07
255.00          92.03          .29423570E+07
260.00          91.81          .29423570E+07
265.00          91.62          .29423570E+07
270.00          91.46          .29423570E+07
275.00          91.31          .29423570E+07
280.00          91.18          .29423570E+07
285.00          91.06          .29423570E+07
290.00          90.95          .29423570E+07
295.00          90.86          .29423570E+07
300.00          90.77          .29423570E+07
305.00          90.68          .29423570E+07
310.00          90.60          .29423570E+07
315.00          90.53          .29423570E+07
320.00          90.46          .29423570E+07
325.00          90.39          .29423570E+07
330.00          90.33          .29423570E+07
335.00          90.27          .29423570E+07
340.00          90.21          .29423570E+07
345.00          90.16          .29423570E+07
350.00          90.11          .29423570E+07
355.00          90.07          .29423570E+07
360.00          90.04          .29423570E+07
365.00          90.01          .29423570E+07
370.00          89.98          .29423570E+07
375.00          89.96          .29423570E+07
380.00          89.94          .29423570E+07
385.00          89.92          .29423570E+07
390.00          89.90          .29423570E+07
395.00          89.88          .29423570E+07
```

Figure 8.12 (Continued)

```
400.00            89.86           .29423570E+07
405.00            89.84           .29423570E+07
410.00            89.82           .29423570E+07
415.00            89.81           .29423570E+07
420.00            89.79           .29423570E+07
425.00            89.78           .29423570E+07
430.00            89.76           .29423570E+07
435.00            89.75           .29423570E+07
440.00            89.73           .29423570E+07
445.00            89.72           .29423570E+07
450.00            89.71           .29423570E+07
455.00            89.69           .29423570E+07
460.00            89.68           .29423570E+07
465.00            89.67           .29423570E+07
470.00            89.65           .29423570E+07
475.00            89.64           .29423570E+07
480.00            89.63           .29423570E+07
485.00            89.62           .29423570E+07
490.00            89.61           .29423570E+07
495.00            89.59           .29423570E+07
500.00            89.58           .29423570E+07
505.00            89.57           .29423570E+07
510.00            89.56           .29423570E+07
515.00            89.55           .29423570E+07
520.00            89.54           .29423570E+07
525.00            89.53           .29423570E+07
530.00            89.52           .29423570E+07
535.00            89.51           .29423570E+07
540.00            89.50           .29423570E+07
545.00            89.49           .29423570E+07
550.00            89.48           .29423570E+07
555.00            89.47           .29423570E+07
560.00            89.46           .29423570E+07
565.00            89.45           .29423570E+07
570.00            89.44           .29423570E+07
575.00            89.44           .29423570E+07
580.00            89.43           .29423570E+07
585.00            89.42           .29423570E+07
590.00            89.41           .29423570E+07
595.00            89.40           .29423570E+07
600.00            89.39           .29423570E+07
605.00            89.38           .29423570E+07
610.00            89.38           .29423570E+07
615.00            89.37           .29423570E+07
620.00            89.36           .29423570E+07
625.00            89.35           .29423570E+07
630.00            89.35           .29423570E+07
635.00            89.34           .29423570E+07
640.00            89.33           .29423570E+07
645.00            89.32           .29423570E+07
650.00            89.31           .29423570E+07
655.00            89.31           .29423570E+07
660.00            89.30           .29423570E+07
665.00            89.29           .29423570E+07
```

Figure 8.12 (Continued)

```
              670.00              89.29          .29423570E+07
              675.00              89.28          .29423570E+07
              680.00              89.27          .29423570E+07
              685.00              89.27          .29423570E+07
              690.00              89.26          .29423570E+07
              695.00              89.25          .29423570E+07
              700.00              89.25          .29423570E+07
              705.00              89.24          .29423570E+07
              710.00              89.23          .29423570E+07
              715.00              89.23          .29423570E+07
              720.00              89.22          .29423570E+07
              725.00              89.21          .29423570E+07
              730.00              89.21          .29423570E+07
              735.00              89.20          .29423570E+07
              740.00              89.19          .29423570E+07
              745.00              89.19          .29423570E+07
              750.00              89.18          .29423570E+07
              755.00              89.18          .29423570E+07
              760.00              89.17          .29423570E+07
              765.00              89.16          .29423570E+07
              770.00              89.16          .29423570E+07
              775.00              89.15          .29423570E+07
              780.00              89.15          .29423570E+07
              785.00              89.14          .29423570E+07
              790.00              89.14          .29423570E+07
              795.00              89.13          .29423570E+07
              800.00              89.12           29423570E+07

TSKIP =     200.0 HOURS     MAX MODELED TEMPERATURE =     95.22 AT  213.00 HOURS
```

Figure 8.12 (Continued)

table input, respectively. The parameter ISPRAY = 1 specifies the regression spray performance model. The parameters ISPRON = 0, TSKIP = 0, NITER = 150, and DTITER = 5 specify that the program should iterate from TSKIP and TSPRON = 0 to 750 hr in 5-hr increments. The parameter NPRINT = 5000 effectively suppresses intermediate output so that only the temperature peak for each run is outputted.

The output for this run is shown printed in Figure 8.16 and plotted in Figure 8.17. From Figure 8.17, there appear to be two temperature peaks, each about 94.0°F. The first occurs at a value of TSKIP of about 425.0 hr and the second roughly 1 day later at a value of TSKIP of about 447.0 hr. The value of TSKIP determined from procedure 1 was 438.0 hr. For a value of TSKIP = 438.0 hr, the temperature peak from Figure 8.17 is about 93.7°F. Therefore, a relatively small error of about 0.3°F would be made by relying on the estimate on TSKIP from procedure 1.

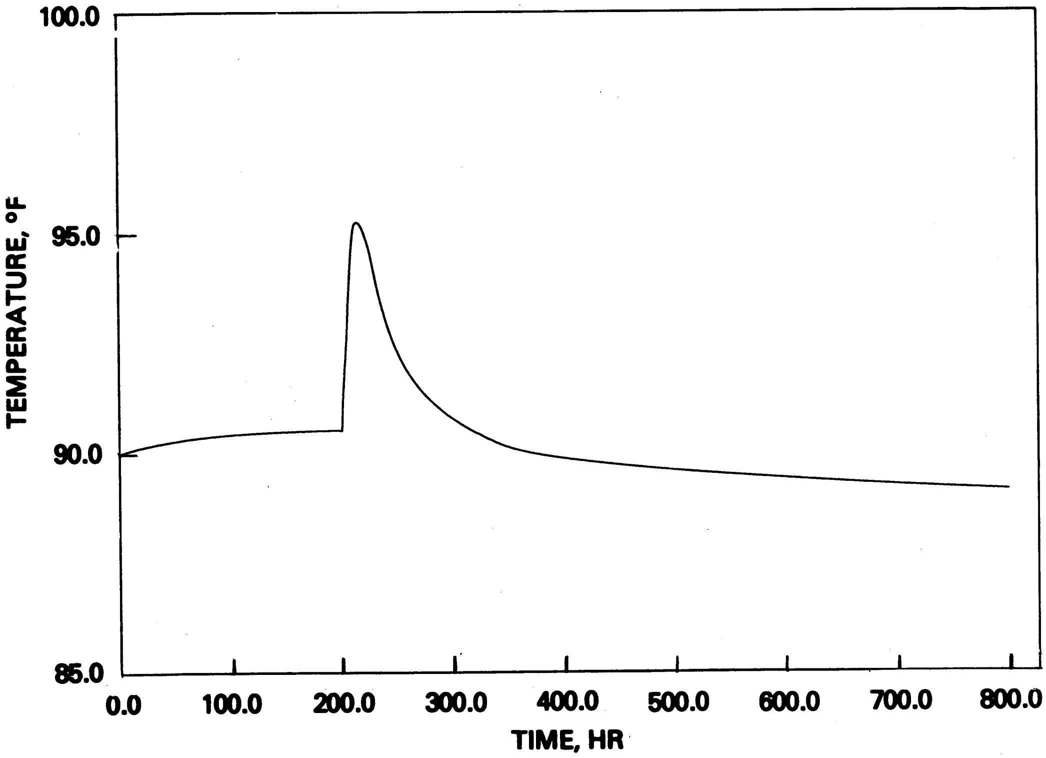

Figure 8.13 Pond temperature in response to design-basis heat load and constant meteorology

The input for the second run of procedure 2 is shown set up in Figure 8.18 for the second peak at TSKIP = 447.0 hr, with ISPRAY = 2, which specifies the rigorous spray model. Output from this run is shown printed in Figure 8.19 and plotted in Figure 8.20. The peak temperature predicted is 93.91°F.

Also shown plotted in Figure 8.20 is the output from the run repeated with the regression spray model (ISPRAY = 1). The agreement between the rigorous and regression ISPRAY performance models is excellent, especially for the highest temperatures. The regression spray model predicts a slightly higher peak temperature of 93.97°F.

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$PARAM WID=183,ALEN=283,HT=12.0,THETA=71.0,VELO=22.47,R=.095,
  Y0=5.0,WDR0=0,NDRIFT=6,DWDR=10,FDRIFT=.0005,.00058,.001914,.004346,
 .00789,.014330$
1176
$HFT NH=14.,TH=0.,.01,1.,1.1,1.9,3.9,5.,8.,12.,24.,29.,140.,840.,2000.,
  HEAT(1)=0.,0.,.85E9,2*.51E9,.5E9,.68E9,.6E9,.4E9,.31E9,.27E9,
   .21E9,.18E9,.1E9,FLOW=14*205200.0$
        COMBINED RUN WITH RIGOROUS MODEL
$INLIST VZERO=2942357,A=422000,NSTEPS=1600,NPRINT=10,Q1=0,F1=1,IEVAP=1,
  DT=.5,IMET=0,ISPRAY=2,
 TSPRON= 438 ,TSKIP=438 $
```

Figure 8.14 Final run of program SPRPND, procedure 1

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$PARAM WID=183,ALEN=283,HT=12.0,THETA=71.0,VELO=22.47,R=.095,
  Y0=5.0,WDR0=0,NDRIFT=6,DWDR=10,FDRIFT=.0005,.00058,.001914,.004346,
 .00789,.014330$
1176
$HFT NH=14.,TH=0.,.01,1.,1.1,1.9,3.9,5.,8.,12.,24.,29.,140.,840.,2000.,
  HEAT(1)=0.,0.,.85E9,2*.51E9,.5E9,.68E9,.6E9,.4E9,.31E9,.27E9,
   .21E9,.18E9,.1E9,FLOW=14*205200.0$
          ITERATE TSKIP FROM 0 TO 750 HOURS STEP 5
$INLIST VZERO=2942357,A=422000,NSTEPS=2000,NPRINT=5000,TZERO=80,IMET=0,
  TSPRON=0,TSKIP=0,DTITER=5,NITER=150,ISPRAY=1,IEVAP=1,Q1=0,F1=1,DT=.5$
```

Figure 8.15 Input data for program SPRPND, iterative run, procedure 2

```
                ITERATE TSKIP FROM 0 TO 750 HOURS STEP 5


SPRAY FIELD PARAMETERS
*******************************************
INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO =      684.89 CM/SEC
INITIAL ANGLE OF DROPS TO HOR., THETA =      1.239 RADIANS
GEOMETRIC MEAN RADIUS OF DROPS, R =      .0950 CM
HEIGHT OF SPRAY FIELD, HT =      365.76 CM
WIDTH OF SPRAY FIELD, WID =      5577.8 CM
LENGTH OF SPRAY FIELD, ALEN =      8625.8 CM
HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, YO =       152.4
HEADING OF WIND W.R.T.LONG AXIS, PHI =       90.00 DEGREES



POND PARAMETERS
*******************************************
INITIAL POND VOLUME,VZERO =      2942357.0 CU.FT.
POND SURFACE AREA,A =      422000.0 SQ.FT.
BLOWDOWN AND LEAKAGE,BLOW =       0.00 CU.FT./HR.
NUMBER OF INTEGRATION STEPS,NSTEPS =  2000
PRINT INTERVAL,NPRINT =  5000
INTEGRATION TIMESTEP,DT =         .50 HOURS
INITIAL POND TEMPERATURE,TZERO =      80.00 DEG.F
DELAY FOR HEAT TABLE,TSKIP =       0.00 HRS
BASE HEAT LOAD ADDED TO TABLE,QBASE =       0.00 HRS
BASE FLOW RATE ADDED TO TABLE ,FBASE =    0.            CU.FT./HR.


                      .....................................
                      : HEAT IN   : TIME FROM : FLOW IN   :
                      :  BTU/HR   :   START   : FT**3/HR  :
                      .....................................
                      :0.         :      0.00 : .205E+06  :
                      :0.         :       .01 : .205E+06  :
                      : .850E+09  :      1.00 : .205E+06  :
                      : .510E+09  :      1.10 : .205E+06  :
                      : .510E+09  :      1.90 : .205E+06  :
                      : .500E+09  :      3.90 : .205E+06  :
                      : .680E+09  :      5.00 : .205E+06  :
                      : .600E+09  :      8.00 : .205E+06  :
                      : .400E+09  :     12.00 : .205E+06  :
                      : .310E+09  :     24.00 : .205E+06  :
                      : .270E+09  :     29.00 : .205E+06  :
                      : .210E+09  :    140.00 : .205E+06  :
                      : .180E+09  :    840.00 : .205E+06  :
                      : .100E+09  :   2000.00 : .205E+06  :

          FOR TIME LESS THAN TSKIP
          Q1 =    0.         BTU/HR
          F1 =     .100E+01 FT**3/HR
```

Figure 8.16   Output from program SPRPND, iterative run, procedure 2

```
                        METEOROLOGICAL TABLE USED AS INPUT

                        REGRESSION EQUATIONS USED FOR SPRAY MODEL

                        SPRAYS WILL BE DELAYED      0.00 HOURS

                                           .................................



                                          ************* MODEL RESULTS *************

                                       ..TIME.......TEMPERATURE (F).........VOLUME....
                                       :  HR                          :    FT**3   :
                                       ..............................................
TSKIP =       0.0 HOURS      MAX MODELED TEMPERATURE =     91.95 AT   474.50 HOURS
TSKIP =       5.0 HOURS      MAX MODELED TEMPERATURE =     91.94 AT   474.50 HOURS
TSKIP =      10.0 HOURS      MAX MODELED TEMPERATURE =     91.93 AT   474.50 HOURS
TSKIP =      15.0 HOURS      MAX MODELED TEMPERATURE =     91.91 AT   474.50 HOURS
TSKIP =      20.0 HOURS      MAX MODELED TEMPERATURE =     91.90 AT   474.50 HOURS
TSKIP =      25.0 HOURS      MAX MODELED TEMPERATURE =     91.88 AT   474.50 HOURS
TSKIP =      30.0 HOURS      MAX MODELED TEMPERATURE =     91.87 AT   474.50 HOURS
TSKIP =      35.0 HOURS      MAX MODELED TEMPERATURE =     91.86 AT   474.50 HOURS
TSKIP =      40.0 HOURS      MAX MODELED TEMPERATURE =     91.85 AT   474.50 HOURS
TSKIP =      45.0 HOURS      MAX MODELED TEMPERATURE =     91.83 AT   474.50 HOURS
TSKIP =      50.0 HOURS      MAX MODELED TEMPERATURE =     91.82 AT   474.50 HOURS
TSKIP =      55.0 HOURS      MAX MODELED TEMPERATURE =     91.81 AT   474.50 HOURS
TSKIP =      60.0 HOURS      MAX MODELED TEMPERATURE =     91.80 AT   474.50 HOURS
TSKIP =      65.0 HOURS      MAX MODELED TEMPERATURE =     91.80 AT   474.50 HOURS
TSKIP =      70.0 HOURS      MAX MODELED TEMPERATURE =     91.79 AT   474.50 HOURS
TSKIP =      75.0 HOURS      MAX MODELED TEMPERATURE =     91.78 AT   474.50 HOURS
TSKIP =      80.0 HOURS      MAX MODELED TEMPERATURE =     91.77 AT   474.50 HOURS
TSKIP =      85.0 HOURS      MAX MODELED TEMPERATURE =     91.77 AT   474.50 HOURS
TSKIP =      90.0 HOURS      MAX MODELED TEMPERATURE =     91.76 AT   474.50 HOURS
TSKIP =      95.0 HOURS      MAX MODELED TEMPERATURE =     91.76 AT   474.50 HOURS
TSKIP =     100.0 HOURS      MAX MODELED TEMPERATURE =     91.75 AT   474.50 HOURS
TSKIP =     105.0 HOURS      MAX MODELED TEMPERATURE =     91.75 AT   474.50 HOURS
TSKIP =     110.0 HOURS      MAX MODELED TEMPERATURE =     91.74 AT   474.50 HOURS
TSKIP =     115.0 HOURS      MAX MODELED TEMPERATURE =     91.74 AT   474.50 HOURS
TSKIP =     120.0 HOURS      MAX MODELED TEMPERATURE =     91.73 AT   475.00 HOURS
TSKIP =     125.0 HOURS      MAX MODELED TEMPERATURE =     91.73 AT   475.00 HOURS
TSKIP =     130.0 HOURS      MAX MODELED TEMPERATURE =     91.73 AT   475.00 HOURS
TSKIP =     135.0 HOURS      MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     140.0 HOURS      MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     145.0 HOURS      MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     150.0 HOURS      MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     155.0 HOURS      MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     160.0 HOURS      MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     165.0 HOURS      MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     170.0 HOURS      MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     175.0 HOURS      MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     180.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     185.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     190.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     195.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     200.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     205.0 HOURS      MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
```

Figure 8.16 (Continued)

```
TSKIP =     210.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     215.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     220.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     225.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     230.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     235.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     240.0 HOURS     MAX MODELED TEMPERATURE =     91.70 AT   475.00 HOURS
TSKIP =     245.0 HOURS     MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     250.0 HOURS     MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     255.0 HOURS     MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     260.0 HOURS     MAX MODELED TEMPERATURE =     91.71 AT   475.00 HOURS
TSKIP =     265.0 HOURS     MAX MODELED TEMPERATURE =     91.72 AT   475.00 HOURS
TSKIP =     270.0 HOURS     MAX MODELED TEMPERATURE =     91.72 AT   450.50 HOURS
TSKIP =     275.0 HOURS     MAX MODELED TEMPERATURE =     91.74 AT   450.50 HOURS
TSKIP =     280.0 HOURS     MAX MODELED TEMPERATURE =     91.75 AT   450.50 HOURS
TSKIP =     285.0 HOURS     MAX MODELED TEMPERATURE =     91.76 AT   450.50 HOURS
TSKIP =     290.0 HOURS     MAX MODELED TEMPERATURE =     91.77 AT   450.50 HOURS
TSKIP =     295.0 HOURS     MAX MODELED TEMPERATURE =     91.81 AT   401.00 HOURS
TSKIP =     300.0 HOURS     MAX MODELED TEMPERATURE =     91.86 AT   401.00 HOURS
TSKIP =     305.0 HOURS     MAX MODELED TEMPERATURE =     91.92 AT   401.00 HOURS
TSKIP =     310.0 HOURS     MAX MODELED TEMPERATURE =     91.99 AT   401.00 HOURS
TSKIP =     315.0 HOURS     MAX MODELED TEMPERATURE =     92.06 AT   401.00 HOURS
TSKIP =     320.0 HOURS     MAX MODELED TEMPERATURE =     92.14 AT   401.00 HOURS
TSKIP =     325.0 HOURS     MAX MODELED TEMPERATURE =     92.22 AT   401.00 HOURS
TSKIP =     330.0 HOURS     MAX MODELED TEMPERATURE =     92.31 AT   401.00 HOURS
TSKIP =     335.0 HOURS     MAX MODELED TEMPERATURE =     92.41 AT   401.00 HOURS
TSKIP =     340.0 HOURS     MAX MODELED TEMPERATURE =     92.52 AT   401.00 HOURS
TSKIP =     345.0 HOURS     MAX MODELED TEMPERATURE =     92.65 AT   401.00 HOURS
TSKIP =     350.0 HOURS     MAX MODELED TEMPERATURE =     92.76 AT   401.00 HOURS
TSKIP =     355.0 HOURS     MAX MODELED TEMPERATURE =     92.88 AT   401.00 HOURS
TSKIP =     360.0 HOURS     MAX MODELED TEMPERATURE =     93.02 AT   401.00 HOURS
TSKIP =     365.0 HOURS     MAX MODELED TEMPERATURE =     93.19 AT   401.00 HOURS
TSKIP =     370.0 HOURS     MAX MODELED TEMPERATURE =     93.31 AT   401.00 HOURS
TSKIP =     375.0 HOURS     MAX MODELED TEMPERATURE =     93.26 AT   401.50 HOURS
TSKIP =     380.0 HOURS     MAX MODELED TEMPERATURE =     92.88 AT   402.00 HOURS
TSKIP =     385.0 HOURS     MAX MODELED TEMPERATURE =     92.82 AT   450.50 HOURS
TSKIP =     390.0 HOURS     MAX MODELED TEMPERATURE =     92.93 AT   450.50 HOURS
TSKIP =     395.0 HOURS     MAX MODELED TEMPERATURE =     93.04 AT   450.50 HOURS
TSKIP =     400.0 HOURS     MAX MODELED TEMPERATURE =     93.16 AT   450.50 HOURS
TSKIP =     405.0 HOURS     MAX MODELED TEMPERATURE =     93.29 AT   450.50 HOURS
TSKIP =     410.0 HOURS     MAX MODELED TEMPERATURE =     93.48 AT   450.00 HOURS
TSKIP =     415.0 HOURS     MAX MODELED TEMPERATURE =     93.72 AT   450.00 HOURS
TSKIP =     420.0 HOURS     MAX MODELED TEMPERATURE =     93.90 AT   450.00 HOURS
TSKIP =     425.0 HOURS     MAX MODELED TEMPERATURE =     94.00 AT   450.50 HOURS
TSKIP =     430.0 HOURS     MAX MODELED TEMPERATURE =     93.80 AT   451.50 HOURS
TSKIP =     435.0 HOURS     MAX MODELED TEMPERATURE =     93.52 AT   475.00 HOURS
TSKIP =     440.0 HOURS     MAX MODELED TEMPERATURE =     93.76 AT   475.00 HOURS
TSKIP =     445.0 HOURS     MAX MODELED TEMPERATURE =     93.92 AT   475.00 HOURS
TSKIP =     450.0 HOURS     MAX MODELED TEMPERATURE =     93.98 AT   475.00 HOURS
TSKIP =     455.0 HOURS     MAX MODELED TEMPERATURE =     93.84 AT   475.50 HOURS
TSKIP =     460.0 HOURS     MAX MODELED TEMPERATURE =     93.58 AT   476.50 HOURS
TSKIP =     465.0 HOURS     MAX MODELED TEMPERATURE =     92.95 AT   495.00 HOURS
TSKIP =     470.0 HOURS     MAX MODELED TEMPERATURE =     93.18 AT   497.00 HOURS
TSKIP =     475.0 HOURS     MAX MODELED TEMPERATURE =     93.20 AT   497.50 HOURS
TSKIP =     480.0 HOURS     MAX MODELED TEMPERATURE =     93.14 AT   498.00 HOURS
TSKIP =     485.0 HOURS     MAX MODELED TEMPERATURE =     92.92 AT   499.00 HOURS
TSKIP =     490.0 HOURS     MAX MODELED TEMPERATURE =     91.96 AT   500.50 HOURS
TSKIP =     495.0 HOURS     MAX MODELED TEMPERATURE =     91.41 AT   518.00 HOURS
TSKIP =     500.0 HOURS     MAX MODELED TEMPERATURE =     91.23 AT   518.50 HOURS
TSKIP =     505.0 HOURS     MAX MODELED TEMPERATURE =     90.94 AT   519.00 HOURS
TSKIP =     510.0 HOURS     MAX MODELED TEMPERATURE =     90.41 AT   522.00 HOURS
```

Figure 8.16 (Continued)

```
TSKIP =     515.0 HOURS     MAX MODELED TEMPERATURE =     89.62 AT   526.50 HOURS
TSKIP =     520.0 HOURS     MAX MODELED TEMPERATURE =     89.22 AT   539.50 HOURS
TSKIP =     525.0 HOURS     MAX MODELED TEMPERATURE =     89.05 AT   542.00 HOURS
TSKIP =     530.0 HOURS     MAX MODELED TEMPERATURE =     88.84 AT   544.00 HOURS
TSKIP =     535.0 HOURS     MAX MODELED TEMPERATURE =     88.35 AT   545.50 HOURS
TSKIP =     540.0 HOURS     MAX MODELED TEMPERATURE =     86.79 AT   548.00 HOURS
TSKIP =     545.0 HOURS     MAX MODELED TEMPERATURE =     85.86 AT   762.00 HOURS
TSKIP =     550.0 HOURS     MAX MODELED TEMPERATURE =     85.86 AT   762.00 HOURS
TSKIP =     555.0 HOURS     MAX MODELED TEMPERATURE =     85.87 AT   762.00 HOURS
TSKIP =     560.0 HOURS     MAX MODELED TEMPERATURE =     85.87 AT   762.00 HOURS
TSKIP =     565.0 HOURS     MAX MODELED TEMPERATURE =     85.88 AT   762.00 HOURS
TSKIP =     570.0 HOURS     MAX MODELED TEMPERATURE =     85.89 AT   762.00 HOURS
TSKIP =     575.0 HOURS     MAX MODELED TEMPERATURE =     85.90 AT   762.00 HOURS
TSKIP =     580.0 HOURS     MAX MODELED TEMPERATURE =     85.91 AT   762.00 HOURS
TSKIP =     585.0 HOURS     MAX MODELED TEMPERATURE =     85.92 AT   762.00 HOURS
TSKIP =     590.0 HOURS     MAX MODELED TEMPERATURE =     85.94 AT   762.00 HOURS
TSKIP =     595.0 HOURS     MAX MODELED TEMPERATURE =     85.96 AT   762.00 HOURS
TSKIP =     600.0 HOURS     MAX MODELED TEMPERATURE =     85.98 AT   762.00 HOURS
TSKIP =     605.0 HOURS     MAX MODELED TEMPERATURE =     86.00 AT   762.00 HOURS
TSKIP =     610.0 HOURS     MAX MODELED TEMPERATURE =     86.03 AT   762.00 HOURS
TSKIP =     615.0 HOURS     MAX MODELED TEMPERATURE =     86.06 AT   762.00 HOURS
TSKIP =     620.0 HOURS     MAX MODELED TEMPERATURE =     86.10 AT   762.00 HOURS
TSKIP =     625.0 HOURS     MAX MODELED TEMPERATURE =     86.15 AT   762.00 HOURS
TSKIP =     630.0 HOURS     MAX MODELED TEMPERATURE =     86.20 AT   762.00 HOURS
TSKIP =     635.0 HOURS     MAX MODELED TEMPERATURE =     86.25 AT   762.00 HOURS
TSKIP =     640.0 HOURS     MAX MODELED TEMPERATURE =     86.31 AT   762.00 HOURS
TSKIP =     645.0 HOURS     MAX MODELED TEMPERATURE =     86.37 AT   762.00 HOURS
TSKIP =     650.0 HOURS     MAX MODELED TEMPERATURE =     86.44 AT   762.00 HOURS
TSKIP =     655.0 HOURS     MAX MODELED TEMPERATURE =     86.50 AT   762.00 HOURS
TSKIP =     660.0 HOURS     MAX MODELED TEMPERATURE =     86.57 AT   762.00 HOURS
TSKIP =     665.0 HOURS     MAX MODELED TEMPERATURE =     86.65 AT   762.00 HOURS
TSKIP =     670.0 HOURS     MAX MODELED TEMPERATURE =     86.73 AT   762.00 HOURS
TSKIP =     675.0 HOURS     MAX MODELED TEMPERATURE =     86.81 AT   762.00 HOURS
TSKIP =     680.0 HOURS     MAX MODELED TEMPERATURE =     86.90 AT   762.00 HOURS
TSKIP =     685.0 HOURS     MAX MODELED TEMPERATURE =     86.99 AT   762.00 HOURS
TSKIP =     690.0 HOURS     MAX MODELED TEMPERATURE =     87.09 AT   762.00 HOURS
TSKIP =     695.0 HOURS     MAX MODELED TEMPERATURE =     87.19 AT   762.00 HOURS
TSKIP =     700.0 HOURS     MAX MODELED TEMPERATURE =     87.30 AT   762.00 HOURS
TSKIP =     705.0 HOURS     MAX MODELED TEMPERATURE =     87.41 AT   762.00 HOURS
TSKIP =     710.0 HOURS     MAX MODELED TEMPERATURE =     87.50 AT   762.00 HOURS
TSKIP =     715.0 HOURS     MAX MODELED TEMPERATURE =     87.58 AT   762.00 HOURS
TSKIP =     720.0 HOURS     MAX MODELED TEMPERATURE =     87.68 AT   762.00 HOURS
TSKIP =     725.0 HOURS     MAX MODELED TEMPERATURE =     87.80 AT   762.00 HOURS
TSKIP =     730.0 HOURS     MAX MODELED TEMPERATURE =     87.85 AT   762.00 HOURS
TSKIP =     735.0 HOURS     MAX MODELED TEMPERATURE =     87.80 AT   762.50 HOURS
TSKIP =     740.0 HOURS     MAX MODELED TEMPERATURE =     87.51 AT   764.50 HOURS
TSKIP =     745.0 HOURS     MAX MODELED TEMPERATURE =     87.04 AT   767.00 HOURS


TSKIP =     750.0 HOURS     MAX MODELED TEMPERATURE =     86.51 AT   770.00 HOURS
```

Figure 8.16 (Continued)

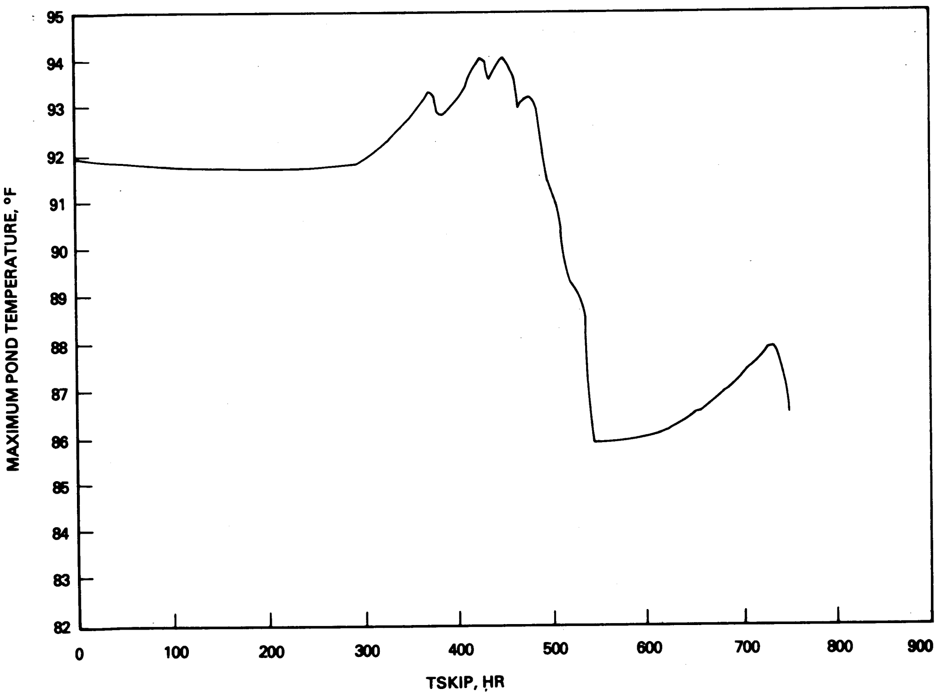

Figure 8.17 Effect of starting time for design-basis accident on peak pond temperature

8.7 Correction Factors for Geographic Differences Between Site and Meteorological Station--Program COMET2

Program COMET2 is used to estimate the differences in the meteorological data bases of the site and the point at which the long-term meteorological data were taken. Monthly average values of wet-bulb temperature, dry-bulb temperature, rms windspeed, barometric pressure, dewpoint temperature, and solar radiation were obtained from program SPSCAN for a 15-month period corresponding to the period of onsite data availability at the Susquehanna site. The input data for COMET2 are shown in Figure 8.21. The output is shown printed in Figure 8.22 and plotted in Figures 8.23 and 8.24. It is clear from the output that there are biases in the two data sets. The average bias for the Susquehanna-site data indicates that the spray-pond temperature should be about 1.36°F lower than predicted from program SPRPND.* The evaporation should also be less by

---

*Although the points in Figure 8.23 fall on both sides of the 45° diagonal line, the Harrisburg data are most conservative at the higher temperatures, which is the region of greater concern.

163,464 ft^3. The Harrisburg data are, therefore, conservative. Although the peak temperature and evaporation could have been corrected by the above amounts, it is suggested that the corrections be performed only if they lead to greater conservatism.

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$PARAM WID=183,ALEN=283,HT=12.0,THETA=71.0,VELO=22.47,R=.095,
  Y0=5.0,WDR0=0,NDRIFT=6,DWDR=10,FDRIFT=.0005,.00058,.001914,.004346,
 .00789,.014330$
1176
$HFT NH=14.,TH=0.,.01,1.,1.1,1.9,3.9,5.,8.,12.,24.,29.,140.,840.,2000.,
  HEAT(1)=0.,0.,.85E9,2*.51E9,.5E9,.68E9,.6E9,.4E9,.31E9,.27E9,
   .21E9,.18E9,.1E9,FLOW=14*205200.0$
        COMBINED RUN WITH RIGOROUS MODEL
$INLIST VZERO=2942357,A=422000,NSTEPS=1600,NPRINT=10,Q1=0,F1=1,IEVAP=1,
  DT=.5,IMET=0,ISPRAY=2,
 TSPRON=447,TSKIP=447$
          COMBINED RUN WITH REGRESSION MODEL
$INLIST VZERO=2942357,A=422000,NSTEPS=1600,NPRINT=10,Q1=0,F1=1,IEVAP=1,
  DT=.5,IMET=0,ISPRAY=1,
 TSPRON=447,TSKIP=447$
```

Figure 8.18 Input for program SPRPND, combined runs for rigorous and regression spray models, TSKIP = 447.0 hours

8.8 Statistical Adjustments

Program SPSCAN calculates the yearly maximum temperature and 30-day water loss for each year of record. The maximum likelihood and 5% and 95% confidence limits are generated for these data. Using the procedures outlined in Appendix A, it is possible to construct the plots of temperature and evaporation, respectively, versus recurrence interval shown in Figures 8.25 and 8.26. It is then possible to estimate correction factors based on the recurrence intervals of the peak temperature and evaporation found. If, for example, the 100-yr recurrence-interval meteorology were chosen as the basis for the temperature and evaporation conditions, correction factors could be developed for the final answer as demonstrated below:

```
         COMBINED RUN WITH RIGOROUS MODEL


SPRAY FIELD PARAMETERS
****************************************
INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO =      684.89 CM/SEC
INITIAL ANGLE OF DROPS TO HOR., THETA =       1.239 RADIANS
GEOMETRIC MEAN RADIUS OF DROPS, R =      .0950 CM
HEIGHT OF SPRAY FIELD, HT =     365.76 CM
WIDTH OF SPRAY FIELD, WID =     5577.8 CM
LENGTH OF SPRAY FIELD, ALEN =     8625.8 CM
HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, YO =      152.4
HEADING OF WIND W.R.T.LONG AXIS, PHI =      90.00 DEGREES



POND PARAMETERS
****************************************
INITIAL POND VOLUME,VZERO =      2942357.0 CU.FT.
POND SURFACE AREA,A =      422000.0 SQ.FT.
BLOWDOWN AND LEAKAGE,BLOW =      0.00 CU.FT./HR.
NUMBER OF INTEGRATION STEPS,NSTEPS =  1600
PRINT INTERVAL,NPRINT =     10
INTEGRATION TIMESTEP,DT =       .50 HOURS
INITIAL POND TEMPERATURE,TZERO =       80.00 DEG.F
DELAY FOR HEAT TABLE,TSKIP =     447.00 HRS
BASE HEAT LOAD ADDED TO TABLE,QBASE =      0.00 HRS
BASE FLOW RATE ADDED TO TABLE ,FBASE =    0.          CU.FT./HR.


                                  ..................................
                                  : HEAT IN  : TIME FROM : FLOW IN  :
                                  :  BTU/HR  :   START   : FT**3/HR :
                                  ..................................
                                  :0.        :      0.00 : .205E+06 :
                                  :0.        :       .01 : .205E+06 :
                                  : .850E+09 :      1.00 : .205E+06 :
                                  : .510E+09 :      1.10 : .205E+06 :
                                  : .510E+09 :      1.90 : .205E+06 :
                                  : .500E+09 :      3.90 : .205E+06 :
                                  : .680E+09 :      5.00 : .205E+06 :
                                  : .600E+09 :      8.00 : .205E+06 :
                                  : .400E+09 :     12.00 : .205E+06 :
                                  : .310E+09 :     24.00 : .205E+06 :
                                  : .270E+09 :     29.00 : .205E+06 :
                                  : .210E+09 :    140.00 : .205E+06 :
                                  : .180E+09 :    840.00 : .205E+06 :
                                  : .100E+09 :   2000.00 : .205E+06 :
```

Figure 8.19 Output from program SPRPND, run for rigorous spray model, TSKIP = 447.0 hours

```
          FOR TIME LESS THAN TSKIP
          Q1 =     0.         BTU/HR
          F1 =      .100E+01 FT**3/HR

METEOROLOGICAL TABLE USED AS INPUT


RIGOROUS SPRAY MODEL CHOSEN


SPRAYS WILL BE DELAYED    447.00 HOURS

                                  ..................................



                                ************* MODEL RESULTS *************


                             ..TIME.......TEMPERATURE (F).........VOLUME....
                             :  HR                          :     FT**3    :
                             ............................................
                                5.00                 79.03          .29423570E+07
                               10.00                 79.24          .29423570E+07
                               15.00                 79.90          .29423570E+07
                               20.00                 79.25          .29423570E+07
                               25.00                 77.87          .29423570E+07
                               30.00                 76.33          .29423570E+07
                               35.00                 75.98          .29423570E+07
                               40.00                 76.19          .29423570E+07
                               45.00                 75.66          .29423570E+07
                               50.00                 74.64          .29423570E+07
                               55.00                 73.33          .29423570E+07
                               60.00                 72.04          .29423570E+07
                               65.00                 71.28          .29423570E+07
                               70.00                 70.24          .29423570E+07
                               75.00                 69.24          .29423570E+07
                               80.00                 68.50          .29423570E+07
                               85.00                 68.33          .29423570E+07
                               90.00                 68.47          .29423570E+07
                               95.00                 67.96          .29423570E+07
                              100.00                 67.25          .29423570E+07
                              105.00                 66.90          .29423570E+07
                              110.00                 67.90          .29423570E+07
                              115.00                 68.26          .29423570E+07
                              120.00                 67.87          .29423570E+07
                              125.00                 67.24          .29423570E+07
                              130.00                 67.56          .29423570E+07
                              135.00                 68.31          .29423570E+07
                              140.00                 68.22          .29423570E+07
                              145.00                 67.67          .29423570E+07
                              150.00                 67.04          .29423570E+07
                              155.00                 67.00          .29423570E+07
```

Figure 8.19 (Continued)

```
 160.00            67.83            .29423570E+07
 165.00            67.93            .29423570E+07
 170.00            67.72            .29423570E+07
 175.00            67.67            .29423570E+07
 180.00            69.07            .29423570E+07
 185.00            69.96            .29423570E+07
 190.00            69.88            .29423570E+07
 195.00            69.58            .29423570E+07
 200.00            69.78            .29423570E+07
 205.00            71.45            .29423570E+07
 210.00            72.66            .29423570E+07
 215.00            72.57            .29423570E+07
 220.00            72.25            .29423570E+07
 225.00            72.57            .29423570E+07
 230.00            73.59            .29423570E+07
 235.00            73.87            .29423570E+07
 240.00            73.55            .29423570E+07
 245.00            73.13            .29423570E+07
 250.00            73.11            .29423570E+07
 255.00            74.03            .29423570E+07
 260.00            73.91            .29423570E+07
 265.00            73.13            .29423570E+07
 270.00            72.59            .29423570E+07
 275.00            73.59            .29423570E+07
 280.00            74.80            .29423570E+07
 285.00            74.77            .29423570E+07
 290.00            74.32            .29423570E+07
 295.00            73.97            .29423570E+07
 300.00            75.25            .29423570E+07
 305.00            76.61            .29423570E+07
 310.00            76.40            .29423570E+07
 315.00            75.83            .29423570E+07
 320.00            75.78            .29423570E+07
 325.00            77.12            .29423570E+07
 330.00            77.57            .29423570E+07
 335.00            77.10            .29423570E+07
 340.00            76.60            .29423570E+07
 345.00            76.32            .29423570E+07
 350.00            77.35            .29423570E+07
 355.00            77.53            .29423570E+07
 360.00            77.12            .29423570E+07
 365.00            76.60            .29423570E+07
 370.00            76.74            .29423570E+07
 375.00            77.73            .29423570E+07
 380.00            78.00            .29423570E+07
 385.00            77.67            .29423570E+07
 390.00            77.29            .29423570E+07
 395.00            78.06            .29423570E+07
 400.00            79.55            .29423570E+07
 405.00            79.75            .29423570E+07
 410.00            79.38            .29423570E+07
 415.00            79.04            .29423570E+07
 420.00            80.17            .29423570E+07
 425.00            81.19            .29423570E+07
```

Figure 8.19 (Continued)

```
430.00          81.04         .29423570E+07
435.00          80.53         .29423570E+07
440.00          80.38         .29423570E+07
445.00          81.42         .29423570E+07
450.00          85.34         .29272932E+07
455.00          89.55         .28972500E+07
460.00          90.63         .28696068E+07
465.00          90.96         .28455993E+07
470.00          92.43         .28229635E+07
475.00          93.90         .28039529E+07
480.00          92.92         .27846809E+07
485.00          91.33         .27653170E+07
490.00          91.46         .27467519E+07
495.00          92.25         .27262648E+07
500.00          91.93         .27065416E+07
505.00          90.13         .26870599E+07
510.00          88.93         .26694924E+07
515.00          89.19         .26522187E+07
520.00          89.40         .26325687E+07
525.00          88.34         .26131694E+07
530.00          87.37         .25969744E+07
535.00          86.76         .25816960E+07
540.00          86.74         .25629735E+07
545.00          86.37         .25429982E+07
550.00          84.18         .25224251E+07
555.00          81.35         .25029815E+07
560.00          79.72         .24860614E+07
565.00          79.61         .24673550E+07
570.00          79.31         .24491142E+07
575.00          79.12         .24352591E+07
580.00          79.10         .24227987E+07
585.00          79.35         .24102278E+07
590.00          80.05         .23967512E+07
595.00          80.42         .23840885E+07
600.00          80.27         .23718274E+07
605.00          79.62         .23593050E+07
610.00          80.23         .23470600E+07
615.00          81.39         .23322636E+07
620.00          80.56         .23156647E+07
625.00          79.23         .23021190E+07
630.00          77.37         .22885307E+07
635.00          77.42         .22755886E+07
640.00          79.20         .22632377E+07
645.00          79.84         .22507591E+07
650.00          79.44         .22381073E+07
655.00          78.64         .22256378E+07
660.00          79.15         .22129448E+07
665.00          79.79         .22000894E+07
670.00          79.97         .21880215E+07
675.00          79.24         .21752503E+07
680.00          79.06         .21636144E+07
685.00          79.71         .21524136E+07
690.00          80.65         .21418406E+07
695.00          80.99         .21311774E+07
700.00          80.25         .21192703E+07
```

Figure 8.19 (Continued)

```
                    705.00              80.12          .21075767E+07
                    710.00              82.22          .20960858E+07
                    715.00              83.20          .20830286E+07
                    720.00              82.83          .20703926E+07
                    725.00              81.96          .20579820E+07
                    730.00              82.92          .20464775E+07
                    735.00              84.40          .20331592E+07
                    740.00              84.11          .20187462E+07
                    745.00              83.14          .20055908E+07
                    750.00              82.40          .19935346E+07
                    755.00              83.11          .19821931E+07
                    760.00              85.22          .19714001E+07
                    765.00              85.41          .19583762E+07
                    770.00              84.54          .19452174E+07
                    775.00              83.38          .19313785E+07
                    780.00              82.38          .19153827E+07
                    785.00              80.04          .18978776E+07
                    790.00              77.97          .18825298E+07
                    795.00              76.14          .18692831E+07
                    800.00              74.86          .18563833E+07

TSKIP =     447.0 HOURS    MAX MODELED TEMPERATURE =    93.91 AT  475.00 HOURS
```

Figure 8.19 (Continued)

$\Delta T = T(100\text{-yr recurrence}) - T_{max} = 93.14°F - 92.74°F = +0.40°F$

and

$$\begin{aligned}\Delta EVAP &= EVAP(100\text{-yr recurrence}) - EVAP_{max} \\ &= 2.435 \times 10^6 - 2.463 \times 10^6 = -28{,}000 \text{ ft}^3\end{aligned}$$

The correction factor for the 100-yr recurrence interval is positive for temperatures and, therefore, should be added to the final result from program SPRPND:

Design-basis maximum temperature = $93.91 + 0.40 \simeq 94.3°F$

The correction for evaporation is negative and, therefore, should not be added to the results:

Design-basis 30-day evaporation = 2.46×10^6 ft^3

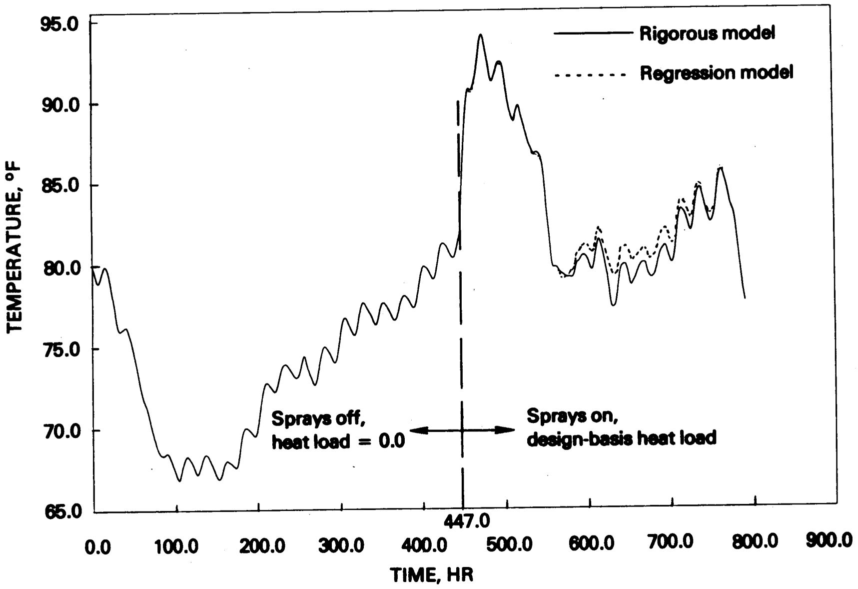

Figure 8.20 Pond temperature in response to ambient meteorology and design-basis heat load, TSKIP = 447.0 hours

8.9 Conclusion

The maximum pond temperature is predicted to be 94.3°F. The maximum 30-day evaporation is predicted to be 2.46 x 10^6 ft^3. These results are conservative because it has been demonstrated that the evaporation and temperature using Susquehanna-site data would be lower than the results using Harrisburg data. In addition, the peak evaporation appears to use meteorological data with greater than a 100-year-recurrence interval.

Water loss from seepage and blowdown or other uses must, of course, be added to the evaporation and drift losses predicted.

It has been demonstrated that procedure 1 may be used to determine the starting time for the final calculations with only a small error in peak temperature, and that the regression spray model is a reliable predictor of the spray performance determined from the rigorous spray model.

```
-.60637276E+00  .40195127E-03  .38449863E-02  .18230236E-02
-.34078270E-01  .30138737E+00 -.25690451E+01  .65576685E-01
-.73791051E-03  .26319278E-05  .35669730E-02  .12911864E-01
-.39275022E-04 -.41450389E-01  .14646531E-03 -.33234415E-03
 .41560445E-03 -.12268707E-02  .11416664E-01 -.86122112E-01
 .28767122E-02 -.29725976E-04  .10168749E-06 -.27394599E-03
 .28406611E-04  .22034012E-05
$INLIST V=2942357.,A=422000.,HEAT=2.3E8,NDRIFT=6,WDR0=0,DWDR=10.,
  QSPRAY=57,          FDRIFT=.0005,.00058,.001914,.004346,.007890,.014330$
15
52.03    57.38    8.91     1378.4  29.54   49.9    53.8    5.48     0.   29.54
66.35    72.79    6.12     1662.2  29.64   59.1    67.5    3.9      0.   29.64
68.19    76.14    6.43     1884.9  29.63   59.7    67.8    3.7      0.   29.63
68.37    75.38    5.90     1539.1  29.67   60.7    69.4    3.2      0.   29.67
60.89    67.87    7.37     1291.5  29.71   58.     60.4    4.       0.   29.71
54.71    63.47    8.61     1648.8  29.58   51.6    56.7    5.6      0.   29.58
62.61    70.6     7.59     1686.6  29.6    55.9    63.1    4.8      0.   29.60
66.46    72.27    7.54     1763.9  29.64   59.1    68.4    4.12     0.   29.64
68.34    76.47    5.74     1377.3  29.71   59.5    68.     3.39     0.   29.71
59.29    64.24    7.46     1182.6  29.7    53.6    58.5    4.18     0.   29.70
59.57    64.74    6.65     1559.6  29.61   54.6    61.     4.36     0.   29.61
65.36    70.57    7.61     1636.9  29.67   58.     65.7    4.53     0.   29.67
69.36    75.01    6.84     1746.9  29.65   60.3    69.4    3.54     0.   29.65
69.63    75.12    6.75     1507.4  29.7    59.6    68.2    3.94     0.   29.70
58.99    62.82    7.31     1157.   29.76   53.2    57.9    4.47     0.   29.76
```

Figure 8.21 Input data for program COMET2

```
 DIFFERENCES IN STEADY STATE TEMPERATURES AND WATER USE FOR SUBJECT SPRAY POND
USING MONTHLY AVERAGE VALUES OF WET BULB,DRY BULB,WIND SPEED,AND SOLAR RADIATION FROM ONSITE
AND OFFSITE MET STATIONS



TIMESTEP IN ITERATION DTIME =     12.527 HOURS
VOLUME OF POND, V =    2942357.0 FT**3
SURFACE AREA OF POND, A =     422000.0 FT**2
RATE OF SPRAYING, QSPRAY =         57.0 FT**3/SEC
STEADY HEAT LOAD, HEAT =  230000000.0 BTU/HR
LOWER LIMIT OF WIND IN DRIFT TABLE WDRO =       0.00 MPH
INCREMENT IN DRIFT TABLE,DWDR =      10.00 MPH



   DRIFT LOSS TABLE
     WIND SPEED, MPH DRIFT LOSS FRACTION

          0.00          .00050000
         10.00          .00058000
         20.00          .00191400
         30.00          .00434600
         40.00          .00789000
         50.00          .01433000
      WET BULB       DRY BULB      WIND SPEED
       SOLAR RAD.                                                PB            POND TEMP         EVAPORATION
       (DEG. F)      (DEG.F)           (MPH)      (BTU/FT**2/DY)  INCHES HG      (DEG. F)             FT**3


DATA SET 1      52.03          57.38           8.91        1378.40        29.54         72.43        2043639.16

DATA SET 2      49.90          53.80           5.48        1378.40        29.54         77.65        1952527.68

                                                               E2-E1 =  5.221     EVAP2-EVAP1 =     -91111.5


    DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

    DIFFERENCE DUE TO WET BULB =              -1.098 DEG. F
    DIFFERENCE DUE TO DRY BULB TEMP. =         -.183 DEG. F
    DIFFERENCE DUE TO WIND SPEED =             5.387 DEG. F
    DIFFERENCE DUE TO INSOLATION =             0.000 DEG. F
    DIFFERENCE DUE TO BAROMETRIC PRESSURE =    0.000 DEG F
    SUMMATION OF INDIVIDUAL DIFFERENCES =      4.105 DEG. F
```

Figure 8.22   Input deck for program SPRCO

```
*********************************************************************************************************/

                WET BULB       DRY BULB      WIND SPEED
                 SOLAR RAD.                                               PB             POND TEMP        EVAPORATION
                 (DEG. F)      (DEG.F)          (MPH)      (BTU/FT**2/DY)  INCHES HG      (DEG. F)            FT**3

DATA SET 1        66.35         72.79           6.12          1662.20        29.44          83.33         2292962.49

DATA SET 2        59.10         67.50           3.90          1662.20        29.64          80.46         2180291.13

                                                                       E2-E1 = -2.878    EVAP2-EVAP1 =    -112671.4

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                -3.602 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =          -.175 DEG. F
     DIFFERENCE DUE TO WIND SPEED =               .827 DEG. F
     DIFFERENCE DUE TO INSOLATION =              0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =     0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =      -2.950 DEG. F
**********************************************************************************************************

                WET BULB       DRY BULB      WIND SPEED
                 SOLAR RAD.                                               PB             POND TEMP        EVAPORATION
                 (DEG. F)      (DEG.F)          (MPH)      (BTU/FT**2/DY)  INCHES HG      (DEG. F)            FT**3

DATA SET 1        68.19         76.14           6.43          1884.90        29.63          84.85         2424193.83

DATA SET 2        59.70         67.80           3.70          1884.90        29.63          81.17         2214258.36

                                                                       E2-E1 = -3.686    EVAP2-EVAP1 =    -209935.5

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                -4.269 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =          -.472 DEG. F
     DIFFERENCE DUE TO WIND SPEED =              1.023 DEG. F
     DIFFERENCE DUE TO INSOLATION =              0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =     0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =      -3.717 DEG. F
```

Figure 8.22 (Continued)

```
************************************************************************************************************************

                 WET BULB         DRY BULB       WIND SPEED                            PB            POND TEMP       EVAPORATION
                  SOLAR RAD.                                                                                            FT**3
                  (DEG. F)        (DEG.F)            (MPH)      (BTU/FT**2/DY)   INCHES HG      (DEG. F)

DATA SET 1         68.37           75.38             5.90          1539.10          29.67          84.55         2342843.19

DATA SET 2         60.70           69.40             3.20          1539.10          29.67          81.30         2206192.05

                                                                            E2-E1 = -3.250    EVAPAP2-EVAP1 =    -136651.1

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                -3.912 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =           -.382 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                .999 DEG. F
     DIFFERENCE DUE TO INSOLATION =               0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =      0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =       -3.295 DEG. F
************************************************************************************************************************

                 WET BULB         DRY BULB       WIND SPEED                            PB            POND TEMP       EVAPORATION
                  SOLAR RAD.                                                                                            FT**3
                  (DEG. F)        (DEG.F)            (MPH)      (BTU/FT**2/DY)   INCHES HG      (DEG. F)

DATA SET 1         60.89           67.87             7.37          1291.50          29.71          79.35         2127673.35

DATA SET 2         58.00           60.40             4.00          1291.50          29.71          79.99         1841507.91

                                                                            E2-E1 =    .639    EVAP2-EVAP1 =     -286165.4

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                -1.378 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =           -.061 DEG. F
     DIFFERENCE DUE TO WIND SPEED =               1.290 DEG. F
     DIFFERENCE DUE TO INSOLATION =               0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =      0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -.149 DEG. F
```

Figure 8.22 (Continued)

```
*******************************************************************************************************

              WET BULB        DRY BULB      WIND SPEED
               SOLAR RAD.                                                PB          POND TEMP       EVAPORATION
               (DEG. F)       (DEG.F)          (MPH)      (BTU/FT**2/DY)  INCHES HG     (DEG. F)           FT**3

DATA SET 1      54.71          63.47           8.61         1648.80         29.58          75.06        2216888.45

DATA SET 2      51.60          56.70           5.60         1648.80         29.58          78.26        1865384.62

                                                                      E2-E1 =  3.203    EVAP2-EVAP1 =   -351503.8

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =               -1.603 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =          -.371 DEG. F
     DIFFERENCE DUE TO WIND SPEED =              2.988 DEG. F
     DIFFERENCE DUE TO INSOLATION =              0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =     0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =       1.014 DEG. F
*******************************************************************************************************

              WET BULB        DRY BULB      WIND SPEED
               SOLAR RAD.                                                PB          POND TEMP       EVAPORATION
               (DEG. F)       (DEG.F)          (MPH)      (BTU/FT**2/DY)  INCHES HG     (DEG. F)           FT**3

DATA SET 1      62.61          70.60           7.59         1686.60         29.60          80.78        2269915.48

DATA SET 2      55.90          63.10           4.80         1686.60         29.60          78.99        2063438.26

                                                                      E2-E1 = -1.787    EVAP2-EVAP1 =   -206477.2

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETEF

     DIFFERENCE DUE TO WET BULB =               -3.164 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =           .004 DEG. F
     DIFFERENCE DUE TO WIND SPEED =              1.045 DEG. F
     DIFFERENCE DUE TO INSOLATION =              0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =     0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =      -2.115 DEG. F
```

Figure 8.22 (Continued)

```
********************************************************************************************************************************************

                WET BULB         DRY BULB       WIND SPEED
                 SOLAR RAD.                                                      PB              POND TEMP           EVAPORATION
                 (DEG. F)        (DEG.F)            (MPH)        (BTU/FT**2/DY)  INCHES HG       (DEG. F)                FT**3


DATA SET 1        66.46            72.27            7.54          1763.90         29.64            83.02             2294305.86

DATA SET 2        59.10            68.40            4.12          1763.90         29.64            80.52             2231119.09

                                                                            E2-E1 = -2.497     EVAP2-EVAP1 =        -63186.8

      DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

      DIFFERENCE DUE TO WET BULB =                 -3.724 DEG. F
      DIFFERENCE DUE TO DRY BULB TEMP. =            -.135 DEG. F
      DIFFERENCE DUE TO WIND SPEED =                1.234 DEG. F
      DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
      DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
      SUMMATION OF INDIVIDUAL DIFFERENCES =        -2.625 DEG. F
********************************************************************************************************************************************

                WET BULB         DRY BULB       WIND SPEED
                 SOLAR RAD.                                                      PB              POND TEMP           EVAPORATION
                 (DEG. F)        (DEG.F)            (MPH)        (BTU/FT**2/DY)  INCHES HG       (DEG. F)                FT**3


DATA SET 1        68.34            76.47            5.74          1377.30         29.71            84.47             2353480.48

DATA SET 2        59.50            68.00            3.39          1377.30         29.71            80.39             2148689.17

                                                                            E2-E1 = -4.080     EVAP2-EVAP1 =       -204791.3

      DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

      DIFFERENCE DUE TO WET BULB =                 -4.428 DEG. F
      DIFFERENCE DUE TO DRY BULB TEMP. =            -.521 DEG. F
      DIFFERENCE DUE TO WIND SPEED =                 .865 DEG. F
      DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
      DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
      SUMMATION OF INDIVIDUAL DIFFERENCES =        -4.084 DEG. F
```

Figure 8.22 (Continued)

```
****************************************************************************************************

                WET BULB       DRY BULB      WIND SPEED                                    PB           POND TEMP        EVAPORATION
                 SOLAR RAD.                                                              INCHES HG      (DEG. F)             FT**3
                 (DEG. F)       (DEG.F)          (MPH)        (BTU/FT**2/DY)

DATA SET 1        59.29          64.24           7.46          1182.60          29.70            78.29          2022014.79

DATA SET 2       -53.60          58.50           4.18          1182.60          29.70            78.39          1829890.64

                                                                         E2-E1 =   .096      EVAP2-EVAP1 =     -192124.1

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -2.958 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =            -.311 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                1.508 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -1.761 DEG. F
****************************************************************************************************

                WET BULB       DRY BULB      WIND SPEED                                    PB           POND TEMP        EVAPORATION
                 SOLAR RAD.                                                              INCHES HG      (DEG. F)             FT**3
                 (DEG. F)       (DEG.F)          (MPH)        (BTU/FT**2/DY)

DATA SET 1        59.57          64.74           6.65          1559.60          29.61            79.49          2052606.74

DATA SET 2        54.60          61.00           4.36          1559.60          29.61            78.77          1977817.37

                                                                         E2-E1 =  -.723      EVAP2-EVAP1 =      -74789.4

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -2.197 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =             .396 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                 .929 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =         -.872 DEG. F
```

Figure 8.22 (Continued)

```
****************************************************************************************************

                WET BULB        DRY BULB      WIND SPEED
                 SOLAR RAD.                                                PB           POND TEMP          EVAPORATION
                 (DEG. F)       (DEG.F)          (MPH)       (BTU/FT**2/DY)  INCHES HG    (DEG. F)              FT**3

DATA SET 1        65.36          70.57            7.61          1636.90         29.67         82.13          2223929.43

DATA SET 2        58.00          65.70            4.53          1636.90         29.67         79.71          2125769.65


     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -3.664 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =            -.008 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                1.103 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -2.569 DEG. F
****************************************************************************************************

                WET BULB        DRY BULB      WIND SPEED
                 SOLAR RAD.                                                PB           POND TEMP          EVAPORATION
                 (DEG. F)       (DEG.F)          (MPH)       (BTU/FT**2/DY)  INCHES HG    (DEG. F)              FT**3

DATA SET 1        69.36          75.01            6.84          1746.90         29.65         85.05          2357392.80

DATA SET 2        60.30          69.40            3.54          1746.90         29.65         81.30          2244560.67
                                                                           E2-E1 = -3.743   EVAP2-EVAP1 =    -112832.1

     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -4.692 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =            -.329 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                1.183 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -3.839 DEG. F

*********************************************                 ****************************************************
```

Figure 8.22 (Continued)

```
               WET BULB        DRY BULB       WIND SPEED
                SOLAR RAD.                                                    PB            POND TEMP         EVAPORATION
                (DEG. F)       (DEG.F)           (MPH)      (BTU/FT**2/DY)  INCHES HG      (DEG. F)             FT**3


DATA SET 1       69.63          75.12            6.75          1507.40         29.70          84.90           2322665.82

DATA SET 2       59.60          68.20            3.94          1507.40         29.70          80.41           2176958.91

                                                                          E2-E1 = -4.485    EVAP2-EVAP1 =     -145706.9
     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -5.182 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =            -.354 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                 .976 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -4.560 DEG. F

**********************************************************************************************************************
               WET BULB        DRY BULB       WIND SPEED
                SOLAR RAD.                                                    PB            POND TEMP         EVAPORATION
                (DEG. F)       (DEG.F)           (MPH)      (BTU/FT**2/DY)  INCHES HG      (DEG. F)             FT**3


DATA SET 1       58.99          62.82            7.31          1157.00         29.76          78.22           1973356.18

DATA SET 2       53.20          57.90            4.47          1157.00         29.76          78.21           1807507.15

                                                                          E2-E1 =  -.005    EVAP2-EVAP1 =     -165849.0
     DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1 BY PARAMETER

     DIFFERENCE DUE TO WET BULB =                 -2.978 DEG. F
     DIFFERENCE DUE TO DRY BULB TEMP. =            -.263 DEG. F
     DIFFERENCE DUE TO WIND SPEED =                1.418 DEG. F
     DIFFERENCE DUE TO INSOLATION =                0.000 DEG. F
     DIFFERENCE DUE TO BAROMETRIC PRESSURE =       0.000 DEG F
     SUMMATION OF INDIVIDUAL DIFFERENCES =        -1.823 DEG. F

**********************************************************************************************************************
     SAMPLE R SQUARED FOR EQUILIBRIUM TEMP. =          .843          STANDARD ERROR =        .506 DEG.F
     SAMPLE R SQUARED FOR EVAPORATION =           .755          STANDARD ERROR =  83445.879FT**3
     AVERAGE E, DATA SET 1 =         81.061
     AVERAGE E, DATA SET 2 =         79.701
     AVERAGE E2 - AVERAGE E1 =         -1.3596
     AVERAGE EVAP2 - AVERAGE EVAP1 = -163463.6920
```

Figure 8.22 (Continued)

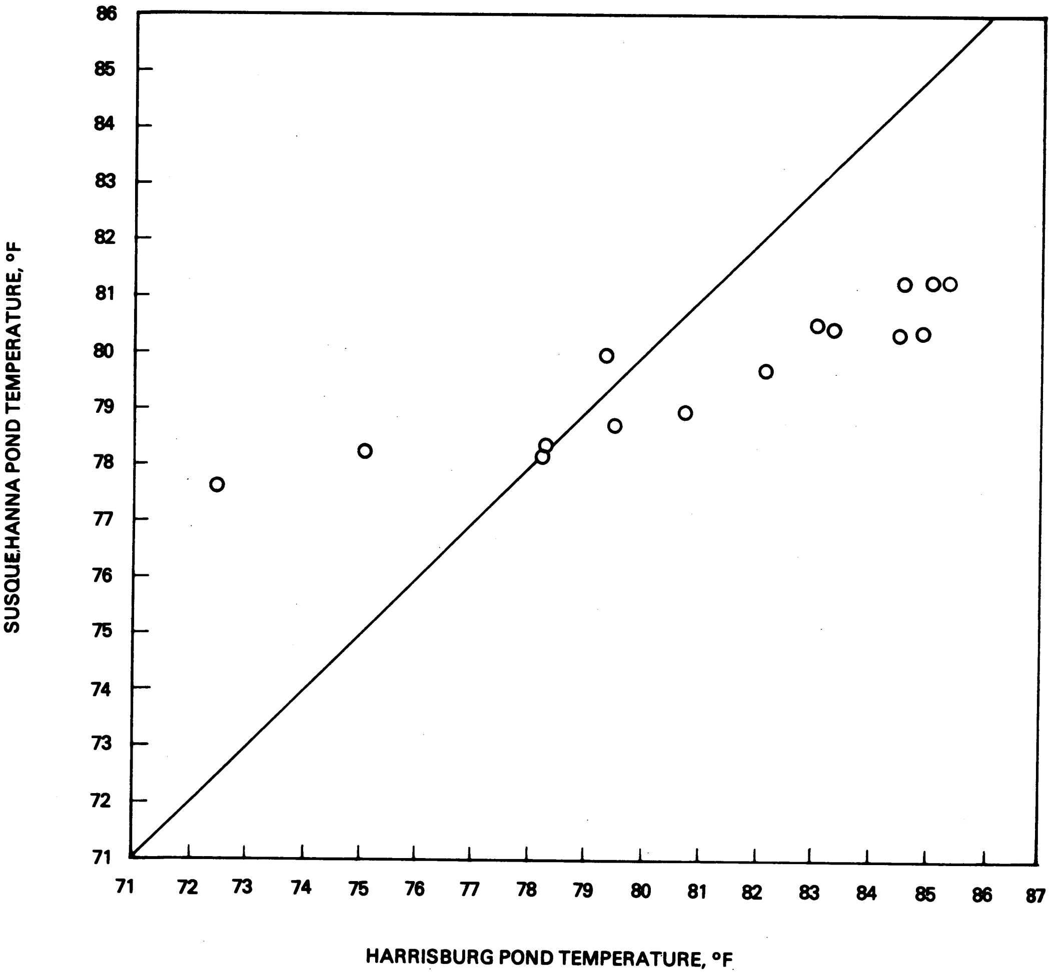

Figure 8.23 Comparison of Susquehanna site and Harrisburg spray-pond temperatures, program COMET2

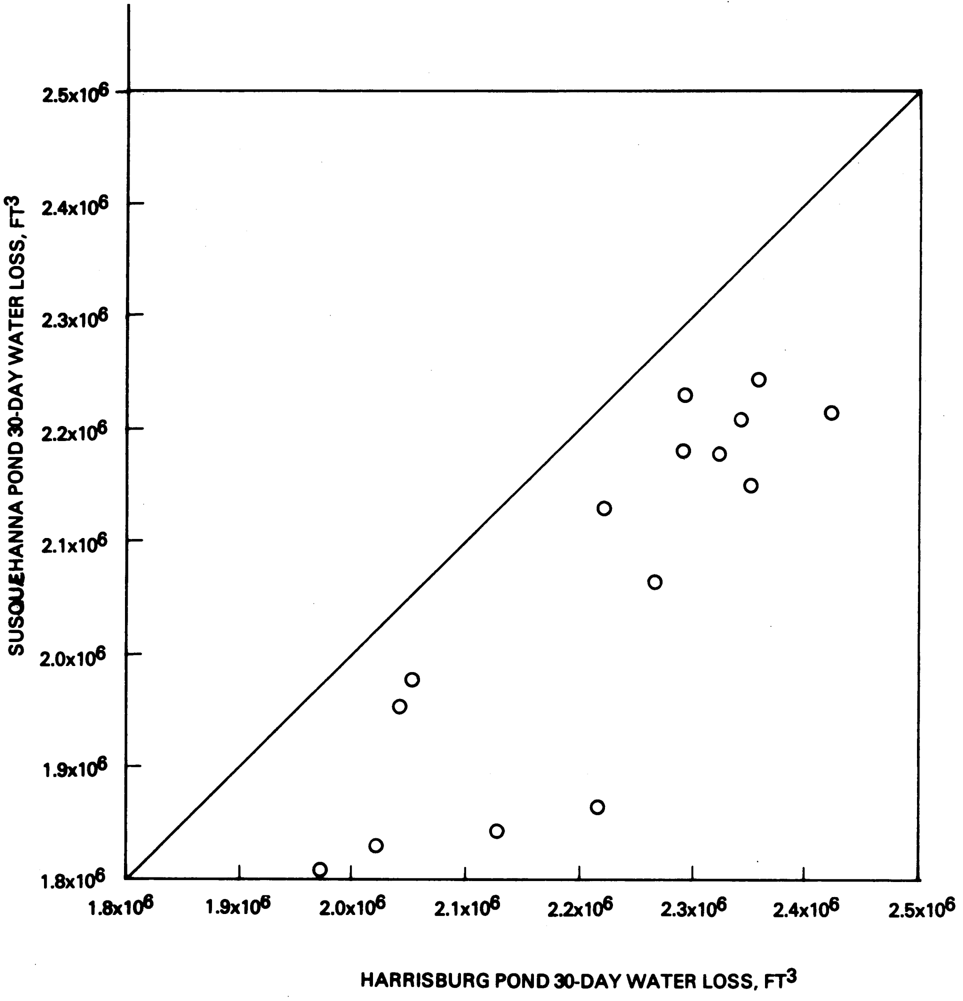

Figure 8.24 Comparison of Susquehanna site and Harrisburg pond water losses, program COMET2

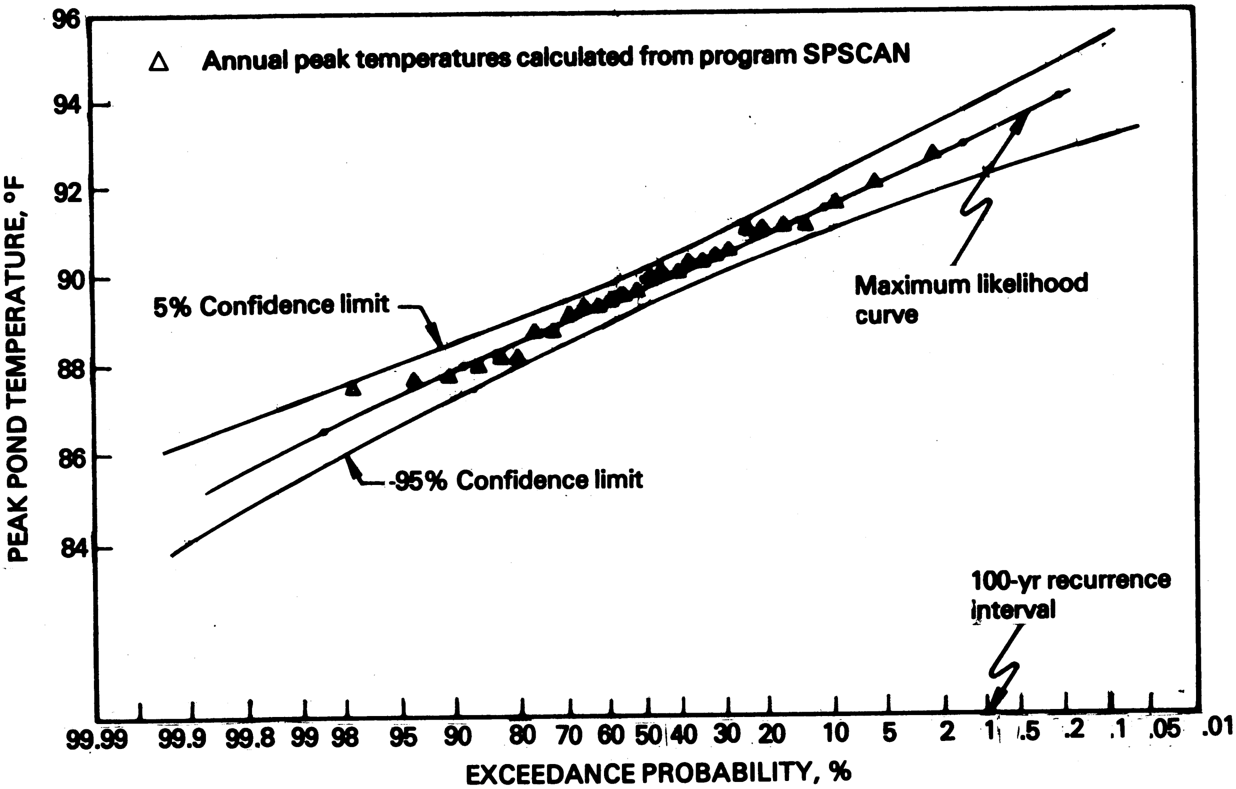

Figure 8.25 Exceedance probability for annual peak pond temperature

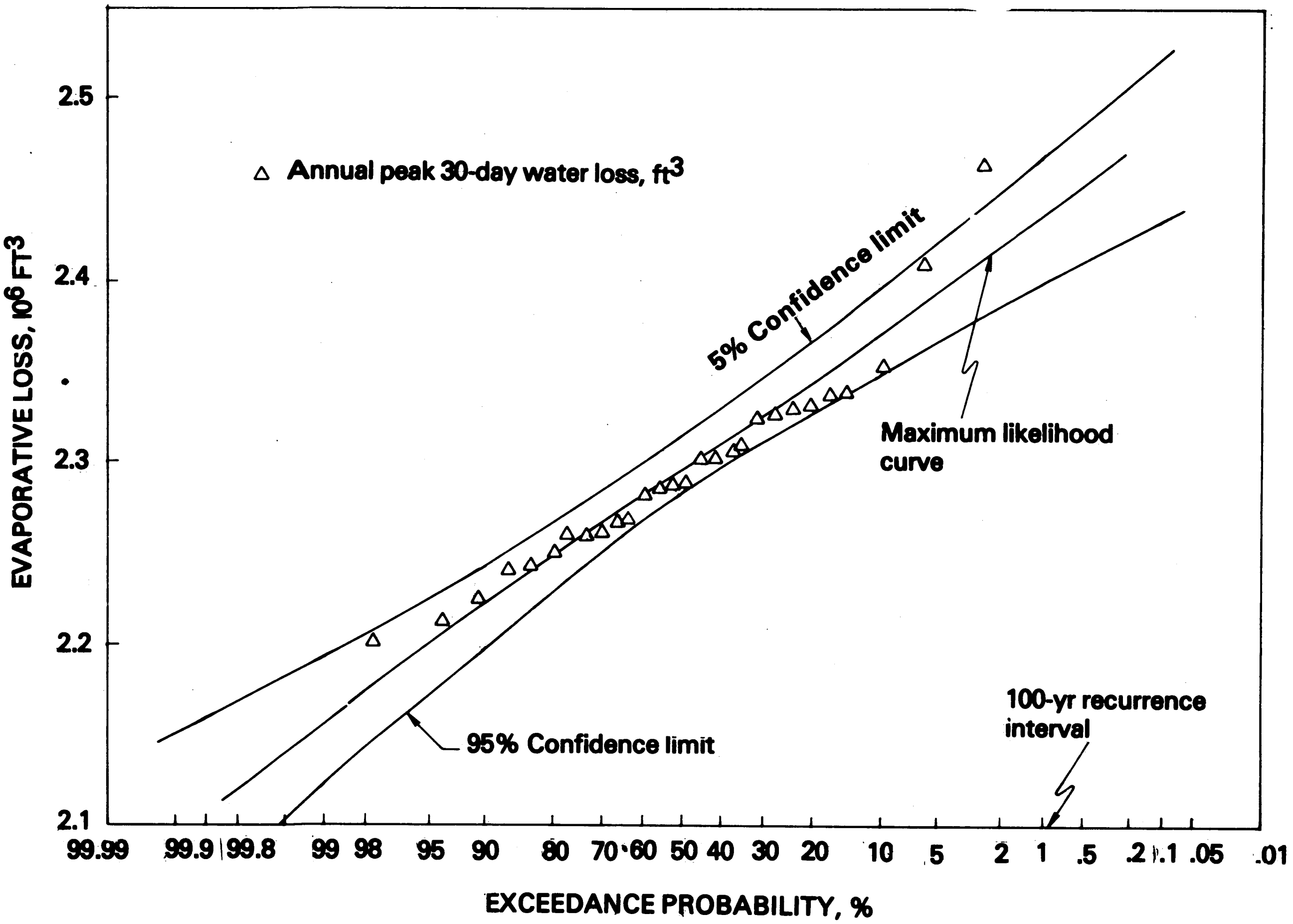

Figure 8.26 Exceedance probability for annual peak 30-day pond water loss

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APPENDIX A

STATISTICAL TREATMENT OF OUTPUT

Program SPSCAN, in addition to determining the peak ambient pond temperature for the entire length of record, determines the maximum ambient temperature and evaporation for each year of the record and performs several manipulations of the yearly maximums to facilitate graphic analyses:

(1) The data are ranked from highest to lowest temperature.

(2) Their "probability" or plotting position is determined based on the number of years in the data set using the formulae (Ref. 20):

$$P_1 = 1 - (0.5)^{1/N} \qquad \text{(A.1)}$$

$$P_N = (0.5)^{1/N} \qquad \text{(A.2)}$$

$$P_i = P_1 - (i-1)\Delta P \qquad \text{(A.3)}$$

where

$$\Delta P = \frac{2\left(0.5 - P_1\right)}{N-1}$$

N = number of data points in the set

P_1 = plotting position of the highest yearly maximum

P_N = plotting position of the lowest yearly maximum

P_i = plotting position of each individual point

(3) The first two moments of the distribution of any variable T (mean and standard deviation) are determined from the formulae (Ref. 20):

$$M = \frac{\Sigma T}{N} \qquad \text{(sample mean)} \qquad (A.4)$$

$$s^2 = \frac{\Sigma T^2 - (\Sigma T)^2/N}{N - 1} \qquad \text{(standard deviation)}^2 \qquad (A.5)$$

where

Σ implies the sum over all N values in the data set

(4) The maximum likelihood curve and confidence limits of temperature and water loss are calculated. The probabilities of the data are assumed to be representable by Student's t distribution.

A.1 Maximum Likelihood Curve

The maximum likelihood frequency curve for any variable T in probability coordinates is described by the equation:

$$T = M + sk \qquad (A.6)$$

where

M = sample mean of T

s = standard deviation of T

and

k = the 100 $(1 - P)^{th}$ percentile of Student's t distribution with N - 1 degrees of freedom,

where P = the probability (independent variable)

N = the sample size.

A.2 Confidence Limits

The 5% and 95% confidence limits of T are calculated from the formulae

$$T_{95} = T + \sqrt{\frac{s^2}{N}\left(1 + \frac{k^2}{2}\right)} \quad k \qquad (A.7)$$

$$T_5 = T - \sqrt{\frac{s^2}{N}\left(1 + \frac{k^2}{2}\right)} \quad k \tag{A.8}$$

The 95% and 5% confidence limits and maximum likelihood curve are calculated for probabilities P ranging from 0.001 to 0.999. These points should be plotted as smooth curves on probability-scale paper along with the ranked raw data.

The error-limit curves express the probability of a value falling outside of the error banks in any given year. For the 95% and 5% bands, therefore, there is 1 chance in 20 that the ambient temperature value for any given recurrence interval is greater than indicated by the 5% curve and 1 chance in 20 that it is less than the 95% curve.

The conservatism of choosing the design-basis event coincident with the most adverse meteorological conditions may be demonstrated with the following procedure.

The maximum-likelihood curves for temperature T (°F) and 30-day evaporation, may be extrapolated to the 100-yr recurrence intervals (0.01 probability per year) T_{100} and W_{100}, respectively, or to any other justifiable recurrence interval. Correction factors for peak pond temperature ΔT and evaporation ΔW_e are determined by comparing T_{100} and W_{100} with their corresponding highest observed values from the record, T_{max} and W_{max}:

$$\Delta T = T_{100} - T_{max} \text{ °F} \tag{A.10}$$

$$\Delta W_e = W_{100} - W_{max} \text{ ft}^3\text{/30 days} \tag{A.11}$$

Only correction factors greater than zero should be considered. If the maximum observed temperature or evaporation is higher than the 100-yr (or other period) recurrence values, no correction factor is taken. These correction factors may be added directly to the peak loaded pond temperature and evaporations determined in subsequent calculations.

An example of the statistical procedure is offered in Section 7.

APPENDIX B

COMPUTER CODES

```
      PROGRAM SPRCO(INPUT,OUTPUT,TAPE7,TAPE9,TAPE5=INPUT,TAPE6=OUTPUT,
     1 PUNCH,TAPE4=PUNCH)
C      SPRAY POND CORRELATION MODEL
C     RICHARD CODELL
C     U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON D.C.
C     GENERATES A SET OF PERFORMANCES FROM THE HIGH WIND SPEED(HWS) MODEL
C     AND THE LOW WIND SPEED MODEL(LWS) AND CORRELATES THE RESULTS TO
C     A SET OF MULTILE LINEAR REGRESSION EQUATIONS
      DIMENSION TSEG(11),HUM(11)                                        000130
      COMMON/LWSCOM/ ATOP(12),ASIDE(12)                                 000140
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,RHOA,DIFF,           000160
     1 PR,AK,DT,H,EVAP,NSTEPS,CON6,DT06,DT02,TDROP                      000170
     1 ,U0,V0,SC                                                        000180
      C(Z)=(Z-32)/1.8                                                   000190
C     ALPHA IS CONVERGENCE PARAMETER OF LWS MODEL
      DATA ALPHA/-.2/
      DATA NPNTS,VELO,THETA,Y0,R,PB,PHI/200,22.5,71.0,5.0,.104,
     1 29.92,90.0/
      DATA TWETO,DTDRY0,WINDO,THOTO,RTW,RTD,RW,RTH/50.0,20.0,
     1 0.1,90.0,30.0,30.0,20.0,30.0/
      NAMELIST/INPUT/ NPNTS,HT,ALEN,WID,VELO,THETA,Y0,R,PB,
     1 Q,PHI,TWETO,DTDRY0,WINDO,THOTO,RTW,RTD,RW,RTH
      REWIND 7
      REWIND 9                                                          000230
      WRITE(6,22)
   22 FORMAT(1H1,30X,'COEFFICIENTS FOR EFFICIENCY AND EVAPORATION'/
     1 10X,'FROM A SPRAY FIELD'///30X,'INPUT VARIABLES')
      READ(5,INPUT)
      WRITE(6,200) NPNTS,VELO,THETA,R,PB,HT,WID,ALEN,Y0,Q,PHI
  200 FORMAT(///,20X,'NUMBER OF RANDOM POINTS,NPNTS = ',I5/
     1 20X,'INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VELO = ',F10.2,
     2 ' FT/SEC'/
     3 20X,'INITIAL ANFLE OF DROPS TO HOR., THETA = ',F10.3,' DEGREES'/
     4 20X,'GEOMETRIC MEAN RADIUS OF DROPS, R = ',F10.4,' CM'/
     5 20X,'ATMOSPHERIC PRESSURE, PB = ',F10.2,' INCHES HG'/
     6 20X,'HEIGHT OF SPRAY FIELD, HT = ',F10.2,' FT'/
     7 20X,'WIDTH OF SPRAY FIELD, WID = ',F10.1,' FT'/
     8 20X,'LENGTH OF SPRAY FIELD, ALEN = ',F10.1,' FT'/
     8 20X,'HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, Y0 = ',F10.1,
     * ' FT'/20X,'FLOWRATE OF WATER SPRAYED, Q = ',F10.2,' CU.FT./SEC',/
     * 20X,'HEADING OF WIND W.R.T.LONG AXIS, PHI = ',F10.2,' DEGREES'//)
C     CONVERT SPRAY PARAMETERS TO METRIC UNITS
      VELO=VELO*30.48
      THETA =THETA*(3.1415926/180.0)
      HT=HT*30.48
      WID=WID*30.48
      ALEN=ALEN*30.48
      Y0=Y0*30.48
      Q=Q*28316
      TWETH=TWETO+RTW
      TDRY0=TWETO+DTDRY0
      TDRYH=TWETH+RTD+DTDRY0
      WH=WINDO+RW
      THOTH=THOTO+RTH
      WRITE(6,201) TWETO,TWETH,TDRY0,TDRYH,WINDO,WH,THOTO,THOTH
  201 FORMAT(/40X,'RANGES OF METEOROLOGICAL PARAMETERS'/20X,
     1 'WET BULB TEMPERATURE = ',F10.3,' TO',F10.3,' DEG.F'/20X,
     3 'DRY BULB TEMPERATURE = ',F10.3,' TO',F10.3,' DEG.F'/ 20X,
     2 'WIND SPEED = ',F10.3,' TO',F10.3,' MPH'/20X,
     3 'SPRAYED TEMPERATURE = ',F10.3,' TO',F10.3,' DEG.F'//)
C     NPNTS = THE NUMBER OF POINTS IN THE CORRELATION
C     HT = THE HEIGHT OF THE SPRAY FIELD, FT
```

Figure B.1 Listing of program SPRCO

```
C     ALEN = THE LENGTH OF THE SPRAY FIELD, FT
C     WID = THE WIDTH OF THE SPRAY FIELD, FT
C     VELO = THE INITIAL VELOCITY OF THE DROPS LEAVING THE NOZZLE, FT/SEC
C     THETA = THE ANGLE OF THE DROPS LEAVING THE NOZZLE W.R.T. HORIZON, DEGREES
C     YO = THE HEIGHT OF THE NOZZLES ABOVE POND SURFACE, FT
C     R = THE GEOMETRIC MEAN DROP SIZE, CM
C     PB = BAROMETRIC PRESSURE,INCHES MERCURY
C     Q = QUANTITY OF WATER SPRAYED THROUGH FIELD, CUBIC FEET PER SECOND
C     TWETO=LOWER LIMIT OF RANGE OF WET BULB T.,F
C     DTDRYO = LOWER LIMIT ON RANGE OF DRY BULB T ADDED TO WET BULB T, F
C     WINDO = LOWER LIMIT OF WIND SPEED RANGE,MPH
C     THOTO = LOWER LIMIT OF SPRAYED WATER TEMPERATURE, F
C     RTW = RANGE OF WET BULB TEMPERATURE, F
C     RTD = RANGE OF DRY BULB TEMPERATURE, F
C     RW = RANGE OF WIND SPEED, MPH
C     RTH = RANGE OF SPRAYED TEMPERATURE, F
      WRITE(9) NPNTS
C     AREA OF SIDE OF SPRAY POND IN HWS MODEL
      ASIDEH=HT*ALEN                                                    000300
      NSTEPS=10
      DLEN=ALEN/10                                                      000340
      DWID=WID/10                                                       000350
      DO 801 J=1,10                                                     000360
      I=12-J                                                            000370
C     TOP AND SIDE AREAS FOR EACH SEGMENT IN LWS MODEL
      ATOP(I)=J*DLEN*DWID*J-(J-1)*DLEN*DWID*(J-1)                       000380
      ASIDE(I)=((J-1)*DLEN+(J-1)*DWID)*2*HT                             000390
  801 CONTINUE                                                          000400
      ASIDE(1)=(ALEN+WID)*2*HT                                          000410
      ASIDE(12)=0                                                       000430
      CALL INIT(R,THETA,YO,VELO)
      WRITE(6,6)
    6 FORMAT(10X,'PT NO.',T20,'TWET',T30,'TDRY',T40,'THOT',T50,'WIND',
     1 T61,'HUMID',T71,'ETA',T81,'ETA',T92,'EVAP.',T105,'EVAP.',
     2 /T22,'F',T32,'F',T42,'F',T51,'MPH',T92,'LWS',T105,'HWS',
     3 T71,'LWS',T81,'HWS'/)
      DO 1 I=1,NPNTS                                                    000520
C     GENERATE RANDOM MET DATA
      CALL RANDIN(TWETO,DTDRYO,WINDO,THOTO,RTW,RTD,RW,                  000530
     1 RTH,TWET,TDRY,WIND,THOT,PB)                                      000540
      WIND=WIND*ABS(SIN(PHI*.017453293))                                000560
C   CONVERT MPH TO CM/SEC                                               000570
      WIND1=WIND*44.7
C     CALCULATE HUMIDITY
      CALL PSY1(TDRY,TWET,PB,DP,PV,HUMID,ENTHAL,VOLUME,RH)              000590
      THOT1=C(THOT)
      TDRY1=C(TDRY)
      TWET1=C(TWET)
C      HIGH WIND SPEED MODEL
C     USE HIGH WIND SPEED MODEL
      CALL HWS(THOT1,HUMID,TDRY1,ASIDEH,TWAV,WIND1,Q,R,EVAPS)
C     HWS EFFICIENCY AND EVAPORATION
      ETA2=(THOT1-TWAV)/(THOT1-TWET1)
      ETA2S=ETA2                                                        000670
      EVAPSS=EVAPS/Q                                                    000680
C     DELIBERATELY SET TO EXCEED FORMAT, THEREBY PRINTING STARS
      ETA2=-9999                                                        000700
      EVAPS=-9999999
      IF(TDRY.GT.THOT) GOTO 1111                                        000710
      DO 444 L=2,11                                                     000720
      TSEG(L)=TDRY1+1.0
```

Figure B.1 (Continued)

```
  444 HUM(L)=HUMID+.01
    5 FORMAT(10X,I5,5F10.4,3X,F7.4,F10.4,2(5X,F9.6))
C     LOW WIND SPEED MODEL
      CALL LWS(THOT1,HUMID,TDRY1,ALEN,WID,TWAV,Q,R,
     1 TSEG,HUM,ALPHA,HT,EVAPS)
C     LWS EFFICIENCY AND EVAPORATION
      ETA2=(THOT1-TWAV)/(THOT1-TWET1)
      EVAPS=EVAPS/Q
 1111 CONTINUE
      WRITE(9) TWET,TDRY,THOT,WIND,HUMID,ETA2,
     1 ETA2S,EVAPS,EVAPSS
      WRITE(6,5) I,TWET,TDRY,THOT,WIND,HUMID,ETA2,ETA2S,EVAPS,EVAPSS
    1 CONTINUE
C     GENERATE REGRESSION EQUATIONS
      CALL FITSPR
      STOP
      END
      SUBROUTINE RANDIN(TWETO,DTDRY0,WINDO,THOTO,RTW,RTD,
     1 RW,RTH,TWET,TDRY,WIND,THOT,PB)
C     GENERATES RANDOM VALUES OF METEOROLOGICAL VARIABLES
      DO 1 I=1,10
      TWET=TWETO+RTW*RANF(J)
      TDRY=TWET+DTDRY0+RTD*RANF(J)
C     CHECK FOR PLAUSIBILITY OF TWET WITH RESPECT TO TDRY
      CALL PSY1(TDRY,TWET,PB,DP,PV,HUMID,H,V,RH)
      IF(HUMID.GT.0) GOTO 2
      GOTO 1
    2 WIND=WINDO+RW*RANF(J)
      THOT=THOTO+RTH*RANF(J)
      IF(THOT.LE.TDRY.AND.WIND.LT.1.0) GOTO 1
      GOTO 3
    1 CONTINUE
    3 CONTINUE
      RETURN
      END
      SUBROUTINE LWS(THOT,HUMID,TAIR,ALEN,WID,TWAV,Q,R,TSEG,
     1 HUM,ALPHA,HT,EVAPS)
C     LOW WIND SPEED MODEL
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,
     1 RHOA,DIFF,PR,AK,DT,H,EVAP,NSTEPS,CON6,DT06,
     2 DT02,TDROP,U0,V0,SC
      COMMON/LWSCOM/ ATOP(12),ASIDE(12)
      DIMENSION VUP(12),FLOW(12),QT(12),RHO2(12),VH(12)
      DIMENSION TSEG(11),HUM(11),HOUT(11)
      DIMENSION HFIL(12),TFIL(12)
      DIMENSION TM2(12),TM1(12),HM2(12),HM1(12)
      DO 491 I=1,12
      TM2(I)=0
      TM1(I)=0
      HM2(I)=0
  491 HM1(I)=0
      TLAST=0
      DATA HVAP,CP,RHO/580.0,1.0,1.0/
      ICNT=0
C     DENSITY OF AMBIENT AIR GM/CC
      RHO1=(1+HUMID)/((81.86*TAIR+22387)*(.03448+HUMID/18))
      FLOW(11)=0
      QT(1)=0
      FLOW(1)=0
      RHO2(1)=RHO1
      ATOT=ALEN*WID
      TSEG(1)=TAIR
```

Figure B.1 (Continued)

```
      HUM(1)=HUMID                                                      00127C
C     CONCENTRATION OF WATER IN AIR
      CWA=HUMID/((81.86*TAIR+22387)*(.03448+HUMID/18))                  001280
C     BEGIN ITERATIVE SOLUTION
      DO 801 NITER=1,20                                                 001290
      DO 101 J=1,10                                                     001300
      I=12-J                                                            001310
C     DENSITY OF AIR IN EACH SEGMENT GM/CC
      RHO2(I)=(1+HUM(I))/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))     001320
C     HUMID VOLUME, CC/GM BDA
      VH(I)=((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))                  001330
  101 CONTINUE                                                          001340
  105 CONTINUE                                                          001350
      DO 1001 J=1,10                                                    001360
      I=12-J                                                            001370
      DRHO=RHO1-RHO2(I)                                                 001380
      ARG=980*DRHO*HT*.5/RHO1                                           001390
      ICNT=1                                                            001400
      IF(ARG.LT.0.0) GOTO 668                                           001410
C     UPWARD VELOCITY OF AIR LEAVING EACH SEGMENT
      VUP(I)=SQRT(ARG)                                                  001420
  668 CONTINUE                                                          001430
C     MATERIAL BALANCE ON EACH SEGMENT
      QT(I)=VUP(I)*ATOP(I)/VH(I)                                        001440
      FLOW(I-1)=FLOW(I)+QT(I)                                           001450
 1001 CONTINUE                                                          001460
      ICNT=ICNT+1                                                       001470
  104 CONTINUE                                                          001480
C     ENTHALPY OF AIR ENTERING FIRST SEGMENT, CAL/GM BDA
      HOUT(1)=FLOW(1)*(.238*TAIR+HUMID*(HVAP+.45*TAIR))                 001490
      TSEG(1)=TAIR                                                      001510
      EVAPS=0                                                           001520
      HUM(1)=HUMID                                                      001530
      SUMTC=0                                                           001540
      DO 201 I=2,11                                                     001550
      TEMP=TSEG(I-1)+273.2                                              001560
C     VISCOSITY OF AIR, GM/(SEC CM)
      VIS=2.7936E-6*TEMP**.73617                                        001570
C     DENSITY OF AIR, GM/CC
      RHOA=.353/TEMP                                                    001580
C     DIFFUSION COEFF OF AIR(CM**2/SEC)
      DIFF=5.8758E-6*TEMP**1.8615
C     PRANTL NO
      PR=.93176*TEMP**(-.042784)                                        001600
C     SCHMIDT NO
      SC=2.2705*TEMP**(-.21398)                                         001610
C     THERMAL CONDUCTIVITY OF AIR,CM/SEC
      AK=3.9273E-7*TEMP**.88315                                         001620
      CON4=AK/R                                                         001630
      CON6=2*R*RHOA/VIS                                                 001640
      CON5=DIFF/R                                                       001650
      TDROP=THOT                                                        001660
C     CALCULATE TEMPERATURE AND EVAPORATION OF FALLING DROPS
      CALL DROP(TSEG(I-1),CWA)                                          001670
C     SENSIBLE HEAT TRANSFER IN SEGMENT
      HSEG=RHO*CP*(Q*ATOP(I)/ATOT)*(THOT-TDROP)                         001680
C     EVAPORATION IN SEGMENT
      EVAP1=EVAP*Q*ATOP(I)/(ATOT*VOL)                                   001690
C     SENSIBLE HE AT LEAVING SEGMENT AND ENTERING NEXT
      HOUT(I)=HSEG+HOUT(I-1)*(1-QT(I-1)/(QT(I-1)+FLOW(I-1)))            001700
C     HUMIDITY IN SEGMENT
      HUM(I)=HUM(I-1)+EVAP1/FLOW(I-1)                                   001710
```

Figure B.1 (Continued)

```
C     TEMPERATURE IN SEGMENT
      TSEG(I)=(HOUT(I)/FLOW(I-1)-HUM(I)*HVAP)/(.238+.45*HUM(I))
      EVAPS=EVAPS+EVAP1
      CWA=HUM(I)/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))
      SUMTC=SUMTC+TDROP*ATOP(I)
  201 CONTINUE
C     AVERAGE TEMPERATURE OF WATER FALLING TO POND SURFACE
      TWAV=SUMTC/ATOT
      IF(NITER.LT.3) GOTO 49
      DO 492 I=2,11
C     SECOND ORDER SMOOTHING OPERATOR TO AID CONVERGENCE
      HFIL(I)=ALPHA*(HM2(I)-2*HM1(I)+HUM(I))
      TFIL(I)=ALPHA*(TM2(I)-2*TM1(I)+TSEG(I))
  492 CONTINUE
      DO 493 I=2,11
      TSEG(I)=TSEG(I)+TFIL(I)
      HUM(I)=HUM(I)+HFIL(I)
  493 CONTINUE
   49 DO 494 I=2,11
      TM2(I)=TM1(I)
      TM1(I)=TSEG(I)
      HM2(I)=HM1(I)
  494 HM1(I)=HUM(I)
      IF(ABS((TLAST-TWAV)/TWAV).LT.0.002) GOTO 800
      TLAST=TWAV
  801 CONTINUE
      WRITE(6,20)
   20 FORMAT(10X,'NO CONVERGENCE AFTER 20 TRIES')
  800 RETURN
      END
      SUBROUTINE HWS(THOT,HUMID,TAIR,ASIDE,TWAV,
     1 WIND,Q,R,EVAPS)
C     HIGH WIND SPEED MODEL
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,RHOA,DIFF,
     1 PR,AK,DT,H,EVAP,NSTEPS,CON6,DT06,DT02,TDROP
     1 ,U0,V0,SC
      DIMENSION TSEG(11),HUM(11),HOUT(11)
      DATA HVAP,CP,RHO/580.0,1.0,1.0/
      CON7=RHO*CP*Q/10
      CON8=Q/(10*VOL)
C     GMS OF BDA ENTERING SPRAY FIELD FROM UPWIND
      FLOW=WIND*ASIDE/((81.86*TAIR+22387)*(.03448+HUMID/18))
C     ENTHALPY OF AIR ENTERING SPRAY FIELD,CAL/SEC
      HOUT(1)=FLOW*(.238*TAIR+HUMID*(HVAP+.45*TAIR))
      TSEG(1)=TAIR
      HUM(1)=HUMID
C     CONCENTRATION OF WATER IN AIR
      CWA=HUMID/((81.86*TAIR+22387)*(.03448+HUMID/18))
      EVAPS=0
      SUMTC=0
      DO 1 I=2,11
      TEMP=TSEG(I-1)+273.2
C     VISCOSITY OF AIR GM/(CM SEC)
      VIS=2.7936E-6*TEMP**.73617
C     DENSITY OF AIR GM/CC
      RHOA=.353/TEMP
C     DIFFUSION COEFFICIENT OF AIR CM**2/SEC
      DIFF=5.8758E-6*TEMP**1.8615
C     PRANTL NO
      PR=.93176*TEMP**(-.042784)
C     SCHMIDT NO
      SC=2.2705*TEMP**(-.21398)
```

Figure B.1 (Continued)

```
C     THERMAL CONDUCTIVITY OF AIR CM/SEC
      AK=3.9273E-7*TEMP**.88315
      CON4=AK/R
      CON6=SQRT(2*R*RHOA/VIS)
      CON5=DIFF/R
      TDROP=THOT
C     TEMPERATURE AND EVAPORATION OF DROP
      CALL DROP(TSEG(I-1),CWA)
C     SENSIBLE HEAT ENTERING SEGMENT FROM DROPS
      HSEG=CON7*(THOT-TDROP)
C     EVAPORATION FROM ALL DROPS INTO SEGMENT
      EVAP1=EVAP*CON8
C     ENTHALPY LEAVING SEGMENT AND ENTERING NEXT
      HOUT(I)=HOUT(I-1)+HSEG
C     HUMIDITY OF SEGMENT
      HUM(I)=HUM(I-1)+EVAP1/FLOW
C     AIR TEMPERATURE IN SEGMENT
      TSEG(I)=(HOUT(I)/FLOW-HUM(I)*HVAP)/(.24+.45*HUM(I))
      EVAPS=EVAPS+EVAP1
C    CWA = CONCENTRATION OF WATER IN AIR, GM/CC
      CWA=HUM(I)/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))
      SUMTC=SUMTC+TDROP
    1 CONTINUE
C     AVERAGE TEMPERATURE OF WATER FALLING TO POND SURFACE
      TWAV=SUMTC/10
      RETURN
      END
      SUBROUTINE DROP(TAIR,CINF)
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,RHOA,DIFF,
     1 PR ,AK,DT,H,EVAP,NSTEPS,CON6,DT06,DT02,TDROP
     1 ,U0,V0,SC
C     CALCULATE HEAT AND MASS TRANSFER FROM A DROP
      EVAP=0
      ICNT=1
C        BEGIN FOURTH ORDER RUNGE-KUTTA INT.OF EQUATIONS
      DO 1 I=1,NSTEPS
      CALL FTDROP(ICNT,TDROP,DTD1,DI1,TAIR,CINF)
      ICNT=ICNT+1
      TDROP1=TDROP+DT02*DTD1
      CALL FTDROP(ICNT,TDROP1,DTD2,DI2,TAIR,CINF)
      TDROP2=TDROP+DTD2*DT02
      CALL FTDROP(ICNT,TDROP2,DTD3,DI3,TAIR,CINF)
      ICNT=ICNT+1
      TDROP3=TDROP+DTD3*DT
      CALL FTDROP(ICNT,TDROP3,DTD4,DI4,TAIR,CINF)
      TDROP=TDROP+(DTD1+2*(DTD2+DTD3)+DTD4)*DT06
      EVAP=EVAP+(DI1+2*(DI2+DI3)+DI4)*DT06
    1 CONTINUE
      RETURN
      END
      SUBROUTINE FTDROP(ICNT,TDRP,DTD,DI,TAIR,CINF)
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,RHOA,DIFF,
     1 PR,AK,DT,H,EVAP,NSTEPS,CON6,DT06,DT02,TDROP
     1 ,U0,V0,SC
C     RATE OF HEAT AND MASS TRANSFER FROM A DROP
      COMMON/RESTOR/ SQV(100)
      DATA RG/82.02/
      TDK=TDRP+273.2
C     VAPOR PRESSURE OF WATER ATM
      P=EXP(71.02499-7381.6477/TDK-9.0993037*ALOG(TDK)
     1 +.0070831558*TDK)
```

Figure B.1 (Continued)

```
      SRE=CON6*SQV(ICNT)                                                002740
      HC=CON4*(1+.3*PR**.3333333*SRE)                                   002750
      HD=CON5*(1+.3*SC**.3333333*SRE)                                   002760
      CDROP=P*18.0/(RG*TDK)                                             002770
C     RATE OF MASS TRANSFER
      DI=CON3*HD*(CDROP-CINF)                                           002780
      DATA HVAP/580.0/
C     RATE OF TEMPERATURE CHANGE
      DTD=-CON1*(DI*HVAP+CON3*HC*(TDRP-TAIR))                           002800
      RETURN                                                            002810
      END                                                               002820
      SUBROUTINE INIT(R,THETA,Y0,VEL0)
      COMMON A,VOL,AM,CON1,CON2,CON3,CON4,CON5,VIS,RHOA,DIFF,           004170
     1 PR,AK,DT,H,EVAP,NSTEPS,CON6,DT06,DT02,TDROP                      004180
     1 ,U0,V0,SC                                                        004190
      COMMON/RESTOR/SQV(100)                                            004210
      VOL=(3.1415926*4/3)*R**3                                          004220
      DATA G/980.0/                                                     004230
      DATA HVAP,CP,RHO/597.0,1.0,1.0/                                   004240
      A=3.1415926*R**2                                                  004250
      CON1=1.0/VOL                                                      004260
      CON2=HVAP*12.566371*R**2                                          004270
      CON3=12.566371*R**2                                               004280
      V0=VEL0*SIN(THETA)                                                004290
      U0=VEL0*COS(THETA)                                                004300
      TFALL=V0/G+SQRT((V0/G)**2+2*Y0/G)                                 004310
      DT=TFALL/NSTEPS                                                   004320
      DT06=DT/6                                                         004330
      DT02=DT/2                                                         004340
      NUM=2*NSTEPS+10                                                   004350
      DO 1 I=1,NUM                                                      004360
      T=(I-1)*DT02                                                      004370
      V=SQRT(U0**2+(V0-980*T)**2)                                       004380
    1 SQV(I)=SQRT(V)                                                    004390
      RETURN                                                            004400
      END                                                               004410
      SUBROUTINE FITSPR                                                 004440
C     FITS SPRAY EFFICIENCY OF HWS AND LWS MODELS TO REGRESSION
C     EQUATIONS AND COMPARES FITTED RESULTS TO ORIGINAL COMPUTATIONS
      DIMENSION EV(200),YEVAP(200)                                      004450
      DIMENSION T(200),TW(200),THOT(200),WIND(200),CH(6),CL(7),         004460
     1 CEH(6),CEL(7),TL(200),TWL(200),THOTL(200),WINDL(200),ETA(200),   004470
     2 ETAL(200),EVAPH(200),EVAPL(200),X(1200),A( 7, 8),P(200),
     3 JJJ( 7),IHLD( 7),YP(200),ETAH(200)
      REWIND 9                                                          004510
      REWIND 7                                                          004520
      READ(9) NPNTS
      NPL=0                                                             004550
      DO 1 I=1,NPNTS                                                    004560
C     READ FROM SCRATCH FILE
      READ(9) TW(I),T(I),THOT(I),WIND(I),HUMID,
     1 TETA,ETAH(I),TEVAP,EVAPH(I)
C     CHECK TO SEE IF LWS MODEL WAS USED                                004600
      IF(TETA.LE.0.0) GOTO 1                                            004610
      NPL=NPL+1                                                         004620
      TWL(NPL)=TW(I)                                                    004630
      TL(NPL)=T(I)                                                      004640
      THOTL(NPL)=THOT(I)                                                004650
      WINDL(NPL)=WIND(I)                                                004660
      ETAL(NPL)=TETA                                                    004670
      EVAPL(NPL)=TEVAP                                                  004680
C     REVISED SCRATCH FILE ELIMINATING PTS WHERE LWS NOT USED
```

Figure B.1 (Continued)

```
      WRITE(7) TW(I),T(I),THOT(I),WIND(I),HUMID,
     1 TETA,ETAH(I),TEVAP,EVAPH(I)
    1 CONTINUE
      PRINT 101,NPNTS,NPL
  101 FORMAT(10X,'NUMBER OF POINTS GENERATED = ',I5,/
     1 10X,'NUMBER OF POINTS PLOTTED = ',I5)
C     PUT HWS DATA INTO ARRAY FOR ETA EQN
      DO 2 I=1,NPNTS
      X(I)=T(I)
      I1=I+NPNTS
      I2=I1+NPNTS
      I3=I2+NPNTS
      I4=I3+NPNTS
      X(I1)=TW(I)
      X(I2)=THOT(I)
      X(I3)=WIND(I)
      X(I4)=SQRT(WIND(I))
    2 CONTINUE
C     MULTIPLE REGRESSION ON HWS EFFICIENCY
      CALL SURFIT(X,ETAH,NPNTS,5,7 ,A,WORK,P,JJJ,IHLD,E)
C     SAVE COEFFICIENTS OF EQN FOR ETAH
      DO 4 I=1,6
    4 CH(I)=A(I,1)
      IF(E.EQ.1.0) WRITE(6,6)
    6 FORMAT(10X,'CONVERGENCE ERROR')
      WRITE(6,5) (CH(I),I=1,6)
    5 FORMAT(1H1,10X,'FOR HWS EFFICIENCY,CONSTANT AND COEFF OF T,TWET,TH
     1OT,'/,10X,'WIND AND WIND**.5 ARE',/(10X,E15.8))
C     EVAPORATION FOR HWS MODEL
C     REGRESSION OF HWS EVAPORATION
      CALL SURFIT(X,EVAPH,NPNTS,5,7 ,A,WORK,P,JJJ,IHLD,E)
      IF(E.EQ.1.0) WRITE(6,6)
      DO 7 I=1,6
    7 CEH(I)=A(I,1)
      WRITE(6,8) (CEH(I),I=1,6)
    8 FORMAT(///,10X,'FOR HWS EVAPORATION,CONSTANT AND COEFICIENT OF T,
     1 TWET,THOT,WIND AND WIND**.5 ARE',/(10X,E15.8))
C     SETUP LWS DATA FOR ETAL EQUATION
      DO 10 I=1,NPL
      X(I)=TL(I)
      I1=I+NPL
      I2=I1+NPL
      I3=I2+NPL
      I4=I3+NPL
      I5=I4+NPL
      X(I1)=TL(I)**2
      X(I2)=TL(I)**3
      X(I3)=TWL(I)
      X(I4)=THOTL(I)
      X(I5)=THOTL(I)**2
   10 CONTINUE
C     MULTIPLE REGRESSION FOR LWS EFFICIENCY
      CALL SURFIT(X,ETAL,NPL,6,7 ,A,WORK,P,JJJ,IHLD,E)
      IF(E.EQ.1.0) WRITE(6,6)
C     SAVE COEFF OF EQN FOR ETAL
      DO 11 I=1,7
   11 CL(I)=A(I,1)
      WRITE(6,12) (CL(I),I=1,7)
   12 FORMAT(///,10X,'FOR LWS EFFICIENCY,CONSTANT AND COEFF OF T,T**2,
     1 T**3,TWET,THOT AND THOT**2 ARE'/(10X,E15.8))
C     REGRESSION FOR LWS EVAPORATION
      CALL SURFIT(X,EVAPL,NPL,6,7 ,A,WORK,P,JJJ,IHLD,E)
```

Figure B.1 (Continued)

```
      IF(E.EQ.1.0) WRITE(6,6)
      DO 13 I=1,7
   13 CEL(I)=A(I,1)
      WRITE(6,14) (CEL(I),I=1,7)
   14 FORMAT(///,10X,'FOR LWS EVAPORATION,CONSTANT AND COEFF OF T,T**2,
     1 T**3,TWET,THOT AND THOT**2 ARE'/(10X,E15.8))
      REWIND 7
C     COMPARE REGRESSION TO ORIGINAL
      DO 31 I=1,NPL
      READ(7) TW(I),T(I),THOT(I),WIND(I),HUMID,
     1 TETA,ETAH(I),TEVAP,EVAPH(I)
C    CHOOSE HIGHER INPUT EFF
      IF(TETA.GT.ETAH(I)) GOTO 32
      EV(I)=EVAPH(I)
      ETA(I)=ETAH(I)
      GOTO 31
   32 ETA(I)=TETA
      EV(I)=TEVAP
   31 CONTINUE
C    PICK HIGHER CORRELATION COEFF
      DO 33 I=1,NPL
      EH=CH(1)+CH(2)*T(I)+CH(3)*TW(I)+CH(4)*THOT(I)+
     1 CH(5)*WIND(I)+CH(6)*SQRT(WIND(I))
      EL=CL(1)+CL(2)*T(I)+CL(3)*T(I)**2+CL(4)*T(I)**3+
     1 CL(5)*TW(I)+CL(6)*THOT(I)+CL(7)*THOT(I)**2
      IF(EH.GT.EL) GOTO 34
      YP(I)=EL
      YEVAP(I)=CEL(1)+CEL(2)*T(I)+CEL(3)*T(I)**2+CEL(4)*T(I)**3
     1 +CEL(5)*TW(I)+CEL(6)*THOT(I)+CEL(7)*THOT(I)**2
      GOTO 33
   34 YP(I)=EH
      YEVAP(I)=CEH(1)+CEH(2)*T(I)+CEH(3)*TW(I)+CEH(4)*THOT(I)+
     1 CEH(5)*WIND(I)+CEH(6)*SQRT(WIND(I))
   33 CONTINUE
      WRITE(6,81)
   81 FORMAT(1H1,30X,'CORRELATION OF SPRAY EFFICIENCY')
C     PLOT SCATTERGRAMS FOR DATA VS REGRESSION
      CALL SCATTER(ETA,YP,NPL)
      WRITE(6,82)
   82 FORMAT(1H1,30X,'CORRELATION OF EVAPORATION FRACTION')
      CALL SCATTER(EV,YEVAP,NPL)
      WRITE(4,201) CH,CL,CEH,CEL
  201 FORMAT(4E15.8)
      STOP
      END
      SUBROUTINE SCATTER(X,Y,NPNTS)
C     PLOTS SCATTERGRAM OF X ARRAY VS Y ARRAY AND CALCULATES
C     CORRELATION COEFFICIENTS
      DIMENSION ICHAR(11),X(200),Y(200),MA(70,42)
      DATA ICHAR/1H ,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1HZ/
      DO 1 I=1,70
      DO 1 J=1,42
    1 MA(I,J)=1
C     SCALE INPUT
      X0=1.0E50
      X1=-X0
      SXX=0
      SYY=0
      SXY=0
      XAV=0
      YAV=0
```

Figure B.1 (Continued)

```
      DO 100 I=1,NPNTS
      SXX=X(I)**2+SXX
      SYY=Y(I)**2+SYY
      SXY=X(I)*Y(I)+SXY
      XAV=XAV+X(I)
      YAV=YAV+Y(I)
      IF(X(I).GT.X1) X1=X(I)
      IF(Y(I).GT.X1) X1=Y(I)
      IF(X(I).LT.X0) X0=X(I)
      IF(Y(I).LT.X0)X0=Y(I)
  100 CONTINUE
      RANGE=X1-X0
      SXX=NPNTS*SXX-XAV**2
      SYY=NPNTS*SYY-YAV**2
      SXY=NPNTS*SXY-XAV*YAV
      R2=SXY**2/(SXX*SYY)
      SERR=SQRT(((SXX*SYY)-SXY**2)/(I*(I-2)*SXX))
      WRITE(6,20) R2,SERR,X0,X1
   20 FORMAT(30X,'CORRELATION COEFF R**2 = ',F8.4,/
     1 30X,'STANDARD ERROR = ',F10.4/,30X,
     1 'MIN AND MAX OF PLOT SCALES = ',2E15.6)
      DO 2 K=1,NPNTS
      N=((X(K)-X0)/RANGE)*70+.5
      IF(N.GT.70) N=70
      IF(N.LT.1) N=1
      M=((Y(K)-X0)/RANGE)*42+.5
      IF(M.GT.42) M=42
      IF(M.LT.1)M=1
      MA(N,M)=MA(N,M)+1
    2 CONTINUE
      DO 3 N=1,70
      DO 3 M=1,42
      IF(MA(N,M).LT.9) GOTO 4
      MA(N,M)=ICHAR(11)
      GOTO 3
    4 K=MA(N,M)
      MA(N,M)=ICHAR(K)
    3 CONTINUE
      WRITE(6,7)
      DO 5 J=1,42
      J1=42-J+1
    5 WRITE(6,6) (MA(I,J1),I=1,70)
      WRITE(6,7)
    6 FORMAT(26X,1H*,70A1,1H*)
    7 FORMAT(26X,1H*,7(10HI*********))
      WRITE(6,8)
    8 FORMAT(/26X,'PLOTTED CHARACTERS ARE NUMBER OF POINTS FALLING AT TH
     1AT POSITION')
      RETURN
      END
      SUBROUTINE SURFIT(X,Y,N,M,MX,A,WORK,P,JJJ,IHLD,E)
      DIMENSION X(1),Y(1),A(MX,1),WORK(1),P(1),JJJ(1),IHLD(1)
C     MULTIPLE LINEAR REGRESSION ROUTINE
C     R CODELL  AFTER US ARMY MISSILE COMMAND, REDSTONE ARSENAL ALA
      E=0
      LB=M+2
      LV=M+1
      L=1
      JJJ=1
      DO4 I=2,M
      JJJ(I)=N*L+1
```

Figure B.1 (Continued)

```
    4 L=L+1
      DO 1 I=1,LV
      DO 1 J=1,LB
    1 A(I,J)=0.
      A=N
      DO 5 I=1,N
    5 P(I)=1.
      DO 2 I=1,LV
      DO 3 J=1,N
    3 A(I,LB)=A(I,LB)+Y(J)*P(J)
      IF(I.EQ.LV) GOTO 211
      K=JJJ(I)
      DO 2 L=1,N
      P(L)=X(K)
    2 K=K+1
  211 DO 88 I=1,N
   88 P(I)=1.
      DO 9 I=1,M
      LL=I+1
      DO 6 J=LL,LV
      K=JJJ(J-1)
      DO 7 KK=1,N
      A(I,J)=A(I,J)+P(KK)*X(K)
    7 K=K+1
    6 A(J,I)=A(I,J)
      K=JJJ(I)
      DO 9 MM=1,N
      P(MM)=X(K)
    9 K=K+1
      DO 101 I=2,LV
      K=JJJ(I-1)
      DO 101 KK=1,N
      A(I,I)=A(I,I)+X(K)**2
  101 K=K+1
      DO 21 I=1,LV
   21 IHLD(I)=I
      JJ=LB
      DO 55 I=1,LV
      KK=LV-I
      IF(KK) 10,10,26
   26 LL=KK+1
      IJJ=1
      L=I
      WORK=A
      DO 17 II=1,LL
      DO 17 J=1,LL
      IF(ABS(WORK)-ABS(A(II,J))) 18,17,17
   18 WORK=A(II,J)
      L=J+I-1
      IJJ=J
   17 CONTINUE
      IF(IJJ-1)222,222,19
   19 DO 20 II=1,LV
      Z=A(II,1)
      A(II,1)=A(II,IJJ)
   20 A(II,IJJ)=Z
      IY=IHLD(I)
      IHLD(I)=IHLD(L)
      IHLD(L)=IY
  222 DO 111 L=1,KK
      IF(ABS(A)-ABS(A(L+1,1))) 77,111,111
```

Figure B.1 (Continued)

```
   77 DO 99 J=1,JJ
      Z=A(1,J)
      A(1,J)=A(L+1,J)
   99 A(L+1,J)=Z
  111 CONTINUE
   10 JJ=JJ-1
      IF(A)11,8,11
   11 DO 12 J=1,JJ
   12 WORK(J)=A(1,J+1)/A
      KK=JJ+1
      DO 33 K=1,M
      DO 33 J=2,KK
   33 A(K,J-1)=A(K+1,J)-A(K+1,1)*WORK(J-1)
      DO 55 J=1,JJ
   55 A(LV,J)=WORK(J)
      DO 22 I=1,M
      L=I+1
      DO 22 J=L,LV
      IF(IHLD(I)-IHLD(J)) 22,22,23
   23 IY=IHLD(I)
      IHLD(I)=IHLD(J)
      IHLD(J)=IY
      Z=A(I,1)
      A(I,1)=A(J,1)
      A(J,1)=Z
   22 CONTINUE
   13 RETURN
    8 E=1.
      GOTO 13
      END
      SUBROUTINE PSY1(DB,WB,PB,DP,PV,W,H,V,RH)
C     THIS ROUTINE CALCULATES' VAPOR PRESSURE PV, HUMIDITY RATIO W,
C         ENTHALPY H, VOLUME V, RELATIVE HUMIDITY RH, AND
C         DEW POINT TEMPERATURE DP\
C         WHEN THE DRY BULB TEMPERATURE DB, WET BULB TEMPERATURE WB,
C         AND BAROMETRIC PRESSURE PB ARE GIVEN
C     UNITS' DB, WB, + DP )F>\ PB, + PV )IN OF HG>\ W)= WATER VAPOR
C         PER = DRY AIR>\ H )BTU/= OF DRY AIR>\ V )FT**3/= OF DRY
C         AIR\ RH IS A FRACTION, NOT (
      C(F)=(F-32.0E0)/1.8E0
      PVP=PVSF(WB)
      WSTAR=0.622*PVP/(PB-PVP)
      IF (WB.GT.32.0) GO TO 105
      PV=PVP-5.704E-4*PB*(DB-WB)/1.8
      GO TO 110
  100 PV=PVP
      GO TO 110
  105 CDB=C(DB)
      CWB=C(WB)
      HL=597.31+0.4409*CDB-CWB
      CH=0.2402+0.4409*WSTAR
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
      PV=PB*EX/(1.+EX)
  110 W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1.0+7000.0*W/4360.0)/PB
      H=0.24*DB+(1061.0+0.444*DB)*W
      IF (PV.GT.0.0) GO TO 115
      PV=0.0
      DP=0.0
      RH=0.0
      RETURN
  115 IF (DB.NE.WB) GO TO 120
```

Figure B.1 (Continued)

```
      DP=DB
      RH=1.0
      RETURN
  120 DP=DPF(PV)
      RH=PV/PVSF(DB)
      RETURN
      END
      FUNCTION PVSF(X)
      DIMENSION A(6),B(4),P(4)
      DATA A/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.49149/
      DATA B/-9.09718,-3.56654,0.876793,0.0060273/
      T=(X+459.688)/1.8
      IF (T.LT.273.16) GO TO 100
      Z=373.16/T
      P(1)=A(1)*(Z-1.0)
      P(2)=A(2)*ALOG10(Z)
      Z1=A(4)*(1.0-1.0/Z)
      P(3)=A(3)*(10.0**Z1-1.0)
      Z1=A(6)*(Z-1.0)
      P(4)=A(5)*(10.0**Z1-1.0)
      GO TO 105
  100 Z=273.16/T
      P(1)=B(1)*(Z-1.0)
      P(2)=B(2)*ALOG10(Z)
      P(3)=B(3)*(1.0-1.0/Z)
      P(4)=ALOG10(B(4))
  105 SUM=0.0
      DO 110 I=1,4
  110 SUM=SUM+P(I)
      PVSF=29.921*10.0**SUM
      RETURN
      END
      FUNCTION DPF(PV)
C     THIS ROUTINE CALCULATES DEW-POINT TEMPERATURE FOR A GIVEN
C          VAPOR PRESSURE PV
      DP(A,B,C,Y)=A+(B+C*Y)*Y
      Y=ALOG(PV)
      IF (PV.GT.0.1836) GO TO 100
      DPF=DP(71.98,24.873,0.8927,Y)
      RETURN
  100 DPF=DP(79.047,30.579,1.8893,Y)
      RETURN
      END
```

Figure B.1 (Continued)

```
      PROGRAM DRIFT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     THIS PROGRAM COMPUTES THE DRIFT LOSS FROM A SPRAY POND FOR
C     VARIOUS WIND SPEEDS.  COMPUTATIONS ARE BASED ON A CONSERVATIVE
C     BALLISTIC MODEL OF DROP TRAJECTORIES.
C     WK NUTTLE AND R CODELL, U.S. NUCLEAR REGULATORY COMMISSION
C     WASHINGTON D.C. 20555
C
      COMMON WND,VUP,DIA,A,W
      REAL GAMMA(2),WIND(16),KX(4),KY(4),DIAM(21)
      REAL PROPOR(21),DIS(2),RAD(21),XPRIM(21)
      REAL XI(2,16),YI(2,16),VI(2,16),SPRAY(50,2)
      INTEGER TITLE(60)
      DATA GAMMA/0.,180./
C     WIND SPEED TABLE
      DATA WIND/0.,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,
     1 30.,35.,40.,45.,50./
C     DIAMETER OF DROPS IN TYPICAL SPRAYCO DISTRIBUTION
      DATA DIAM/4000.,3600.,2800.,2290.,2000.,1650.,1340.,1190.,1000.,85
     15.,640.,580.,520.,460.,425.,400.,365.,330.,300.,260.,200./
C     FRACTION OF DROPS IN CORRESPONDING DIAMETER RANGE
      DATA PROPOR/.15,.15,.2,.1,.1,.1,.05,.05,.03,.03,.02,.006,.004,.003
     1,.002,.001,.001,.001,.001,.0005,.0005/
C     ASSUMED 50 CM/SEC UPDRAFT IN SPRAY FIELD
      VUP=50
C     XI AND YI ARE COORDINATES OF UPWIND AND DOWNWIND APOGEE FOR
C     EACH WIND SPEED IN TABLE
      DATA XI/235.,-235.,216.,-254.,195.,-270.,173.,-286.,151.,-296.,
     1128.,-306.,104.,-311.,80.,-319.,57.,-327.,32.,-338.,8.,-349.,
     2-38.,-375.,-87.,-403.,-136.,-442.,-185.,-471.,-232.,-512./
      DATA YI/359.,359.,355.,363.,350.,367.,345.,369.,341.,370.,337.,
     1369.,332.,367.,328.,364.,324.,360.,321.,355.,317.,351.,311.,342.,
     2305.,333.,299.,325.,294.,318.,290.,311./
C     VI IS HORIZONTAL DROP VELOCITY AT EACH UPWIND OR DOWNWIND APOGEE
      DATA VI/331.,331.,398.,259.,461.,180.,519.,96.,574.,7.2,626.,
     1-81.,676.,-167.,723.,-246.,769.,-320.,807.,-388.,850.,-451.,932.,
     2-566.,1002.,-669.,1069.,-757.,1132.,-844.,1193.,-919./
      NAMELIST/DROPSZ/DIAM,PROPOR
    1 READ(5,520) TITLE
  520 FORMAT(80A1)
      IF(TITLE(1).EQ.'S') STOP
      WRITE(6,570) TITLE
      READ(5,DROPSZ)
  570 FORMAT(1H1,5(/),T20,'TITLE: ',80A1)
      READ(5,550) NUM
  550 FORMAT(I2)
      WRITE(6,510) NUM
  510 FORMAT(     5(/),T20,'SPRAY GEOMETRY (',I2,' POINTS)'//,T23,
     1'FEET FROM EDGE',T42,'FRAC. OF SPRAYS',/)
      DO 7 N=1,NUM
      READ(5,560) SPRAY(N,1),SPRAY(N,2)
  560 FORMAT(2F10.0)
    7 WRITE(6,500) SPRAY(N,1),SPRAY(N,2)
  500 FORMAT(T20,2F15.6,/)
      WRITE(6,540)
  540 FORMAT(1X,5(/),T20,'DRIFT LOSS FRACTION',//,T27,'WIND SPEED',T42,
     1'LOSS FRAC.',/)
C     DT IS THE TIMESTEP IN PATHWAY INTEGRATION, SEC
      DATA DT,DTO2,PI/.01,.005,3.1415926/
      DO 20 J=1,16
      WND=WIND(J)*5280./3600.*12.*2.54
      DO 2 M=1,21
```

Figure B.2 Listing of program DRIFT

```
      DIA=DIAM(M)/10000.
      A=PI*DIA**2/4
      W=PI*DIA**3/6
C
C     INITIALIZE TRAJECTORY CALCULATIONS
C
      DO 6 I=1,2
      GAM=GAMMA(I)*3.1416/180.
      X=XI(I,J)
      Y=YI(I,J)
      VYN=0
      VXN=VI(I,J)*COS(GAM)
      DO 3 K=1,1000
      CALL FUN(VXN,VYN,KX(1),KY(1))
      VXN1=VXN-KX(1)*DT
      VYN1=VYN-KY(1)*DT
      CALL FUN(VXN1,VYN1,KX(2),KY(2))
      X=X+DTO2*(VXN+VXN1)
      Y=Y+DTO2*(VYN+VYN1)
      VXN=VXN-DTO2*(KX(1)+KX(2))
      VYN=VYN-DTO2*(KY(1)+KY(2))
      DIS(I)=X
      IF(Y.LE.0.) GO TO 6
    3 CONTINUE
      RAD(M)=.1
      XPRIM(M)=10000.
      GO TO 2
    6 CONTINUE
C
C     SOLVE FOR RADIUS OF SPRAY DISTRIBUTION AND DISPLACEMENT
C     DOWN WIND
C
      RAD(M)=(DIS(1)-DIS(2))/2.
      XPRIM(M)=(DIS(1)+DIS(2))/((-2.))
    2 CONTINUE
C
C     COMPUTE DRIFT LOSS FRACTION
C
      DRFTFC=0.
      DO 19 I=1,NUM
      XDW=SPRAY(I,1)*12.*2.54
      DRFTLS=0.
      DO 18 M=1,21
      IF(XDW.GT.(XPRIM(M)+RAD(M)))GO TO 18
      IF(XDW.GT.(XPRIM(M)-RAD(M)))GO TO 16
      DRFTLS=DRFTLS+PROPOR(M)
      GO TO 18
   16 IF(XDW.GT.XPRIM(M)) GO TO 17
      DRFTLS=DRFTLS+PROPOR(M)-PROPOR(M)*(ACOS((XPRIM(M)-XDW)/RAD(M))/3.1
     14159)
      GO TO 18
   17 DRFTLS=DRFTLS+PROPOR(M)*(ACOS((XDW-XPRIM(M))/RAD(M))/3.14159)
   18 CONTINUE
   19 DRFTFC=DRFTLS*SPRAY(I,2)+DRFTFC
      WRITE(6,530) WIND(J),DRFTFC
  530 FORMAT(T20,F15.3,F15.8,/)
   20 CONTINUE
      GO TO 1
      END
      SUBROUTINE FUN(VX,VY,DVX,DVY)
C   VELOCITY COMPONENTS OF DROP
      COMMON WND,VUP,DIA,A,W
```

Figure B.2 (Continued)

```
      DATA RHO,VIS/.001204,.0001831/
C    DROP VELOCITIES WITH RESPECT TO WINDS
      RVX=VX+WND
      RVY=VY-VUP
      V=SQRT(RVX**2+RVY**2)
      RE=DIA*V*RHO/VIS
      IF(RE.GT.2.0) GOTO 11
      CD=24/RE
      GOTO 15
   11 IF(RE.GT.500.0) GOTO 12
      CD=18.5/RE**.6
      GOTO 15
   12 CD=0.44
   15 DRAG=CD*A*RHO*V**2/2
      DVX=DRAG*RVX/V/W
      DVY=DRAG*RVY/V/W+980.0
      RETURN
      END
```

Figure B.2 (Continued)

```
      PROGRAM SPSCAN(INPUT,OUTPUT,TAPE9,TAPE8=/495,TAPE5=INPUT          SPSCAN 2
     1,TAPE6=OUTPUT,PUNCH,TAPE4,DEBUG=OUTPUT)                           SPSCAN 3
C                                                                       SPSCAN 4
C     PROGRAM SPSCAN IS A PROGRAM UNDER DEVELOPMENT BY THE STAFF OF THE SPSCAN 5
C     HYDROLOGIC ENGINEERING SECTION OF THE U.S. NUCLEAR REGULATORY     SPSCAN 6
C     COMMISSION FOR USE IN EVALUATING THE DESIGN BASIS METEOROLOGY OF  SPSCAN 7
C     SMALL SPRAY   PONDS USED AS THE ULTIMATE HEAT SINK OF A NUCLEAR   SPSCAN 8
C     POWER PLANT.  THE PROGRAM USES HISTORICAL WEATHER DATA PROVIDED   SPSCAN 9
C     ON TAPE BY THE NATIONAL WEATHER SERVICE AND A SIMPLIFIED POND     SPSCAN10
C     TEMPERATURE MODEL TO DETERMINE THE PERIOD OF RECORD WHICH WOULD   SPSCAN11
C     RESULT IN EITHER THE  LOWEST COOLING PERFORMANCE OR HIGHEST       SPSCAN12
C     EVAPORATIVE WATER LOSS IN A GIVEN POND.  THE USE OF THE PROGRAM   SPSCAN13
C     AND THE ANALYTICAL TECHNIQUES WHICH IT EMPLOYS ARE FULLY DESCRIBEDSPSCAN14
C     IN LITERATURE AVAILABLE THROUGH THE HYDROLOGIC ENGINEERING        SPSCAN15
C     SECTION.  ALL QUESTIONS AND COMMENTS SHOULD BE ADDRESSED TO       SPSCAN16
C     R. CODELL.                                                        SPSCAN17
C                                                                       SPSCAN18
      REAL LAT1,LAT,YRMODY(3),YRMAX(40,8)                               AUG6    1
      COMMON/COEF/ CEH(6),CEL(7),CH(6),CL(7),FEVAP,FDR,WDRO,NDRIFT,     SPSCAN20
     1 DWDR,FDRIFT(20),HEAT,CON1,CON2,CON3,DTSPRY,DTIME,QSPRAY,CON4,CON5SPSCAN21
     1 ,CEMIN,CEMAX,CMIN,CMAX                                           SPSCAN22
      LAT1=0.                                                           SPSCAN24
      WRITE(6,100)                                                      SPSCAN25
  100 FORMAT(1H1,20(/),10X,'U.S. NUCLEAR REGULATORY COMMISSION- ULTIMATESPSCAN26
     1 HEAT SINK SPRAY   POND METEOROLOGICAL SCANNING MODEL'            SPSCAN27
                                                                        SPSCAN28
      NAMELIST/INPUT/N,A,V,LAT,ISRCH,IPRNT,YRMODY                       SPSCAN29
     1 ,QSPRAY,HEAT,NDRIFT,WDRO,DWDR,FDRIFT                             SPSCAN30
     1 ,CEMIN,CEMAX,CMIN,CMAX                                           SPSCAN31
      HEAT=2.0E8                                                        SPSCAN32
      QSPRAY=50                                                         SPSCAN33
      NDRIFT=3                                                          SPSCAN34
      FDRIFT(1)=0.0                                                     SPSCAN35
      FDRIFT(2)=.00001                                                  SPSCAN36
      FDRIFT(3)=.00002                                                  SPSCAN37
      WDRO=0.0                                                          SPSCAN38
      DWDR=5.0                                                          SPSCAN39
      CMIN=0.1                                                          SPSCAN40
      CMAX=0.8                                                          SPSCAN41
      CEMIN=0.0                                                         SPSCAN42
      CEMAX=0.05                                                        SPSCAN43
      READ(5,555) CH,CL,CEH,CEL                                         SPSCAN44
  555 FORMAT(4E15.8)                                                    SPSCAN45
      DATA N,ISRCH,IPRNT/1,1,0/                                         SPSCAN46
C                                                                       SPSCAN47
C     READ DATA CARD                                                    SPSCAN48
C                                                                       SPSCAN49
    1 READ(5,INPUT)                                                     SPSCAN50
      CON4=QSPRAY*3600                                                  SPSCAN51
      CON3=62.4*3600                                                    SPSCAN52
      CON5=1/(62.4*V)                                                   SPSCAN53
      DTSPRY=HEAT/(QSPRAY*3600*62.4)                                    SPSCAN54
      IF(N.EQ.0) STOP                                                   SPSCAN55
C                                                                       SPSCAN56
C     IF THIS IS THE FIRST DATA CARD OR IF LAT HAS CHANGED, GENERATE A  SPSCAN57
C     NEW INTERMEDIATE FILE.                                            SPSCAN58
C                                                                       SPSCAN59
      IF(ABS(LAT1-LAT).GE..001) CALL SUB1(LAT)                          SPSCAN60
      LAT1=LAT                                                          SPSCAN61
      IF(N.GT.99) GO TO 4                                               SPSCAN62
      IF(V.LT.0.)V=V*(-43560.)                                          SPSCAN63
      IF(A.LT.0.)A=A*(-43560.)                                          SPSCAN64
```

Figure B.3 Listing of program SPSCAN

```
      A1=A/43560.                                                       SPSCAN65
      V1=V/43560.                                                       SPSCAN66
C                                                                       SPSCAN67
C     PRINT POND PARAMETERS.                                            SPSCAN68
C                                                                       SPSCAN69
      WRITE(6,510)N,A,A1,V,V1,ISRCH,IPRNT                               SPSCAN70
  510 FORMAT(5(/),T20,10('*'),' POND NUMBER ',I2,' HAS THE FOLLOWING PARSPSCAN71
     1AMETERS ',25('*'),//,T35,'SURFACE AREA'2X,F12.2,' FT**2 (',F9.2,  SPSCAN72
     2' ACRES)',//,T35,'VOLUME',8X,F12.2,' FT**3 (',F9.2,' ACRE-FT)',//,SPSCAN73
     3T35,'ISRCH = ',I2,T65,'IPRNT = ',I2)                              SPSCAN74
      WRITE(6,550)N                                                     SPSCAN75
  550 FORMAT(5(/),T20,10('*'),' POND NUMBER ',I2,' HAS BEEN MODELLED TO SPSCAN76
     1DETERMINE THE WORST ',13('*'),/,T38,  'PERIODS FOR COOLING AND EVASPSCAN77
     2PORATIVE WATER LOSS',/,1H1)                                       SPSCAN78
      WRITE(6,551)QSPRAY,HEAT,CEMIN,CEMAX,CMIN,CMAX                     SPSCAN79
  551 FORMAT(//,T20,10('*'),'SPRAY PARAMETERS',/,T35,'SPRAY RATE = ',   SPSCAN80
     1F10.2, ' CFS',T35,'BASE HEAT LOAD = ',E12.2,' BTU/HR',/           SPSCAN81
     2,T35,'MINIMUM EVAPORATIVE LOSS FRACTION = ',F10.6,/               SPSCAN82
     3,T35,'MAXIMUM EVAPORATIVE LOSS FRACTION = ',F10.6,/               SPSCAN83
     4,T35,'MINIMUM SPRAY EFFICIENCY = ',F10.4,/,                       SPSCAN84
     5T35,'MAXIMUM SPRAY EFFICIENCY = ',F10.4)                          SPSCAN85
      WRITE(6,552)                                                      SPSCAN86
  552 FORMAT(//,T20,10('*'),'DRIFT LOSS TABLE',//,                      SPSCAN87
     1T30,'WIND SPEED - MPH',T60,'DRIFT LOSS FRACTION')                 SPSCAN88
      DO 553 I=1,NDRIFT                                                 SPSCAN89
        WINDSP=(I-1)*DWDR+WDR0                                          SPSCAN90
  553 WRITE(6,554)WINDSP,FDRIFT(I)                                      SPSCAN91
  554 FORMAT(/,T35,F10.2,T67,F10.6)                                     SPSCAN92
C                                                                       SPSCAN93
C     MODEL TO FIND YEARLY MAXIMUM TEMPERATURES AND 30 DAY EVAPORATIVE  SPSCAN94
C     LOSSES.                                                           SPSCAN95
C                                                                       SPSCAN96
      CALL SUB2(A,V,YRMAX)                                              AUG6   2
C     RANK YEARLY MAXIMUM TEMPERATURES AND 30 DAY EVAPORATIVE LOSSES\   SPSCAN98
C     COMPUTE 100 YEAR EXCEEDENCES, SAMPLE MEANS, STANDARD DEVIATIONS,  SPSCAN99
C     AND SKEWS.                                                        SPSCA100
C                                                                       SPSCA101
      CALL SUB5(YRMAX)                                                  SPSCA102
      IF(ISRCH.LE.0.OR.ISRCH.GE.6) GO TO 1                              SPSCA103
C     PRINT AND/OR PUNCH DAILY METEOROLOGY FOR THE PERIODS OF RECORD    SPSCA104
C     PRECEEDING THE HIGHEST ISRCH POND TEMPERATURES. (ISRCH ) 6)       SPSCA105
C                                                                       SPSCA106
      DO 2 I=1,ISRCH                                                    SPSCA107
      DO 3 J=1,3                                                        SPSCA108
      J1=J+1                                                            SPSCA109
    3 YRMODY(J)=YRMAX(I,J1)                                             SPSCA110
      CALL SUB3(YRMODY,IPRNT)                                           AUG6   3
      IF(IPRNT.EQ.1) WRITE(6,520)                                       SPSCA112
  520 FORMAT(1H1)                                                       SPSCA113
    2 CONTINUE                                                          SPSCA127
      GO TO 1                                                           SPSCA128
    4 YRMODY(3)=1.                                                      SPSCA129
C                                                                       SPSCA130
C     CALCULATE AND PRINT MONTHLY AVERAGES OF EACH PARAMETER IN METABL. SPSCA131
C                                                                       SPSCA132
      CALL SUB4(YRMODY,LAT   )                                          SPSCA133
      GO TO 1                                                           SPSCA134
      END                                                               SPSCA135
      SUBROUTINE SUB1(LAT)                                              SUB1   2
C                                                                       SUB1   3
C                                                                       SUB1   4
      REAL METABL(27,10),SRAD(25),LAT                                   SUB1   5
      COMMON IDATE(3), IHOUR(6),WINDSP(6),TEMPDB(6),TEMPWB(6),TEMPDP(6),SUB1   6
     1HUMID(6),PRESSR(6),SKY(6)                                         SUB1   7
```

Figure B.3 (Continued)

```
      DATA METABL/270*0./
      DATA SRAD /25*0./
      WRITE(6,520) LAT
  520 FORMAT(5(/),T20,10('*'),' SUBROUTINE SUB1 HAS BEEN CALLED FOR LATI
     1TUDE = ',F5.2,' DEG. NORTH ',5('*'),/)
C
C     POSITION TAPE TO FIRST OF MAY.
C
      CALL READRC
      I=(121-IDATE(3))*4-2
      DO 2 J=1,I
    2 READ(8)
    3 CALL READRC
      IF(IHOUR(1).NE.0) GO TO 3
      IF(IDATE(2).LT.5) GO TO 3
C
C     READ IN FIRST 6 LINES OF DATA
C
      DO 4 I=1,6
      METABL(I,1)=IDATE(1)
      METABL(I,2)=IDATE(2)
      METABL(I,3)=IDATE(3)
      METABL(I,4)=IHOUR(I)
      METABL(I,5)=WINDSP(I)
      METABL(I,6)=TEMPDB(I)
      METABL(I,7)=TEMPDP(I)
      METABL(I,8)=SKY(I)
      METABL(I,9)=TEMPWB(I)
    4 METABL(I,10)=PRESSR(I)
C
C     MAKE SURE THAT THE FIRST LINE OF DATA IS COMPLETE.
C     IF DATA ARE MISSING, SUBSTITUTE FROM THE SECOND OR THIRD LINES
C     IF FIRST THREE LINES ARE BAD, SKIP TO THE NEXT DAY.
C
      INDEX=1
      IYR=IDATE(1)
      IMON=IDATE(2)
      IDAY=IDATE(3)
      I=1
      GO TO 6
    5 IF(I.EQ.3) GO TO 12
      I=I+1
      DO 7 J=5,10
    7 IF(METABL(1,J).GE.999.) METABL(1,J)=METABL(I,J)
    6 DO 1 J=5,10
      IF(METABL(1,J).GE.9999.) GO TO 5
    1 CONTINUE
      INDEX=2
C
C     READ IN REST OF FIRST DAY'S DATA.
C
      DO 8 K=7,19,6
      K5=K+5
      CALL READRC
      IK1=I-K+1
      DO 8 I=K,K5
      IK1=I-K+1
      METABL(I,1)=IDATE(1)
      METABL(I,2)=IDATE(2)
      METABL(I,3)=IDATE(3)
      METABL(I,4)=IHOUR(IK1)
      METABL(I,5)=WINDSP(IK1)
      METABL(I,6)=TEMPDB(IK1)
      METABL(I,7)=TEMPDP(IK1)
```

Figure B.3 (Continued).

```
      METABL(I,8)=SKY(IK1)
      METABL(I,9)=TEMPWB(IK1)
    8 METABL(I,10)=PRESSR(IK1)
      CALL READRC
      DO 9 I=1,3
      I24=I+24
      METABL(I24,1)=IDATE(1)
      METABL(I24,2)=IDATE(2)
      METABL(I24,3)=IDATE(3)
      METABL(I24,4)=IHOUR(I)
      METABL(I24,5)=WINDSP(I)
      METABL(I24,6)= TEMPDB(I)
      METABL(I24,7)=TEMPDP(I)
      METABL(I24,8)=SKY(I)
      METABL(I24,9)=TEMPWB(I)
    9 METABL(I24,10)=PRESSR(I)
      METABL(25,4)=24.
C
C     SEARCH DATA RECORD FOR MISSING DATA AND INTERPOLATE TO
C     COMPLETE RECORD.
C
      DO 10 I=1,25
      DO 10 K=5,10
      IF (METABL(I,K).LT.9999.) GO TO 10
      I1=I+1
      IF(METABL(I1,K).GE.9999.) GO TO 11
      I0=I-1
      METABL(I,K)=METABL(I1,K)-(METABL(I1,K)-METABL(I0,K))*.5
      GO TO 10
   11 I2=I+2
C
C     IF THREE OR MORE CONSECUTIVE HOURS OF DATA ARE MISSING, SKIP
C     TO THE NEXT DAY.
C
      IF(METABL(I2,K).GE.9999.) GO TO 12
      I0=I-1
      METABL(I,K)=METABL(I2,K)-(METABL(I2,K)-METABL(I0,K))*.6667
      METABL(I1,K)=METABL(I2,K)-(METABL(I2,K)-METABL(I0,K))*.3333
   10 CONTINUE
C
C     GENERATE SOLAR RADIATION TERM.
C
      CALL SOLAR(LAT,IYR,IMON,IDAY,SRAD)
C
C     APPLY CLOUD COVER ADJUSTMENT (AFTER WUNDERLICH) AND READ SOLAR RAD
C     IATION TERM INTO METABL.
C
      DO 13 I=1,25
   13 METABL(I,8)=SRAD(I)*.94*(1.-.65*METABL(I,8)**2)
C     WRITE ONE DAY'S WEATHER RECORD IN TO INTERMEDIATE STORAGE.
C
      WRITE(9) METABL
C
C     IF NEXT DAY IS FIRST OF OCTOBER,SKIP TO NEXT MAY FIRST.
C
   20 IF(METABL(26,2).LE.9) GO TO 14
C
C     SEPARATE YEARS BY BLANK DATA RECORD.
C
      DO 15 I=1,27
      DO 15 J=1,10
   15 METABL(I,J)=0.
      WRITE(9) METABL
      DO 16 I=1,847
```

Figure B.3 (Continued)

```
      READ(8)                                                           SUB1 136
C                                                                       SUB1 137
C     IF END OF RECORD ENCOUNTERED,RETURN TO MAIN PROGRAM.              SUB1 138
C                                                                       SUB1 139
      IF(EOF(8).NE.0) GO TO 17                                          SUB1 140
   16 CONTINUE                                                          SUB1 141
      GO TO 3                                                           SUB1 142
C                                                                       SUB1 143
C     READ IN NEXT DAY'S DATA.                                          SUB1 144
C                                                                       SUB1 145
   14 DO 18 I=1,3                                                       SUB1 146
      I24=I+24                                                          SUB1 147
      DO 18 K=1,10                                                      SUB1 148
   18 METABL(I,K)=METABL(I24,K)                                         SUB1 149
      METABL(1,4)=0.                                                    SUB1 150
      DO 19 I=4,6                                                       SUB1 151
      METABL(I,1)=IDATE(1)                                              SUB1 152
      METABL(I,2)=IDATE(2)                                              SUB1 153
      METABL(I,3)=IDATE(3)                                              SUB1 154
      METABL(I,4)=IHOUR(I)                                              SUB1 155
      METABL(I,5)=WINDSP(I)                                             SUB1 156
      METABL(I,6)=TEMPDB(I)                                             SUB1 157
      METABL(I,7)=TEMPDP(I)                                             SUB1 158
      METABL(I,8)=SKY(I)                                                SUB1 159
      METABL(I,9)=TEMPWB(I)                                             SUB1 160
   19 METABL(I,10)=PRESSR(I)                                            SUB1 161
      INDEX=1                                                           SUB1 162
      IYR=IDATE(1)                                                      SUB1 163
      IMON=IDATE(2)                                                     SUB1 164
      IDAY=IDATE(3)                                                     SUB1 165
      I=1                                                               SUB1 166
      GO TO 6                                                           SUB1 167
C                                                                       SUB1 168
C     WRITE ERROR MESSAGE WHEN DATA ARE SKIPPED                         SUB1 169
C                                                                       SUB1 170
   12 WRITE(6,500) IMON,IDAY,IYR                                        SUB1 171
  500 FORMAT(T35,'DISCONTINUITY IN DATA CAUSED ',I2,'/',I2,'/',I2,' TO BSUB1 172
     1E SKIPPED')                                                       SUB1 173
C                                                                       SUB1 174
C     FLAG RECORD CONTAINING BAD DATA.                                  SUB1 175
C                                                                       SUB1 176
      METABL(2,1)=9999.                                                 SUB1 177
      WRITE(9) METABL                                                   SUB1 178
      GO TO (3,20),INDEX                                                SUB1 179
   17 REWIND 9                                                          SUB1 180
      REWIND 8                                                          SUB1 181
      RETURN                                                            SUB1 182
      END                                                               SUB1 183
      SUBROUTINE SUB2(A,V,YRMAX)                                        AUG6   4
C   IMPROVED VERSION OF NUTTLE PROGRAM USING 2ND ORDER RK               SUB2   3
C   R CODELL,SEPT 19,1979                                               SUB2   4
C                                                                       SUB2   5
C     MODELS POND TEMPERATURE RESPONSE USING DATA IN INTERMEDIATE       SUB2   6
C     STORAGE.  RETURNS YEARLY MAXIMUM TEMPERATURES AND 30 DAY EVAPOR-  SUB2   7
C     ATIVE LOSSES WITH THEIR DATES OF OCCURENCE.                       SUB2   8
C                                                                       SUB2   9
      COMMON/COEF/ CEH(6),CEL(7),CH(6),CL(7),FEVAP,FDR,WDRO,NDRIFT,     SUB2  10
     1 DWDR,FDRIFT(20),HEAT,CON1,CON2,CON3,DTSPRY,DTIME,QSPRAY,CON4,CON5SUB2  11
     1 ,CEMIN,CEMAX,CMIN,CMAX                                           SUB2  12
      REAL ABSMAX(4),METABL(27,10),SRAD(25),TEMPDB(25),                 AUG6   5
     1TEMPDP(25),WINDSP(25),KN(4),EV(4),EVAP(30),TEMPMX(5)              SUB2  14
     2,EVPMAX(4),YRMAX(40,8),MAXT                                       AUG6   6
      DIMENSION TEMPWB(25),PRESSR(25)                                   SUB2  16
      DATA DT02,DT06,DT/.5,.16666667,1.0/                               SUB2  17
      DO 39 I=1,40                                                      SUB2  18
```

Figure B.3 (Continued)

```
      DO 39 J=1,8                                                        SUB2  19
   39 YRMAX(I,J)=0.                                                      SUB2  20
      CON1=A/(62.4*24*V)                                                 SUB2  21
      CON2=A/(62.4*1040*24)                                              SUB2  22
      LNDX=0                                                             SUB2  23
      MAXT=0.                                                            AUG6   7
      ABSMAX(1)=0.                                                       SUB2  29
      EVPMAX(1)=0.                                                       SUB2  30
      TEMPMX(1)=0.                                                       SUB2  31
      EVTOT=0.                                                           SUB2  32
   10 READ(9) METABL                                                     SUB2  33
      IF(EOF(9).NE.0) GO TO 12                                           SUB2  34
      IF(METABL(2,1).GE.9999.) GO TO 10                                  SUB2  35
      PONDTP=METABL(1,7)                                                 SUB2  36
      DO 30 I=1,30                                                       SUB2  37
   30 EVAP(I)=0                                                          SUB2  38
    1 CONTINUE                                                           SUB2  39
      DO 131 J=1,25                                                      SUB2  40
      SRAD(J)=METABL(J,8)                                                SUB2  41
      TEMPDB(J)=METABL(J,6)                                              SUB2  42
      TEMPDP(J)=METABL(J,7)                                              SUB2  43
      WINDSP(J)=METABL(J,5)                                              SUB2  44
      TEMPWB(J)=METABL(J,9)                                              SUB2  45
      PRESSR(J)=METABL(J,10)                                             SUB2  46
  131 CONTINUE                                                           SUB2  47
      DO 132 J=1,24                                                      SUB2  48
      JP1=J+1                                                            SUB2  49
C                                                                        SUB2  50
C     CALCULATION OF POND TEMPERATURE AND EVAPORATIVE WATER LOSS USING   SUB2  51
C     THE LINEAR HEAT EXCHANGE EQUATIONS IN A SECOND ORDER RUNGE-KUTTA   SUB2  52
C     NUMERICAL INTEGRATION.                                             SUB2  53
C                                                                        SUB2  54
      CALL TFUN(PONDTP,TEMPDB(J),WINDSP(J),SRAD(J),TEMPDP(J),            SUB2  55
     1 KN(1),EV(1),TEMPWB(J) ,PRESSR(J))                                 SUB2  56
      PTP1=PONDTP+KN(1)*DT                                               SUB2  57
      CALL TFUN(PTP1,TEMPDB(JP1),WINDSP(JP1),SRAD(JP1),TEMPDP(JP1),      SUB2  58
     1 KN(2),EV(2),TEMPWB(JP1),PRESSR(JP1))                              SUB2  59
      PONDTP=PONDTP+(KN(1)+KN(2))*DTO2                                   SUB2  60
      EVAP(1)=EVAP(1)+(EV(1)+EV(2))*DTO2                                 SUB2  61
C                                                                        SUB2  62
C     COLLECT MAXIMUM TEMPERATURE                                        SUB2  63
C                                                                        SUB2  64
      IF(PONDTP.GT.MAXT) MAXT=PONDTP                                     AUG6   8
  132 CONTINUE                                                           SUB2  66
C                                                                        SUB2  67
C     SEARCH FOR YEARLY MAXIMUM TEMPERATURE AND EVAPORATIVE WATER LOSS.  SUB2  68
C                                                                        SUB2  69
      DO 33 I=1,30                                                       SUB2  70
   33 EVTOT=EVTOT+EVAP(I)                                                SUB2  71
      IF(EVTOT.LT.EVPMAX(1))GO TO 13                                     SUB2  72
      EVPMAX(1)=EVTOT                                                    SUB2  73
      EVPMAX(2)=METABL(1,1)                                              SUB2  74
      EVPMAX(3)=METABL(1,2)                                              SUB2  75
      EVPMAX(4)=METABL(1,3)                                              SUB2  76
   13 DO 29 I=1,29                                                       SUB2  77
      I30=30-I                                                           SUB2  78
      I1=I30+1                                                           SUB2  79
   29 EVAP(I1)=EVAP(I30)                                                 SUB2  80
      EVAP(1)=0.                                                         SUB2  81
      EVTOT=0.                                                           SUB2  82
      IF(MAXT.LT.ABSMAX(1)) GO TO 8                                      AUG6   9
      ABSMAX(1)=MAXT                                                     AUG6  10
      ABSMAX(2)=METABL(1,1)                                              SUB2  85
      ABSMAX(3)=METABL(1,2)                                              SUB2  86
      ABSMAX(4)=METABL(1,3)                                              SUB2  87
```

Figure B.3 (Continued)

```
    8 MAXT=0.0                                                          AUG6  11
C                                                                       SUB2  92
C     READ IN NEXT DAY'S DATA.                                          SUB2  93
C                                                                       SUB2  94
   11 READ(9) METABL                                                    SUB2  95
      IF(EOF(9).NE.0.0) GOTO 12                                         SUB2  96
      IF(METABL(1,1).GT.0.) GO TO 14                                    SUB2  97
      LNDX=LNDX+1                                                       SUB2  98
      YRMAX(LNDX,1)=ABSMAX(1)                                           SUB2  99
      YRMAX(LNDX,2)=ABSMAX(2)                                           SUB2 100
      YRMAX(LNDX,3)=ABSMAX(3)                                           SUB2 101
      YRMAX(LNDX,4)=ABSMAX(4)                                           SUB2 102
      YRMAX(LNDX,5)=EVPMAX(1)                                           SUB2 103
      YRMAX(LNDX,6)=EVPMAX(2)                                           SUB2 104
      YRMAX(LNDX,7)=EVPMAX(3)                                           SUB2 105
      YRMAX(LNDX,8)=EVPMAX(4)                                           SUB2 106
      DO 15 I=1,5                                                       SUB2 107
      IF(ABSMAX(1).GE.TEMPMX(1))GO TO 16                                SUB2 108
   15 CONTINUE                                                          SUB2 109
      GO TO 20                                                          SUB2 110
   16 IF(I.GE.5) GO TO 17                                               SUB2 111
      I5=5-I                                                            SUB2 112
      DO 18 J=1,I5                                                      SUB2 113
      L=5-J                                                             SUB2 114
      L1=L+1                                                            SUB2 115
   18 TEMPMX(L1)=TEMPMX(L)                                              SUB2 116
   17 TEMPMX(I)=ABSMAX(1)                                               SUB2 119
   20 ABSMAX(1)=0.                                                      SUB2 122
      EVPMAX(1)=0.                                                      SUB2 123
      MAXT=0.0                                                          AUG6  12
      GO TO 10                                                          SUB2 126
   14 IF(METABL(2,1).LT.9999.) GO TO 1                                  SUB2 127
      MAXT=0.0                                                          AUG6  13
      GO TO 11                                                          SUB2 132
C                                                                       SUB2 133
C     END OF DATA FILE ENCOUNTERED. RETURN TO MAIN PROGRAM.             SUB2 134
C                                                                       SUB2 135
   12 REWIND 9                                                          SUB2 136
      RETURN                                                            SUB2 137
      END                                                               SUB2 138
      SUBROUTINE TFUN(PT,DB,W,SRAD,DP,DT,DE,TW,PINCH)                   TFUN   2
      COMMON/COEF/ CEH(6),CEL(7),CH(6),CL(7),FEVAP,FDR,WDRO,NDRIFT,     TFUN   3
     1 DWOR,FDRIFT(20),HEAT,CON1,CON2,CON3,DTSPRY,DTIME,QSPRAY,CON4,CON5TFUN   4
     1 ,CEMIN,CEMAX,CMIN,CMAX                                           TFUN   5
C    CONVERT PRESSURE TO MM HG                                          TFUN   6
      PAIR=PINCH*25.40                                                  TFUN   7
C     SPRAY HEAT TRANSFER AND WATER LOSS                                TFUN   8
      TSPRAY=PT+DTSPRY                                                  TFUN   9
C     HWS EFFICIENCY                                                    TFUN  10
      ETA=CH(1)+CH(2)*DB+CH(3)*TW+CH(4)*TSPRAY+CH(5)*W+CH(6)*SQRT(W)    TFUN  11
C     LWS EFFICIENCY                                                    TFUN  12
      EL=CL(1)+CL(2)*DB+CL(3)*DB**2+CL(4)*DB**3+CL(5)*TW+               TFUN  13
     1 CL(6)*TSPRAY+CL(7)*TSPRAY**2                                     TFUN  14
      IF(ETA.LT.EL) ETA=EL                                              TFUN  15
      IF(ETA.LT.CMIN) ETA=CMIN                                          TFUN  16
      IF(ETA.GT.CMAX) ETA=CMAX                                          TFUN  17
C     SPRAY HEAT LOSS                                                   TFUN  18
      HSPRAY=HEAT-QSPRAY*CON3*ETA*(TSPRAY-TW)                           TFUN  19
      IF(ETA.EQ.EL) GOTO 3                                              TFUN  20
C     HIGH WIND SPEED EVAPORATION                                       TFUN  21
      FEVAP=CEH(1)+CEH(2)*DB+CEH(3)*TW+CEH(4)*TSPRAY+                   TFUN  22
     1 CEH(5)*W+CEH(6)*SQRT(W)                                          TFUN  23
      GOTO 4                                                            TFUN  24
C     LOW WIND SPEED EVAPORATION                                        TFUN  25
    3 FEVAP=CEL(1)+CEL(2)*DB+CEL(3)*DB**2+CEL(4)*DB**3+CEL(5)*TW        TFUN  26
```

Figure B.3 (Continued)

```
     1 +CEL(6)*TSPRAY+CEL(7)*TSPRAY**2
C       DRIFT LOSS
    4 NTBL=(W-WDR0)/DWDR+1
      IF(NTBL.GE.NDRIFT) NTBL=NDRIFT-1
      FDR=FDRIFT(NTBL)+((W-WDR0-(NTBL-1)*DWDR)/DWDR)*
     1 (FDRIFT(NTBL+1)-FDRIFT(NTBL))
      IF(FEVAP.LT.CEMIN) FEVAP=CEMIN
      IF(FEVAP.GT.CEMAX) FEVAP=CEMAX
      ESPRAY=(FDR+FEVAP)*CON4
C     SURFACE HEAT TRANSFER AND EVAPORATION FROM RYAN,1973
      DTV=(PT+460)/(1-.378*PWAT(PT)/PAIR)-
     1 (DB+460)/(1-.378*PWAT(DP)/PAIR)
      DTV3=0
      IF(DTV.LE.0.0) GOTO 1500
      DTV3=DTV**0.33333333
 1500 FU=(22.4*DTV3+14*W)
      HC=0.26*(PT-DB)*FU
      HBR=4.026E-8*(460+PT)**4
      HE=(PWAT(PT)-PWAT(DP))*FU
      HAN=1.16E-13*(DB+460)**6*(1-CC**2*.17)
C    CONSERVATIVE ASSUMPTION NO CLOUDS
      DATA CC/0.0/
      HR=SRAD-HC+HAN-HBR-HE
      DT=HSPRAY*CON5+HR*CON1
      DE=HE*CON2+ESPRAY
      RETURN
      END
      FUNCTION PWAT(T)
C     VAPOR PRESSURE OF AIR IN MM HG FOR T IN DEG.F
      TK=(T-32)/1.8+273.1
      PWAT=760*EXP(71.02499-7381.6677/TK-9.0993037*ALOG(TK)
     1 +.0070831558*TK)
      RETURN
      END
      SUBROUTINE SUB3(YRMODY,IPRNT)
C
C    PRINTS AND/OR PRNCHES DATA FROM INTERMEDIATE
C    FILE FOR PERIOD OF #NDYS# DAYS BEFORE AND 30
C    DAYS FOLLOWING YRMODY.
C
C        IF IPRINT=1,DATA IS PRINTED
C        IF IPRINT=-1, DATA IS PUNCHED
C        IF IPRINT=0, DATA IS BOTH PRINTED AND PUNCHED
C
      REAL YRMODY(3),METABL(27,10),JNDX
      INTEGER IDATE(3)
      N=0
      DATA NDYS/20/
      JNDX=0.
       IPNCH=0
      IF(IPRNT.EQ.1) GO TO 40
      IF(IPRNT.EQ.0) IPRNT=1
      IPNCH=1
   40 CONTINUE
C
C    POSITION TAPE9 TO #NDYS# DAYS BEFORE DATE
C     PROVIDED IN YRMODY.  IF DATA IS NOT AVAILABLE,
C     POSITION TAPE9 TO FIRST DAY OF DATA IN THE
C     SAME YEAR AS YRMODY.
C
      READ(9) METABL
      YR=METABL(1,1)
      REWIND 9
      IF (YRMODY(1).LE.YR) GO TO 1
      N=(YRMODY(1)-YR)*154.
```

Figure B.3 (Continued).

```
      DO 2 I=1,N                                                        AUG6  45
    2 READ(9) METABL                                                    AUG6  46
      N=0                                                               AUG6  47
    1 IF (YRMODY(2).LE.5.)GO TO 3                                       AUG6  48
      N=((YRMODY(2)-5.)*31.)                                            AUG6  49
      IF(YRMODY(2).GT.6.)N=N-1                                          AUG6  50
    3 CONTINUE                                                          AUG6  51
      N=YRMODY(3)+N-NDYS                                                AUG6  52
      IF(N.GT.0)GO TO 4                                                 AUG6  53
      NDYS=NDYS+N                                                       AUG6  54
      GO TO 6                                                           AUG6  55
    4 DO 5 I=1,N                                                        AUG6  56
    5 READ(9) METABL                                                    AUG6  57
    6 CONTINUE                                                          AUG6  58
      NDYS6=NDYS+30                                                     AUG6  59
      N=0                                                               AUG6  60
C                                                                       AUG6  61
C   GENERATE OUTPUT                                                     AUG6  62
C                                                                       AUG6  63
      DO 35 I=1,NDYS6                                                   AUG6  64
      READ(9)METABL                                                     AUG6  65
      IF(METABL(2,1).GE.9999.)GO TO 35                                  AUG6  66
      IF(IPNCH.NE.1) GO TO 41                                           AUG6  67
      IF(I.EQ.1) PUNCH(4,610)NDYS6,METABL(1,2),METABL(1,3),METABL(1,1)  AUG6  68
  610 FORMAT('** APPROXIMATELY ',I2,' DAYS OF MET. DATA FOLLOW. DATA AREAUG6  69
     1PUNCHED 2 HOURS TO A',/,'**** CARD BEGINNING WITH HOUR 0 ON',3F3  AUG6  70
     2.0,'  THE FORMAT FOR THE DATA IS I3,2(',/,'****3F5.1,F6.1,F4.2,F4 AUG6  71
     2.0)WHERE FIELD 1 IS THE CARD NUMBER AND THE FOLLOWING',/,'****VA  AUG6  72
     3RIABLE SEQUENCE IS REPEATED:WIND SPEED,DRY BULB,DEWPOINT,SOLAR RA AUG6  73
     5D-',/,'****IATION,CLOUD COVER,AND RELATIVE HUMIDITY.')            AUG6  74
      DO 42 L=1,23,2                                                    SUB3  41
      L1=L+1                                                            SUB3  42
      N=N+1                                                             SUB3  43
   42 WRITE(4,590)N,((METABL(J,K),K=5,10),J=L,L1)                       SUB3  44
  590 FORMAT (I3,2(3F5.1,F6.1,F7.2,F7.2))                               SUB3  45
      IF(IPRNT.NE.1) GO TO 35                                           SUB3  46
   41 CONTINUE                                                          SUB3  47
      IDATE(1)=METABL(1,2)                                              SUB3  48
      IDATE(2)=METABL(1,3)                                              SUB3  49
      IDATE(3)=METABL(1,1)                                              SUB3  50
      WRITE(6,500) IDATE                                                SUB3  51
      DO 39 J=1,24                                                      SUB3  52
   39 WRITE(6,520)(METABL(J,K),K=4,10)                                  SUB3  53
      WRITE(6,510)                                                      SUB3  54
  500 FORMAT(1H1,5(/),T20,10('*'),' METEOROLOGY FOR '2(I2,'/'),I2,44('*'SUB3  55
     1),///,T25,71('.'),/,T25,',  HOUR   , WIND SP.,DRY BULB ,DEWPOINT ,SUB3  56
     2SOLAR RAD WET BULB ,ATM.PRESS,',/,T25,',',T35,',  (MPH)  , (DEG.F)SUB3  57
     3 , (DEG.F) ,BTU/FT2/D, (DEG.F) ,  PSIA   ,',/,T25,71('.'))        SUB3  58
  510 FORMAT(T25,71('.'))                                               SUB3  59
  520 FORMAT(T25,',',3X,F3.0,3X,',',2X,F4.1,3X,',',2X,F5.1,2X,',',2X,   SUB3  60
     1F5.1,2X,',',2X,F6.1,1X,',',F7.2,2X,',',F7.2,2X,',')               SUB3  61
   35 CONTINUE                                                          SUB3  62
      IF(IPNCH.EQ.1) WRITE(6,600)N                                      SUB3  94
  600 FORMAT(1H1,5(/),T20,10('*'),'NUMBER OF CARDS PUNCHED = ',I3,' ',  SUB3  95
     140('*'))                                                          SUB3  96
      REWIND 9                                                          SUB3  97
      RETURN                                                            SUB3  98
      END                                                               SUB3 103
      SUBROUTINE SUB4(YRMODY,LAT)                                       SUB4   2
C                                                                       SUB4   3
C     PRINTS OUT AVERAGE MONTHLY VALUES FOR METEOROLOGIC PARAMETERS     SUB4   4
C     BEGINNING WITH DATE GIVEN IN YRMODY AND ENDING WITH THE LAST      SUB4   5
C     DAY ON THE DATA TAPE.                                             SUB4   6
C                                                                       SUB4   7
```

Figure B.3 (Continued)

```
      REAL YRMODY(3),METABL(27,10),LAT
      INTEGER IDATE(3),MON(5),MONTH(5)
      DATA MON/121,152,182,213,244/
      DATA MONTH/'MAY','JUNE','JULY','AUGUST','SEPTEMBER'/
      INDX=0
      WINDSP=0.
      TEMPDP=0.
      TEMPDB=0.
      SOLARD=0.
      IDATE(1)=YRMODY(2)
      PRESSR=0.0
      TWET=0.0
      IDATE(2)=YRMODY(3)
      IDATE(3)=YRMODY(1)
      WRITE(6,500) IDATE
  500 FORMAT(    5(/),T20,10('*'),' THE MONTHLY AVERAGE VALUES FROM',
     12(I2,'/'),I2,' TO END OF DATA ',13('*'),//)
      WRITE(6,510)
  510 FORMAT(T30,61('.'),/,T30'*RMS WIND *DRY BULB *DEWPOINT *  SOLAR  *
     1WET BULB *ATM.PRESS*',/,T30,'*  SPEED  * (DEG.F) * (DEG.F) *RADIAT
     2ION* (DEG.F) *  PSIG   *')
      IYR=1900+IDATE(3)
      WRITE(6,520) IYR
  520 FORMAT(T20,I4,T30,61('.'),/,T30,'*',T40,'*',T50,'*',T60,'*',T70,
     1'*',T80,'*',T90,'*')
C
C     POSITION TAPE9 TO FIRST DAY OF MONTH PROVIDED IN YRMODY.
C
      READ(9) METABL
      YR=METABL(1,1)
      REWIND 9
      IF(YRMODY(1).LE.YR) GO TO 1
      N=(YRMODY(1)-YR)*154.+1.
      DO 2 I=1,N
    2 READ(9)METABL
    1 N=((YRMODY(2)-5.)*31.)
      IF(N.LE.0) GO TO 6
      DO 4 I=1,N
    4 READ(9) METABL
    6 IF(METABL(1,3).LE.1.) GO TO 5
      BACKSPACE 9
      READ(9)METABL
      GO TO 6
    5 IF(METABL(2,1).GE.9999.) GO TO 9
C
C     READ IN ONE MONTH'S DATA
C
    8 INDX=INDX+1
      IDATE(1)=METABL(1,2)
      IDATE(2)=METABL(1,3)
      IDATE(3)=METABL(1,1)
      DAYNUM=MON(IDATE(1)-4)+IDATE(2)-1
      IF(MOD(IDATE(3),4).EQ.0) DAYNUM=DAYNUM+1.
      DAYLEN=DAYLIT(LAT,DAYNUM)
      DO 7 I=1,24
      WINDSP=METABL(I,5)**2+WINDSP
      TEMPDB=METABL(I,6)+TEMPDB
      TEMPDP=METABL(I,7)+TEMPDP
      TWET=METABL(I,9)+TWET
      PRESSR=METABL(I,10)+PRESSR
    7 SOLARD=SOLARD+METABL(I,8)/DAYLEN
    9 READ (9) METABL
      IF(METABL(1,1).LE.0.) GO TO 11
```

Figure B.3 (Continued)

```
      IF(METABL(1,3).LE.1.) GO TO 10
      IF(METABL(2,1).GE.9999.) GO TO 9
      GO TO 8
   10 DAYS=INDX
C
C     CALCULATE AND PRINT AVERAGES
C
      INDX=0
      AVGWS=(WINDSP/DAYS/24.)**.5
      AVGDP=TEMPDP/DAYS /24.
      AVGDB=TEMPDB/DAYS/24.
      AVWET=TWET/DAYS/24
      AVPR=PRESSR/DAYS/24
      AVGSR=SOLARD/DAYS
      I=IDATE(1)-4
      WRITE(6,530) MONTH(I),AVGWS,AVGDB,AVGDP,AVGSR,AVWET,AVPR
  530 FORMAT(T20,A10,'*',2X,F5.2,2X,'*',2X,F5.2,2X,'*',2X,F5.2,2X,'*',1X
     1,F6.1,2X,'*',F6.2,3X,'*',F6.2,3X,'*',/,T30,'*',T40,'*',T50,
     3'*',T60,'*',T70,'*',T80,'*',T90,'*')
      WINDSP=0.
      TEMPDB=0.
      TWET=0.0
      TEMPDP=0.0
      PRESSR=0.0
      SOLARD=0.
      GO TO 5
   11 DAYS=INDX
C
C     CALCULATE AND PRINT AVERAGES FOR THE LAST MONTH OF EACH DATA
C     PERIOD
C
      INDX=0
      AVGWS=(WINDSP/DAYS/24.)**.5
      AVGDP=TEMPDP/DAYS/24.
      AVGDB=TEMPDB/DAYS/24.
      AVPR=PRESSR/DAYS/24
      AVWET=TWET/DAYS/24
      AVGSR=SOLARD/DAYS
      WRITE(6,530) MONTH(5),AVGWS,AVGDB,AVGDP,AVGSR,AVWET,AVPR
      WINDSP=0.
      TEMPDB=0.
      TEMPDP=0.
      SOLARD=0.
      PRESSR=0.0
      TWET=0.0
      READ (9) METABL
      IF(EOF(9).NE.0) GO TO 12
      IYR=1900+METABL(1,1)
      WRITE(6,520) IYR
      IF(METABL(2,1).GE.9999.) GO TO 9
      GO TO 8
   12 WRITE(6,540)
  540 FORMAT(T30,61('.'))
      RETURN
      END
      SUBROUTINE SUB5(YRMAX)
C
C     COMPUTES SAMPLE MEAN, STANDARD DEVIATION,SKEW, AND EXCEEDENCE FOR
C     YEARLY MAXIMUM TEMPERATURES AND WATER LOSSES GENERATED BY SUB2
C
      REAL YRMAX(40,8),JUNK(4),P(40),MT,ME
      SUMT=0.
      SUMT2=0.
      SUMT3=0.
```

Figure B.3 (Continued)

```
      SUME=0.
      SUME2=0.
      SUME3=0.
      DO 20 L=1,40
      IF(YRMAX(L,1).LE.0.) GO TO 21
   20 CONTINUE
      L=L+1
   21 L=L-1
C
C     RANK DATA IN ORDER OF DECREASING MAGNITUDE
C
      DO 1 J=1,5,4
      DO 1 I=2,L
      I1=I-1
      IF(YRMAX(I,J).LE.YRMAX(I1,J)) GO TO 1
      DO 2 M=1,4
      MJ=M+J-1
    2 JUNK(M)=YRMAX(I,MJ)
      DO 3 M=1,I
      IF(JUNK(1).GT.YRMAX(M,J)) GO TO 4
    3 CONTINUE
    4 DO 5 K=M,I1
      KM=I-K+M
      KM1=KM-1
      DO 5 L2=1,4
      LJ=L2+J-1
    5 YRMAX(KM,LJ)=YRMAX(KM1,LJ)
      DO 6 L2=1,4
      LJ=L2+J-1
    6 YRMAX(M,LJ)=JUNK(L2)
    1 CONTINUE
C
C     COMPUTE EXCEEDENCES
C
      RL=L
      P(1)=(1.-(.5)**(1./RL))*100.
      X=2.*(50.-P(1))/(RL-1.)
      DO 7 I=2,L
      I1=I-1
    7 P(I)=P(I1)+X
      DO 22 I=1,L
      SUMT=SUMT+YRMAX(I,1)
      SUMT2=SUMT2+YRMAX(I,1)**2
      SUMT3=SUMT3+YRMAX(I,1)**3
      SUME=SUME+YRMAX(I,5)
      SUME2=SUME2+YRMAX(I,5)**2
   22 SUME3=SUME3+YRMAX(I,5)**3
      MT=SUMT/RL
      ST=SQRT((SUMT2-(SUMT**2/RL))/(RL-1.))
      GT=(RL**2*SUMT3-3.*RL*SUMT*SUMT2+2.*SUMT**3)/(ST**3*RL*(RL-1.)*
     1(RL-2.))
      ME=SUME/RL
      SE=SQRT((SUME2-(SUME**2/RL))/(RL-1.))
      WRITE(6,530)
  530 FORMAT(////)
      WRITE(6,500)
  500 FORMAT(T20,10('*'),'THE SAMPLE OF YEARLY MAXIMUM POND TEMPERATURES
     1 AND 30 DAY  ', 10('*'),/,T31,'EVAPORATIVE LOSSES GENERATED BY THI
     2S MODEL IS DESCRIBED BELOW.',///,T28,10('.'),'TEMPERATURE',19('.')
     3,'EVAPORATIVE LOSS',9('.'),/,T28,'*EXCEEDED',15X,  'DATE     *EXCEE
     4DED',15X,'DATE    *',/, T28,'*/100 YR*  (DEG.F)  *(YR.MO.DY.)*/100
     5 YR*   FT**3   *(YR.MO.DY.)*',/,T28,65('.'))
      DO 10 I=1,L
   10 WRITE(6,510) P(I),(YRMAX(I,J),J=1,4),P(I),(YRMAX(I,K),K=5,8)
```

Figure B.3 (Continued)

```
  510 FORMAT(T28,'*',1X,F5.2,1X,'*',3X,F5.2,3X,'*',1X,3F3.0,1X,'*',1X,
     2F5.2,1X,'*',1X,F9.1,1X,'*',1X,3F3.0,1X,'*')
      WRITE(6,520) MT,ME,ST,SE
  520 FORMAT(T28,65('.'),//,T26,'MEAN',T40,F5.2,T70,F9.1,//,T17,
     1 'STANDARD DEV.',T40,F6.3,T70,F10.2)
      VART=ST**2
      VARE=SE**2
      WRITE(6,600)
      CALL EXTREM(MT,VART,L)
      WRITE(6,601)
      CALL EXTREM(ME,VARE,L)
  601 FORMAT(///,35X,'PREDICTED VALUES AND CONFIDENCE LIMITS ON '/,
     1 35X,'30 DAY EVAPORATION, FT**3'/)
  600 FORMAT(///,35X,'PREDICTED VALUES AND CONFIDENCE LIMITS ON '/,
     1 35X,'PEAK TEMPERATURE, DEG.F',/)
      RETURN
      END
      SUBROUTINE EXTREM(MU,V,N)
C     THIS PROGRAM COMPUTES THE NECESSARY POINTS FOR CONSTRUCTING A
C     MAXIMUM LIKELIHOOD FREQUENCY CURVE WITH UPPER AND LOWER ERROR BANDS
          REAL EXCD(20),EXHAT(20),TEX(20),SEXC(20),LEX(20),UEX(20)
      REAL MU
C     MU= MEAN VALUE
C     V= VARIENCE
C     N= SAMPLE SIZE
C     ALPHA= CONFIDENCE LEVEL FOR ERROR BANDS
C             E.G., FOR 5 PER CENT AND 95 PER CENT
C             ERROR BANDS ALPHA = .95
      ALPHA=0.95
      NDF=N-1
      DATA EXCD/.001,.005,.01,.02,.05,.1,.2,.3,.4,.6,.7,.8,
     1 .9,.95,.98,.99,.995,.999/
      DATA M/18/
          DO 18 I=1,M
          PC=EXCD(I)*2.0
          IF(EXCD(I).GT..5) PC=(1.0-EXCD(I))*2.0
          TEX(I)=STUDIN(PC,NDF)
          IF(EXCD(I).GT..5) TEX(T)=-TEX(I)
   18 CONTINUE
C     COMPUTE EXPECTED VALUE LINE
          DO 21 T=1,M
          EXHAT(I)=MU+TEX(I)*SQRT(V)
   21     SEXC(I)=SQRT(V*(1.0+.5*TEX(T)**2)/N)
C
C     COMPUTE UPPER AND LOWER ERROR BANDS
C
   29     ALPHA=(1.0-ALPHA)*2.0
          TA=STUDIN(ALPHA,NDF)
          DO 31 I=1,M
          LEX(I)=EXHAT(I)-SEXC(I)*TA
   31     UEX(I)=EXHAT(I)+SEXC(T)*TA
      WRITE(6,200)
  200 FORMAT(T29,'EXCEEDED',T46,'PREDICTED',T63,'5 PERCENT',
     1 T81,'95 PERCENT'/,T28,'PER 100 YR',T47,'VALUE',T63,'CONFIDENCE',
     2 T81,'CONFIDENCE',/)
          DO 60 I=1,M
      EXCP=EXCD(I)*100.0
   60     WRITE(6,105) EXCP   ,EXHAT(I),LEX(I),UEX(I)
  105 FORMAT(1H ,15X,F20.3,3F18.3)
   50     CONTINUE
      RETURN
          END
```

Figure B.3 (Continued)

```
            FUNCTION STUDIN(ALPHA,N)
C
C        THIS FUNCTION COMPUTES THE UPPER ALPHA/2 PERCENTILE
C        POINT FOR A STUDENT'S T DISTRIBUTION WITH N DEGREES OF FREEDOM
C
         N1=1
         N2=N
         STUDIN=SQRT(FISHIN(ALPHA,N1,N2))
            RETURN
            END
            FUNCTION FISHIN(ALPHA,N1,N2)
C
C        THIS FUNCTION COMPUTES THE ALPHA PERCENTILE POINT FOR
C        FISHER'S F DISTRIBUTION WITH N1 AND N2 DEGREES OF FREEDOM
C
            Y1=N1
            Y2=N2
            IF(N1.EQ.1) Y1=2
            IF(N2.EQ.1) Y2=2
            X=TINORM(1.0-ALPHA)
            Y=(X**2-3.0)/6.0
            IC=0
            Y1=1.0/(Y1-1.0)
            Y2=1.0/(Y2-1.0)
            H=2.0/(Y1+Y2)
            X=X*SQRT(H+Y)/H-(Y1-Y2)*(Y+5.0/6.0-2.0/(3.0*H))
            X=EXP(2.0*X)
            G=1.0
            IB1=2
            IF(MOD(N1,2).EQ.0) GO TO 1
            G=1.7724539
            IB1=1
    1       IB2=2
            IF(MOD(N2,2).EQ.0) GO TO 2
            G=G*1.7724539
            IB2=1
    2       IB3=2
            IF(MOD(N1+N2,2).EQ.0) GO TO 3
            G=G/1.7724539
            IB3=1
    3       IF((IB1+IB2).NE.2) G=G*2.0
            IF((N1+N2).LE.3) GO TO 5
            ND=N1+N2-2-IB3
         NDP1=ND+1
         DO 4 II=1,NDP1,2
         I=II-1
            IF((IB1+I).LE.(N1-2)) G=G*(IB1+I)
            IF((IB2+I).LE.(N2-2)) G=G*(IB2+I)
    4       G=G/(IB3+I)
    5       Y2=N2/(N2+N1*X)
            Y1=1.0-Y2
            Y=1.0+(G*(1.0-ALPHA-FISH(X,N1,N2)))/SQRT(Y1**N1*Y2**N2)
            FISHIN=X*Y
            IF(Y.LT.0)FISHIN=.5*X
            IF(ABS(X/FISHIN-1.0).LT.(.5E-6)) GO TO 7
            IF(ABS(X-FISHIN).LT.(.5E-6)) GO TO 7
            IC=IC+1
            IF(IC.GT.100) GO TO 7
            X=FISHIN
            GO TO 5
    7       RETURN
            END
            FUNCTION TINORM(ALPHA)
```

Figure B.3 (Continued)

```
C                                                                       STAT1121
C     THIS FUNCTION COMPUTES THE ALPHA PERCENTILE FOR THE NORMAL DISTRIBSTAT1122
C                                                                       STAT1123
         DIMENSION A(3),B(3)                                            STAT1124
         DATA A/.010328,.802853,2.515517/, B/.001308,                   STAT1125
     1 .189269,1.432788/                                                STAT1126
         X=ALPHA                                                        STAT1127
         IF(X) 4,4,1                                                    STAT1128
    1 IF(X-1.0) 2,4,4                                                   STAT1129
    2 IF(X.GT.0.5) X=1.0-X                                              STAT1130
         X=SQRT(-2.0*ALOG(X))                                           STAT1131
         TINORN=X-(A(3)+X*(A(2)+X*A(1)))/(1.0+X*(B(3)+X*(B(2)+X*B(1))))STAT1132
         IF(ALPHA.LT..5) TINORN=-TINORN                                 STAT1133
    3 TINORM=TINORN                                                     STAT1134
         RETURN                                                         STAT1135
    4 TINORN=1.0E32                                                     STAT1136
         IF(X.LE.0.0) TINORN=-TINORN                                    STAT1137
         GO TO 3                                                        STAT1138
         END                                                            STAT1139
         FUNCTION FISH(F,N1,N2)                                         STAT1140
C                                                                       STAT1141
C     THIS FUNCTION COMPUTES THE UPPER TAIL AREA OF                     STAT1142
C     FISHER'S F DISTRIBUTION WITH N1 AND N2 DEGREES OF FREEDOM         STAT1143
C                                                                       STAT1144
      LOGICAL E1,E2,E3                                                  STAT1145
         E1=.FALSE.                                                     STAT1146
         E2=.FALSE.                                                     STAT1147
         E3=.FALSE.                                                     STAT1148
         IF (MOD(N1,2).EQ.0) E1=.TRUE.                                  STAT1149
         IF(MOD(N2,2).EQ.0) E2=.TRUE.                                   STAT1150
         X=N2/(N2+N1*F)                                                 STAT1151
         IF(.NOT.(E1.OR.E2)) GO TO 5                                    STAT1152
         IF(E1.AND..NOT.E2) GO TO 1                                     STAT1153
         IF(.NOT.E1.AND.E2) GO TO 2                                     STAT1154
         IF(N1.LE.N2) GO TO 1                                           STAT1155
    2    I=N1                                                           STAT1156
         N1=N2                                                          STAT1157
         X=1.0-X                                                        STAT1158
         E3=.TRUE.                                                      STAT1159
    1    Y=1.0-X                                                        STAT1160
         FISH=0.0                                                       STAT1161
         H=SQRT(X**N2)                                                  STAT1162
         M=N1/2-1                                                       STAT1163
      MP1=M+1                                                           STAT1164
      DO 3 K=1,MP1                                                      STAT1165
         I=K-1                                                          STAT1166
         FISH=FISH+H                                                    STAT1167
    3    H=(H*Y*(N2+2.0*I))/(2.0*K)                                     STAT1168
         IF(E3) GO TO 4                                                 STAT1169
         FISH=1.0-FISH                                                  STAT1170
         RETURN                                                         STAT1171
    4    I=N1                                                           STAT1172
         N1=N2                                                          STAT1173
         N2=I                                                           STAT1174
         RETURN                                                         STAT1175
    5    Y=1.0-X                                                        STAT1176
         H=.63661977*SQRT(X*Y)                                          STAT1177
         FISH=.63661977*ACOS(SQRT(X))                                   STAT1178
         IF(N2.EQ.1) GO TO 8                                            STAT1179
         M=N2-2                                                         STAT1180
         DO 6 I=1,M,2                                                   STAT1181
         FISH=FISH+H                                                    STAT1182
```

Figure B.3 (Continued)

```
6      H=H*X*(I+1)/(I+2)                                                STAT1183
8      IF (N1.EQ.1) RETURN                                              STAT1184
       H=H*N2                                                           STAT1185
       M=N1-2                                                           STAT1186
       DO 7 I=1,M,2                                                     STAT1187
       FISH=FISH+H                                                      STAT1188
7      H=H*Y*(N2+I)/(I+2)                                               STAT1189
      RETURN                                                            STAT1190
      END                                                               STAT1191
      SUBROUTINE READRC                                                 READRC 2
C                                                                       READRC 3
C     READS WIND SPEED, DRY BULB TEMPERATURE, WET BULB TEMPERATURE,     READRC 4
C     DEW POINT, RELATIVE HUMIDITY, STATION PRESSURE, AND TENTHS OF     READRC 5
C     CLOUD COVER FROM NATIONAL WEATHER SERVICE DATA TAPES.  WIND SPEED READRC 6
C     IS RETURNED IN MPH, TEMPERATURE IN DEGREES FARENHEIT, AND PRESSUREREADRC 7
C     IN MM-HG.  INPUT RECORD IS 495 CHARACTERS LONG.                   READRC 8
C                                                                       READRC 9
      INTEGER JUNK(6,9),ISTAT(2),IWIND(6,4),ITEMP(6,6),IHUMID(6,2),     READRC10
     1IPRESS(6,4),ISKY(6,6)                                             READRC11
      COMMON IDATE(3), IHOUR(6),WINDSP(6),TEMPDB(6),TEMPWB(6),TEMPDP(6),READRC12
     1HUMID(6),PRESSR(6),SKY(6)                                         READRC13
      READ(8,500)    ISTAT,IDATE,(IHOUR(I),(JUNK(I,K),K=1,4),           READRC14
     1(IWIND(I,K),K=1,4),(ITEMP(I,K),K=1,6),IHUMID(I,1),IHUMID(I,2),    READRC15
     2(IPRESS(I,K),K=1,4),(ISKY(I,K),K=1,6),(JUNK(I,K),K=5,9),I=1,6)    READRC16
  500 FORMAT  (   I4,I5,3I2,6(I2,1X,I2,A1,1X,I2,A1,I1,A1,4(I2,A1),1X,   READRC17
     1I2,A1,I4,A1,I3,A1,1X,6A1,    2(A10),A2,A8,A2,4X))                 READRC18
      DO 100 I=1,6                                                      READRC19
      CALL SIGNCK (IWIND(I,3),IWIND(I,4))                               READRC20
      WINDSP(I)=IWIND(I,3)                                              READRC21
      CALL SIGNCK (ITEMP(I,1),ITEMP(I,2))                               READRC22
      WINDSP(I)=WINDSP(I)*1.15078                                       READRC23
      CALL SIGNCK (ITEMP(I,3),ITEMP(I,4))                               READRC24
      CALL SIGNCK (ITEMP(I,5),ITEMP(I,6))                               READRC25
      TEMPDB(I)=ITEMP(I,1)                                              READRC26
      TEMPWB(I)=ITEMP(I,3)                                              READRC27
      TEMPDP(I)=ITEMP(I,5)                                              READRC28
      CALL SIGNCK (IHUMID(I,1),IHUMID(I,2))                             READRC29
      HUMID(I)=IHUMID(I,1)                                              READRC30
      CALL SIGNCK (IPRESS(I,3),IPRESS(I,4))                             READRC31
      PRESSR(I)=IPRESS(I,3)                                             READRC32
      PRESSR(I)=PRESSR(I)*.01                                           READRC33
      ICOVER=0                                                          READRC34
      CALL SIGNCK(ICOVER,ISKY(I,5))                                     READRC35
  100 SKY(I)=ICOVER*.1                                                  READRC36
      RETURN                                                            READRC37
      END                                                               READRC38
      SUBROUTINE SIGNCK(IFLD,ISGN)                                      SIGNCK 2
C     THIS SUBROUTINE FURNISHED BY NATIONAL CLIMATIC CENTER, ASHEVILLE  SIGNCK 3
C         WILL TEST ANY PSYCHROMETRIC WITH A SIGN-OVER-UNITS            SIGNCK 4
C         POSITION READ AS A1 AND THE HIGH ORDER POSITION AS AN         SIGNCK 5
C         I SPECIFICATION OF PROPER WIDTH                               SIGNCK 6
C     THE SIGN SHOULD ENTER THE PARAMETER LIST AS ISGN,                 SIGNCK 7
C         THE REMAINING PORTION AS IFLD                                 SIGNCK 8
C     UPON RETURN FROM THE SUBROUTINE THE VALUE OF IFLD WILL BE         SIGNCK 9
C         AN INTEGER WITH PROPER SIGN                                   SIGNCK10
C     IT WILL BE THE USER'S RESPONSIBILITY TO CONVERT THIS              SIGNCK11
C         TO  DECIMAL WITH PROPER DECIMAL ALIGNMENT                     SIGNCK12
C     INVALID CONDITION CAUSES IFLD TO BE SET TO 9999                   SIGNCK13
      DIMENSION IP(10),MIN(10),NUM(10)                                  SIGNCK14
      DIMENSION INUM(10)                                                SIGNCK15
      DATA INUM/'1','2','3','4','5','6','7','8','9','0'/                SIGNCK16
C     NOTE - SOME COMPUTER SYSTEMS MAY REQUIRE DIFFERENT CHARACTERS AS  SIGNCK17
C     THE LAST CHARACTERS IN ARRAYS IP AND MIN                          SIGNCK18
```

Figure B.3 (Continued)

```fortran
      DATA MIN/'J','K','L','M','N','O','P','Q','R','!'/
      DATA IP/'A','B','C','D','E','F','G','H','I',
     1 72555555555555555555B/
      DATA NUM/1,2,3,4,5,6,7,8,9,0/
      DATA IAST/'*'/
      DATA MINUS/'-'/
      DATA NULL/' '/
      IF (ISGN.EQ.NULL.AND.IFLD.NE.0) GO TO 125
      IF (ISGN.EQ.IAST) GO TO 105
      IF (ISGN.EQ.MINUS) GO TO 110
      DO 100 K=1,10
      IF (ISGN.EQ.IP(K)) GO TO 115
      IF (ISGN.EQ.MIN(K)) GO TO 120
      IF (ISGN.EQ.INUM(K)) GO TO 115
  100 CONTINUE
  105 IFLD=999999
      RETURN
  110 IFLD=10
      RETURN
  125 IFLD=IFLD*10
      RETURN
  115 IFLD=IFLD*10+NUM(K)
      RETURN
  120 IFLD=-(IFLD*10+NUM(K))
      RETURN
      END
      SUBROUTINE SOLAR (LAT,YR,MONTH,DAY,SRAD)
C
C     RETURNS INSOLATION IN BTU/FT**2/DAY AT EACH HOUR OF THE DAY.
C
      INTEGER YR,MONTH,DAY,MONDAT(12)
      REAL LAT,SRAD(25)
      DATA MONDAT/0,31,59,90,120,151,181,212,243,273,304,334/
      LP=MOD(YR,4)
      IF(LP.NE.0)GO TO 120
      DO 100 I=3,12
  100 MONDAT(I)=MONDAT(I)+1
  120 NUM=MONDAT(MONTH)+DAY
C
C     FIND TOTAL POSSIBLE DAILY RADIATION AND LENGTH OF DAYLIGHT.
C
      TOTRAD=HAMN(LAT,YR,NUM)
      DAYNUM=NUM
      DAYLEN=DAYLIT(LAT,DAYNUM)
C
C     CALCULATE THE SINUSOIDAL VARIATION IN DAILY RADIATION.
C
      T1=.5*DAYLEN
      A=.5*TOTRAD
      DATA W/.2618/
      ALPHA=1./(1./(A*W)*SIN(W*T1)-T1/A*COS(W*T1))
      ALPTO=ALPHA*COS(W*T1)
      DO 130 I=1,25
      TO=I-1.
      SRAD(I)=0.
      TO=ABS(TO-12.)
C
C     CALCULATE RATE OF INSOLATION FOR EACH HOUR OF DAYLIGHT.
C
      IF(TO.LE.T1)SRAD(I)=(ALPHA*COS(W*TO)-ALPTO)*DAYLEN
  130 CONTINUE
      IF(LP.NE.0) RETURN
      DO 140 I=3,12
  140 MONDAT(I)=MONDAT(I)-1
```

Figure B.3 (Continued)

```
      RETURN                                                            SOLAR 40
      END                                                               SOLAR 41
      FUNCTION DAYLIT(LAT,DAYNUM)                                       DAYLIT 2
C                                                                       DAYLIT 3
C     RETURNS HOURS OF DAYLIGHT GIVEN LATITUDE OF OBSERVATION AND       DAYLIT 4
C     NUMBER OF THE DAY OF THE YEAR.  LATITUDE MUST BE BETWEEN 25 AND   DAYLIT 5
C     50 DEGREES NORTH.  THE SOURCE FOR THE LENGTH OF DAYLIGHT INFOR-   DAYLIT 6
C     MATION (STORED IN ARRAY 'LENGTH') IS THE SMITHSONIAN METEOROLOG-  DAYLIT 7
C     ICAL TABLES.                                                      DAYLIT 8
C                                                                       DAYLIT 9
      REAL LAT,LATBL(6),LENGTH(6,10) ,DAY(10)                           DAYLIT10
      DATA LATBL/25.,30.,35.,40.,45.,50.01/                             DAYLIT11
      DATA DAY/-10.,13.,79.,145.,172.,197.,263.,333.,355.,378./         DAYLIT12
      DATA (LENGTH(1,I),I=1,10)                                         DAYLIT13
     1 /10.58,10.73,12.15,13.50,13.68,13.53,12.17,10.73,10.58,10.73/    DAYLIT14
      DATA (LENGTH(2,I),I=1,10)                                         DAYLIT15
     2/10.20,10.40,12.15,13.83,14.08,13.87,12.17,10.40,10.20,10.40/     DAYLIT16
      DATA (LENGTH(3,I),I=1,10)                                         DAYLIT17
     3/9.80,10.03,12.15,14.23,14.52,14.26,12.20,10.02,9.80,10.03/       DAYLIT18
      DATA (LENGTH(4,I),I=1,10)                                         DAYLIT19
     4/9.33,9.60,12.18,14.67,15.02,14.70,12.22,9.60,9.33,9.60/          DAYLIT20
      DATA (LENGTH(5,I),I=1,10)                                         DAYLIT21
     5/8.75,9.10,12.19,15.28,15.61,15.23,12.23,9.09,8.75,9.10/          DAYLIT22
      DATA (LENGTH(6,I),I=1,10)                                         DAYLIT23
     6/8.07,8.50,12.22,15.83,16.38,15.88,12.28,8.48,8.07,8.50/          DAYLIT24
      DO 100 I=2,10                                                     DAYLIT25
      I1=I-1                                                            DAYLIT26
      IF(DAYNUM.GE.DAY(I1).AND.DAYNUM.LT.DAY(I))GO TO 110               DAYLIT27
  100 CONTINUE                                                          DAYLIT28
  110 DO 120 K=2,6                                                      DAYLIT29
      K1=K-1                                                            DAYLIT30
      IF(LAT.GE.LATBL(K1).AND.LAT.LT.LATBL(K)) GO TO 130                DAYLIT31
  120 CONTINUE                                                          DAYLIT32
C                                                                       DAYLIT33
C     LINEAR INTERPOLATION OF TABLE 'LENGTH'.                           DAYLIT34
C                                                                       DAYLIT35
  130 DELDY=(DAY(I)-DAYNUM)/(DAY(I)-DAY(I1))                            DAYLIT36
      A=LENGTH(K1,I)-(DELDY*(LENGTH(K1,I)-LENGTH(K1,I1)))               DAYLIT37
      B=LENGTH(K,I)-(DELDY*(LENGTH(K,I)-LENGTH(K,I1)))                  DAYLIT38
      DAYLIT=B-(LATBL(K)-LAT)/5.*(B-A)                                  DAYLIT39
      RETURN                                                            DAYLIT40
      END                                                               DAYLIT41
      FUNCTION HAMN(LAT,YR,MODA)                                        HAMN   2
C     SOLAR RADIATION ON HORIZONTAL SURFACE                             HAMN   3
C         FROM HAMON, WEISS, + WILSON   )100(>                          HAMN   4
C         #MONTHLY WEATHER REVIEW#--PAGE 141--JUNE 1954                 HAMN   5
C     PROGRAM AUTHOR--E.C.LONG.  COMPUTER SCIENCES DIVISION--ORNL       HAMN   6
C     UNION CARBIDE NUCLEAR DIVISION.  OAK RIDGE, TENNESSEE             HAMN   7
C **** DAILY RADIATION RETURNED IN BTU'S ****                           HAMN   8
      REAL DATE(16),L25(16),L30(16),L35(16),L40(16),L45(16),L50(16),    HAMN   9
     1    LT(6),LAT,X(3),Y(3),L(96)                                     HAMN  10
      INTEGER IM(12),N(12),YR                                           HAMN  11
      EQUIVALENCE (L(1),L25(1)),(L(17),L30(1)),(L(33),L35(1)),          HAMN  12
     1    (L(49),L40(1)),(L(65),L45(1)),(L(81),L50(1))                  HAMN  13
      DATA DATE    /-41.0,-11.0,20.0,51.0,79.0,110.0,140.0,             HAMN  14
     1    171.0,201.0,232.0,263.0,293.0,324.0,354.0,385.0,416.0/        HAMN  15
      DATA L25    /1754.0,1616.0,1794.0,2116.0,2399.0,2611.0,2708.0,    HAMN  16
     1    2729.0,2695.0,2571.0,2338.0,2030.0,1754.0,1616.0,             HAMN  17
     2    1794.0,2116.0/                                                HAMN  18
      DATA L30    /1557.0,1390.0,1570.0,1909.0,2266.0,2557.0,2699.0,    HAMN  19
     1    2729.0,2662.0,2503.0,2224.0,1873.0,1557.0,1390.0,             HAMN  20
     2    1570.0,1909.0/                                                HAMN  21
      DATA L35    /1338.0,1149.0,1351.0,1723.0,2124.0,2492.0,2680.0,    HAMN  22
     1    2729.0,2645.0,2426.0,2064.0,1685.0,1338.0,1149.0,             HAMN  23
```

Figure B.3 (Continued)

```
     2     1351.0,1723.0/
      DATA L40     /1103.0,909.7,1103.0,1514.0,1947.0,2397.0,2655.0,
     1     2729.0,2603.0,2342.0,1951.0,1479.0,1103.0,909.7,
     2     1103.0,1514.0/
      DATA L45     /882.7,687.3,881.0,1311.0,1778.0,2289.0,2618.0,
     1     2729.0,2571.0,2247.0,1769.0,1274.0,882.7,687.3,881.0,1311.0/
      DATA L50     /682.3,463.3,631.0,1053.0,1568.0,2165.0,2581.0,
     1     2729.0,2527.0,2136.0,1584.0,1060.0,682.3,463.3,631.7,1053.0/
      DATA LT    /25.0,30.0,35.0,40.0,45.0,50.0/
      DATA     IM     /1,32,60,91,121,152,182,213,244,274,305,335/
      DATA     N     /31,28,31,30,31,30,31,31,30,31,30,31/
      DAYC=MODA
      LEAP=MOD(YR,4)
      IF (LEAP.NE.0) GO TO 110
      DO 100 I=4,16
      DATE(I)=DATE(I)+1.0
  100 CONTINUE
      DO 105 I=2,11
      IM(I)=IM(I)+1
      N(I)=N(I)+1
  105 CONTINUE
  110 SUM=0.0
      IF (MODA.GT.0) GO TO 115
C     FOR MODA)0 FIND AVERAGE SOLAR RADIATION FOR MONTH -MODA
      MO=-MODA
      I1=IM(MO)
      ID=N(MO)
      I2=I1+ID-1
      DAYS=ID
      DAY=I1
      GO TO 120
C     FOR MODA>0 FIND RADIATION FOR DAY #DAYC#
C          DAYC IS EQUIVALENCED TO MODA
  115 I1=1
      ID=1
      I2=1
      DAY=DAYC
      DAYS=1.0
  120 DO 180 II=I1,I2
C     DETERMINE IF DAY IS TABULAR
C          OF IF DAY NOT TABULAR, INDEX OF DAY
      MD=0
      MI=0
      DO 130 I=2,14
      DATEI=DATE(I)
      IF (DAY.NE.DATEI) GO TO 125
      MD=I
      GO TO 140
C     MD HAS INDEX I IF DAY=DATE(I)
  125 IF (DAY.GT.DATEI.AND.DAY.LT.DATE(I+1)) GO TO 135
  130 CONTINUE
      GO TO 140
  135 MI=I
C     MI=I FOR DATE(I))DAY)DATE(I+1)
C     DETERMINE IF LAT IS TABULAR VALUE
  140 IF (MODA.LT.0.AND.II.GT.I1) GO TO 150
      ML=0
      DO 145 I=1,6
      IF (LAT.NE.LT(I)) GO TO 145
      ML=I
C     ML=I FOR LAT TABULAR VALUE
      GO TO 150
  145 CONTINUE
  150 IF (MD*ML.EQ.0) GO TO 155
```

Figure B.3 (Continued)

```
C     TABULAR DATE + LATITUDF
      J=(ML-1)*16+MD
      HAMN=L(J)
      GO TO 175
  155 IF (ML.EQ.0) GO TO 160
C     NON TABULAR DATE + TABULAR LATITUDE
      MI1=MI-1
      J=(ML-1)*16+MI1
      HAMN=YLAG(DAY,DATE(MI1),L(J),4)
      GO TO 175
  160 IF (LAT.LE.32.5) LATF=1
      IF (LAT.GT.32.5.AND.LAT.LE.37.5) LATF=2
      IF (LAT.GT.37.5.AND.LAT.LE.42.5) LATF=3
      IF (LAT.GT.42.5) LATF=4
      X(1)=LT(LATF)
      X(2)=LT(LATF+1)
      X(3)=LT(LATF+2)
      IF (MD.EQ.0) GO TO 165
C     TABULAR DAY + NON TABULAR LATITUDE
      Y(1)=L((LATF-1)*16+MD)
      Y(2)=L(LATF*16+MD)
      Y(3)=L((LATF+1)*16+MD)
      GO TO 170
C     NON TABULAR DATE + NON TABULAR LATITUDE
  165 M1=MI-1
      Y(1)=YLAG(DAY,DATE(M1),L((LATF-1)*16+M1),4)
      Y(2)=YLAG(DAY,DATE(M1),L(LATF*16+M1),4)
      Y(3)=YLAG(DAY,DATE(M1),L((LATF+1)*16+M1),4)
  170 HAMN=YLAG(LAT,X,Y,3)
      DAY=DAY+1.0
  175 DAY=DAY+1.0
  180 SUM=SUM+HAMN
      HAMN=AMIN1(2729.0,AMAX1(SUM/DAYS,0.0))
      IF (LEAP.NE.0) RETURN
      DO 185 I=4,16
      DATE(I)=DATE(I)-1.0
  185 CONTINUE
      DO 190 I=2,11
      IM(I)=IM(I)-1
      N(I)=N(I)-1
  190 CONTINUE
      RETURN
      END
      FUNCTION YLAG(XI,X,Y,N)
C     N-POINT LAGRANGIAN INTERPOLATION WHERE I=1,N
C     SPECIAL VERSION FOR USE WITH FUNCTION #HAMN#
C     PROGRAM AUTHOR--E.C.LONG.  COMPUTER SCIENCES DIVISION--ORNL
C     UNION CARBIDE NUCLEAR DIVISION.  OAK RIDGE, TENNESSEE
      DIMENSION X(N),Y(N)
      S=0.0
      P=1.0
      DO 110 J=1,N
      P=P*(XI-X(J))
      D=1.0
      DO 105 I=1,N
      IF (I.NE.J) GO TO 100
      XD=XI
      GO TO 105
  100 XD=X(J)
  105 D=D*(XD-X(I))
  110 S=S+Y(J)/D
      YLAG=S*P
      RETURN
      END
```

Figure B.3 (Continued).

```
      PROGRAM SPRPND(INPUT,OUTPUT,TAPE6=OUTPUT,TAPE8,TAPE5=INPUT)          SPRPND 2
C    PROGRAM TO CALCULATE MAX TEMPERATURE IN A UHS SPRAY-POND              SPRPND 3
C     RICHARD CODELL, U.S.N.R.C. - WASHINGTON D.C. 20555  JULY 1980        SPRPND 4
      DIMENSION TIME(20)                                                   SPRPND 5
      DIMENSION ITITLE(80)                                                 SPRPND 6
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDRO,DWDR,FDRIFT(20),        SPRPND 7
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,         SPRPND 8
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,      SPRPND 9
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,       SPRPND10
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),           ITER   1
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                        SPRPND12
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                       SPRPND13
      COMMON/SPSW/ TSPRON                                                  SPRPND14
      COMMON/DRPSZ/ R                                                      SPRPND15
      C(Z)=(Z-32)/1.8                                                      SPRPND17
      NAMELIST/HFT/ NH,HEAT,FLOW,TH                                        SPRPND18
      F1=0.0                                                               SPRPND19
      Q1=0.0                                                               SPRPND20
      IMET=0                                                               SPRPND22
      CEMAX=0.1                                                            SPRPND23
      CEMIN=0.                                                             SPRPND24
      CMAX=0.8                                                             SPRPND25
      CMIN=0.2                                                             SPRPND26
      VELO=22.5                                                            JULY30 1
      TA=90.                                                               SPRPND28
      TW=70.                                                               SPRPND29
      TD=60.                                                               SPRPND30
      W=3.                                                                 SPRPND31
      HS=1500.                                                             SPRPND32
      PB=29.92                                                             SPRPND33
      THETA=71.0                                                           JULY30 2
      Y0=5.0                                                               JULY30 3
      R=.104                                                               SPRPND38
      PHI=90.0                                                             SPRPND39
      NITER=0                                                              ITER   2
      DTITER=5.0                                                           ITER   3
C     NUMBER OF STEPS IN INTEGRATION OF DROP HEAT AND MASS TRANSFER        SPRPND40
      NSTDR=10                                                             SPRPND41
      TZERO=80.0                                                           SPRPND42
      DT=0.2                                                               SPRPND43
      DATA M4,NSTEPS,NPRINT/0,100,10/                                      SPRPND44
      NAMELIST /INLIST/ VZERO,BLOW,A,NH,NSTEPS,NPRINT,DT,TZERO,DTMET       SPRPND45
     1 ,TSKIP,QBASE,FBASE,IMET,       ISPRAY,Q1,F1                         SPRPND46
     2 ,HEAT,FLOW,TH                                                       SPRPND47
     1 ,TA,TW,W,TD,HS,PB,IEVAP,TSPRON                                      SPRPND48
     1 ,NITER,DTITER                                                       ITER   4
      NAMELIST/PARAM/ NDRIFT,WDRO,DWDR,FDRIFT,CEMAX,CEMIN,CMAX,CMIN        SPRPND49
     1 ,VELO,THETA,R,HT,WID,ALEN,Y0,PHI,ISPRAY,TA,TD,TW,HS,W,PB            SPRPND50
      READ(5,555) CH,CL,CEH,CEL                                            SPRPND51
 555  FORMAT(4E15.8)                                                       SPRPND52
      READ(5,PARAM)                                                        SPRPND53
C    CONVERT SPRAY PARAMETERS TO METRIC UNITS                              JULY30 4
      VELO=VELO*30.48                                                      JULY30 5
      THETA=THETA*(3.1415926/180.0)                                        JULY30 6
      HT=HT*30.48                                                          JULY30 7
      WID=WID*30.48                                                        JULY30 8
      Y0=Y0*30.48                                                          JULY30 9
      ALEN=ALEN*30.48                                                      JULY3010
      READ(5,101) NMET                                                     SPRPND54
 101  FORMAT(I5)                                                           SPRPND55
C    READ IN MET TABLE (WIND SP.,DRY BULB, DEW PT,TWET,ATM PRESS)          SPRPND56
C    SKIP FIRST 5 CARDS                                                    JULY3011
```

Figure B.4 Listing of program SPRPND

```
      DO 8 I=1,5                                                        JULY3012
    8 READ(8,9)                                                         JULY3013
    9 FORMAT(1H )                                                       JULY3014
      READ(8,1) (G(I,4),G(I,2),G(I,1),G(I,3),G(I,5),G(I,6),I=1,NMET)    SPRPND57
    1 FORMAT(3X,3F5.0,F6.0,2F7.0,3F5.0,F6.0,2F7.0)                      SPRPND58
C    VZERO = VOLUME OF POND FT**3                                       SPRPND59
C    BLOW = BLOWDOWN RATE OUT FT**3/HR                                  SPRPND60
C    A = SURFACE AREA FT**2                                             SPRPND61
C    NSTEPS = NUMBER OF INTEGRATION STEPS                               SPRPND62
C    NPRINT = PRINT EVERY NPRINT STEPS                                  SPRPND63
C    DT = INTEGRATION TIMESTEP, HRS                                     SPRPND64
C    TZERO = INITIAL POND TEMP DEG.F                                    SPRPND65
C    G(I,1)=TD=DEW POINT, DEG.F                                         SPRPND66
C    G(I,2)=TA=DRY BULB DEG.F                                           SPRPND67
C    G(I,3) =HS =  SOLAR RADIATION BTU/(FT**2 DAY)                      SPRPND68
C    G(I,4)= W = WIND SPEED MPH                                         SPRPND69
C   G(I,6)= PR = ATM PRESSURE--INCHES HG                                SPRPND70
C    G(I,5) = TW = WET BULB TEMPERATURE - DEG. F                        SPRPND71
C    QBASE = BASE HEAT LOAD, BTU/HR                                     SPRPND72
C    FBASE = BASE FLOW, FT**3/HR                                        SPRPND73
C    NH = NUMBER OF ENTRIES IN HEAT TABLE                               SPRPND74
C    HEAT = ARRAY OF HEAT INPUTS, BTU/HR                                SPRPND75
C    FLOW = ARRAY OF FLOW RATES, FT**3/HR                               SPRPND76
C    TH = ARRAY OF CORRESPONDING TIMES FOR HEAT AND FLOW ARRAYS         SPRPND77
C    Q1 = HEAT LOAD FOR T LESS THAN TSKIP                               SPRPND78
C     F1 = FLOW FOR T LESS THAN TSKIP                                   SPRPND79
C     (ABOVE 2 USED FOR AMBIENT TEMPERATURE CALCULATION)                SPRPND80
C    HT = HEIGHT OF SPRAY FIELD, FT                                     JULY3015
C    ALEN = LENGTH OF SPRAY FIELD, FT                                   JULY3016
C    WID = WIDTH OF SPRAY FIELD, FT                                     JULY3017
C    VELO = INITIAL VELOCITY OF DROPS, FT/SEC                           JULY3018
C    THETA = ANGLE OF DROPS WITH RESPECT TO HORIZON, DEGREES            JULY3019
C    Y0 = HIEGHT OF NOZZLE ABOVE WATER SURFACE, FT                      JULY3020
C     R = THE GEOMETRIC MEAN DROP SIZE, CM                              SPRPND87
C    PB = BAROMETRIC PRESSURE, INCHES HG                                JULY3021
C     CMAX = MAXIMUM ALLOWED SPRAY EFFICIENCY                           SPRPND89
C     CMIN = MINIMUM ALLOWED SPRAY EFFICIENCY                           SPRPND90
C     CEMAX = MAXIMUM ALLOWED EVAPORATION FRACTION                      SPRPND91
C     CEMIN = MINIMUM ALLOWED EVAPORATION FRACTION                      SPRPND92
      BLOW=0                                                            SPRPND93
      DTMET=1                                                           SPRPND94
      QBASE=0                                                           SPRPND96
      FBASE=0                                                           SPRPND97
C***********************************************************************SPRPND98
C     PROGRAM SWITCHES                                                  SPRPND99
C     TSKIP      DELAY START OF HEAT INPUT FROM TABLE TSKIP HOURS       SPRPN100
C                BEFORE TSKIP HEAT=Q1 AND FLOW=F1                       SPRPN101
C     TSPRON     DELAY SPRAY TURNING ON TSPRON HOURS                    SPRPN102
C                ALSO ASSUMES FULL POND UNTIL TSPRON HOURS              SPRPN103
C     IEVAP      =1, REGULAR WATER LOSS                                 SPRPN104
C     IEVAP      =0, POND REMAINS FULL - NO WATER LOSS                  SPRPN105
C     ISPRAY     =1, REGRESSION SPRAY MODEL                             SPRPN106
C     ISPRAY     =2, RIGOROUS SPRAY MODEL                               SPRPN107
C     IMET       =0, USE METEOROLOGICAL TABLE AS INPUT                  SPRPN108
C     IMET       =1, FIXED METEOROLOGICAL VARIABLES AS READ IN INLIST   SPRPN109
C***********************************************************************SPRPN110
C     AREA OF SIDE OF SPRAY POND IN HWS MODEL                           SPRPN111
      ASIDEH=HT*ALEN                                                    SPRPN112
      DLEN=ALEN/10                                                      SPRPN113
      DWID=WID/10                                                       SPRPN114
      DO 801 J=1,10                                                     SPRPN115
      I=12-J                                                            SPRPN116
C     TOP AND SIDE AREAS FOR EACH SEGMENT IN LWS MODEL                  SPRPN117
```

Figure B.4 (Continued)

```
      ATOP(I)=J*DLEN*DWID*J-(J-1)*DLEN*DWID*(J-1)                       SPRPN118
      ASIDE(I)=((J-1)*DLEN+(J-1)*DWID)*2*HT                             SPRPN119
  801 CONTINUE                                                          SPRPN120
      ASIDE(1)=(ALEN+WID)*2*HT                                          SPRPN121
      ASIDE(12)=0                                                       SPRPN122
      CALL INIT(R,THETA,Y0,VEL0)                                        SPRPN123
      READ(5,HFT)                                                       SPRPN124
      DO 4 I=1,NH                                                       SPRPN125
      TIME(I)=TH(I)                                                     SPRPN126
      TH(I)=TH(I)+1.0E-20                                               SPRPN127
    4 TH(I)=ALOG(TH(I))                                                 SPRPN128
      IF(NH.GT.1) GOTO 710                                              SPRPN129
      FLOW(2)=FLOW(1)                                                   SPRPN130
      HEAT(2)=HEAT(1)                                                   SPRPN131
      NH=2                                                              SPRPN132
      TH(2)=1.0E8                                                       SPRPN133
  710 CONTINUE                                                          SPRPN134
 6000 CONTINUE                                                          SPRPN135
      ISPRAY=2                                                          JULY3022
      TSPRON=0.0                                                        JULY3023
      TSKIP=0.0                                                         JULY3024
      IEVAP=1                                                           JULY3025
      READ(5,480)ITITLE                                                 SPRPN136
  480 FORMAT(80A1)                                                      SPRPN137
C     TERMINATE PROGRAM ON A BLANK TITLE CARD                           SPRPN138
      DO 45 I=1,80                                                      SPRPN139
      IF(ITITLE(I).NE.1H ) GOTO 46                                      SPRPN140
   45 CONTINUE                                                          SPRPN141
      STOP                                                              SPRPN142
   46 CONTINUE                                                          SPRPN143
      READ(5,INLIST)                                                    SPRPN144
      Q1S=Q1                                                            ITER   5
      F1S=F1                                                            ITER   6
      WRITE(6,490) ITITLE                                               SPRPN145
  490 FORMAT(1H1,5(/),T20,80A1)                                         SPRPN146
      WRITE(6,200) VEL0,THETA,R,HT,WID,ALEN,Y0,PHI                      SPRPN147
  200 FORMAT(///,20X,'SPRAY FIELD PARAMETERS'/20X,40('*')/              SPRPN148
     1 20X,'INITIAL VELOCITY OF DROPS LEAVING NOZZLE, VEL0 = ',F10.2,   SPRPN149
     2 ' CM/SEC'/                                                       SPRPN150
     3 20X,'INITIAL ANGLE OF DROPS TO HOR., THETA = ',F10.3,' RADIANS'/ SPRPN151
     4 20X,'GEOMETRIC MEAN RADIUS OF DROPS, R = ',F10.4,' CM'/          SPRPN152
     6 20X,'HEIGHT OF SPRAY FIELD, HT = ',F10.2,' CM'/                  SPRPN153
     7 20X,'WIDTH OF SPRAY FIELD, WID = ',F10.1,' CM'/                  SPRPN154
     8 20X,'LENGTH OF SPRAY FIELD, ALEN = ',F10.1,' CM'/                SPRPN155
     8 20X,'HEIGHT OF SPRAY NOZZLES ABOVE POND SURFACE, Y0 = ',F10.1, / SPRPN156
     * 20X,'HEADING OF WIND W.R.T.LONG AXIS, PHI = ',F10.2,' DEGREES'//)SPRPN157
      WRITE(6,500) VZERO,A,BLOW,      NSTEPS,NPRINT,DT,TZERO,           SPRPN158
     1 TSKIP,QBASE,FBASE                                                SPRPN159
  500 FORMAT(///,20X,'POND PARAMETERS'/20X,40('*')/                     JULY3026
     120X,'INITIAL POND VOLUME,VZERO = ',F13.1,' CU.FT.'/               JULY3027
     220X,'POND SURFACE AREA,A = ',F13.1,' SQ.FT.'/                     JULY3028
     320X,'BLOWDOWN AND LEAKAGE,BLOW = ',F10.2,' CU.FT./HR.'/           JULY3029
     420X,'NUMBER OF INTEGRATION STEPS,NSTEPS = ',I5/                   JULY3030
     520X,'PRINT INTERVAL,NPRINT = ',I5/                                JULY3031
     620X,'INTEGRATION TIMESTEP,DT = ',F10.2,' HOURS'/                  JULY3032
     720X,'INITIAL POND TEMPERATURE,TZERO = ',F10.2,' DEG.F'/           JULY3033
     820X,'DELAY FOR HEAT TABLE,TSKIP = ',F10.2,' HRS'/                 JULY3034
     920X,'BASE HEAT LOAD ADDED TO TABLE,QBASE = ',F10.2,' HRS'/        JULY3035
     120X,'BASE FLOW RATE ADDED TO TABLE ,FBASE = ',E15.6,' CU.FT./HR.')JULY3036
      WRITE(6,501)                                                      JULY3037
  501 FORMAT(///,T43,                                                   JULY3038
     635('.'),/,T43,': HEAT IN  : TIME FROM : FLOW IN  :',/,T43,':  BTU/SPRPN166
     7HR  :   START   : FT**3/HR :',/,T43,35('.'))                      SPRPN167
```

Figure B.4 (Continued)

```
      DO 2 I=1,NH                                                       SPRPN168
    2 WRITE(6,510)HEAT(I),TIME(I),FLOW(I)                               SPRPN169
  510 FORMAT(T43,':',   E9.3,1X,':',2X,F7.2,2X,':',   E9.3,1X,':')      SPRPN170
      WRITE(6,524) Q1,F1                                                SPRPN171
  524 FORMAT(/T30,'FOR TIME LESS THAN TSKIP'/T30,'Q1 = ',E12.3,         SPRPN172
     1 ' BTU/HR'/T30,'F1 = ',E12.3,' FT**3/HR')                         SPRPN173
      IF(IMET.EQ.0) WRITE(6,47)                                         SPRPN174
   47 FORMAT(/20X,'METEOROLOGICAL TABLE USED AS INPUT'/)                SPRPN175
      IF(IMET.EQ.1) WRITE(6,48)                                         SPRPN176
   48 FORMAT(/20X,'FIXED METEOROLOGICAL VALUES USED AS INPUT'/)         SPRPN177
      IF(IMET.EQ.1)WRITE(6,61)TA,TW,W,TD,HS,PB                          JULY3039
   61 FORMAT(/20X,'DRY BULB TEMPERATURE,TA = ',F10.2,' DEG. F'/         JULY3040
     120X,'WET BULB TEMPERATURE,TW = ',F10.2,' DEG. F'/                 JULY3041
     220X,'WIND SPEED,W = ',F10.2,'MPH'/                                JULY3042
     320X,'DEW POINT TEMPERATURE,TD = ',F10.2,' DEG. F'/                JULY3043
     420X,'SOLAR RADIATION,HS = ',F10.2,' BTU/SQ.FT./DAY'/              JULY3044
     520X,'BAROMETRIC PRESSURE,PB = ',F10.2,' IN.HG.')                  JULY3045
      IF(ISPRAY.EQ.2) WRITE(6,49)                                       SPRPN178
   49 FORMAT(/20X,'RIGOROUS SPRAY MODEL CHOSEN'/)                       SPRPN179
      IF(ISPRAY.NE.2) WRITE(6,50)                                       SPRPN180
   50 FORMAT(/20X,'REGRESSION EQUATIONS USED FOR SPRAY MODEL'/)         SPRPN181
      WRITE(6,53) TSPRON                                                SPRPN182
   53 FORMAT(/20X,'SPRAYS WILL BE DELAYED',F10.2,1X,'HOURS',/)          SPRPN183
      WRITE(6,520)                                                      SPRPN184
  520 FORMAT(T43,35('.'),5(/),T41,13('*'),' MODEL RESULTS ',13('*'),///,SPRPN185
     1T38,'..TIME.......TEMPERATURE (F)........VOLUME....',/,T38,':  HR SPRPN186
     2                              :     FT**3   :',/,T38,46('.'))     SPRPN187
 6003 CONTINUE                                                          ITER   7
      T5=0                                                              ITER   8
      M4=0                                                              ITER   9
      F1=F1S                                                            ITER  10
      Q1=Q1S                                                            ITER  11
      T5=0                                                              SPRPN189
      M1=1                                                              SPRPN190
      M2=1                                                              SPRPN191
      X=.001                                                            SPRPN192
      T=TZERO                                                           SPRPN193
      V=VZERO                                                           SPRPN194
      VMIN=0.1*VZERO                                                    ITER  12
C     BEGIN NUMERICAL INTEGRATIONS                                      SPRPN195
      DO 6 M=1,NSTEPS                                                   SPRPN196
C     MIXED TANK SOLUTIONS                                              SPRPN197
      CALL MIXED(F2,F3,T,V,X)                                           SPRPN198
C   FORCE FULL POND IF IEVAP=0                                          SPRPN199
      IF(IEVAP.EQ.0.OR.X.LT.TSPRON) F3=0.0                              SPRPN200
      CALL MIXED(F7,F8,T+DT*F2,V+DT*F3,X+DT)                            SPRPN201
      IF(IEVAP.EQ.0.OR.X.LT.TSPRON) F8=0.0                              SPRPN202
      T=T+DT*(F2+F7)/2                                                  SPRPN203
      V=V+DT*(F3+F8)/2                                                  SPRPN204
      IF(V.LT.VMIN) V=VMIN                                              ITER  13
C     FIND MAX TEMPERATURE FOR MIXED MODEL                              SPRPN205
      IF(T.LT.T5) GOTO 63                                               SPRPN206
      T5=T                                                              SPRPN207
      TIMEM=X                                                           SPRPN208
   63 CONTINUE                                                          SPRPN209
      M4=M4+1                                                           SPRPN210
      X=X+DT                                                            SPRPN211
      IF(NPRINT.GT.M4) GOTO 6                                           SPRPN212
      M4=0                                                              SPRPN213
      WRITE(6,51) X,T,V                                                 SPRPN214
   51 FORMAT(T35,F10.2,T53,F10.2,T70,E15.8)                             SPRPN215
    6 CONTINUE                                                          SPRPN216
      IF(NITER.EQ.0) WRITE(6,566)                                       ITER  14
```

Figure B.4 (Continued)

```
 566 FORMAT(1H0)                                                    ITER  15
     WRITE(6,55) TSKIP,T5,TIMEM                                     ITER  16
  55 FORMAT (  T5,'TSKIP = ',F8.1,' HOURS',5X,'MAX MODELED TEMPERATURE ITER  17
    1= ',F8.2,' AT',F8.2,' HOURS')                                  ITER  18
     IF(NITER.LE.0) GOTO 6001                                       ITER  19
     TSPRON=TSPRON+DTITER                                           ITER  20
     TSKIP=TSKIP+DTITER                                             ITER  21
     NITER=NITER-1                                                  ITER  22
     GOTO 6003                                                      ITER  23
6001 CONTINUE                                                       ITER  24
     GOTO 6000                                                      SPRPN220
     END                                                            SPRPN221
     SUBROUTINE MIXED(FA,FB,T,v,X)                                  MIXED  2
C    MIXED TANK MODEL                                               MIXED  3
     COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),  MIXED  4
    1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,   MIXED  5
    2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR, MIXED  6
    3 ATOP(12) ,ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,  MIXED  7
    4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),     ITER  25
    5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                  MIXED  9
    6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                 MIXED 10
     COMMON/SPSW/ TSPRON                                            MIXED 11
C    LOG-LINEAR INTERPOLATION OF HEAT TABLE                         MIXED 12
     DO 1 M1=M2,NH                                                  MIXED 13
     X1=X-TSKIP                                                     MIXED 14
     IF(X1.LE.0.0) GOTO 300                                         MIXED 15
     X9=ALOG(X1)                                                    MIXED 16
     IF(X9.LT.TH(M1)) GOTO 1                                        MIXED 17
     IF(X9.LT.TH(M1+1)) GOTO 1210                                   MIXED 18
   1 CONTINUE                                                       MIXED 19
1210 F4=(X9-TH(M1))/(TH(M1+1)-TH(M1))                               MIXED 20
     M2=M1                                                          MIXED 21
C    EXTERNAL HEAT INPUT TO POND                                    MIXED 22
     Q1=HEAT(M1)+F4*(HEAT(M1+1)-HEAT(M1))                           MIXED 23
C    CIRCULATION THROUGH POND                                       MIXED 24
     F1=FLOW(M1)+F4*(FLOW(M1+1)-FLOW(M1))                           MIXED 25
C    ADD BASE HEAT LOAD AND FLOW, IF ANY                            MIXED 26
     Q1=Q1+QBASE                                                    MIXED 27
     F1=F1+FBASE                                                    MIXED 28
 300 CONTINUE                                                       MIXED 29
C    LINEAR INTERPOLATION OF MET TABLE                              MIXED 30
     IF(IMET.NE.0) GOTO 100                                         MIXED 31
     M1=X/DTMET+1                                                   MIXED 32
     F4=(X-(M1-1)*DTMET)/DTMET                                      MIXED 33
     TD=G(M1,1)+F4*(G(M1+1,1)-G(M1,1))                              MIXED 34
     TA=G(M1,2)+F4*(G(M1+1,2)-G(M1,2))                              MIXED 35
     HS=G(M1,3)+F4*(G(M1+1,3)-G(M1,3))                              MIXED 36
     W=G(M1,4)+F4*(G(M1+1,4)-G(M1,4))                               MIXED 37
     TW=G(M1,5)+F4*(G(M1+1,5)-G(M1,5))                              MIXED 38
     PB=G(M1,6)+F4*(G(M1+1,6)-G(M1,6))                              MIXED 39
     DATA WMIN/0.1/                                                 MIXED 40
C    MINIMUM WIND SPEED FOR CONTINUITY OF PROGRAM                   MIXED 41
     IF(W.LT.WMIN) W=WMIN                                           MIXED 42
 100 CONTINUE                                                       MIXED 43
     ETA=0.0                                                        MIXED 44
     FDR=0.0                                                        MIXED 45
     FEVAP=0.0                                                      MIXED 46
     HR=0.0                                                         MIXED 47
     HE=0.0                                                         MIXED 48
C    CALCULATE HEAT TRANSFER FROM SURFACE OF POND                   MIXED 49
     CALL EQTEMP(T,HR,HE)                                           MIXED 50
     IF(F1.LE.0.0)F1=1.0                                            JULY3046
     TSPRAY=T+Q1/(62.4*F1)                                          MIXED 51
```

Figure B.4 (Continued)

```
C     DELAY SPRAYS BY TSPRON HOURS                                      MIXED  52
      IF(X.LT.TSPRON) GOTO 201                                          MIXED  53
      IF(ISPRAY.EQ.1) GOTO 200                                          MIXED  54
C     RIGOROUS MODEL                                                    MIXED  55
      CALL SPRAY2(TSPRAY,ETA,FEVAP,FDR)                                 MIXED  56
      GOTO 201                                                          MIXED  57
C     REGRESSION MODEL                                                  MIXED  58
  200 CALL SPRAY(TSPRAY,ETA,FEVAP,FDR)                                  MIXED  59
  201 CONTINUE                                                          MIXED  60
      HSPRAY=Q1-F1*62.4*ETA*(TSPRAY-TW)                                 MIXED  61
C     RATE OF TEMPERATURE CHANGE, DEG F/HR                              MIXED  62
      FA=(HR*A/24+HSPRAY)/(62.4*V)                                      MIXED  63
C     EVAPORATION RATE FROM SURFACE IN FT**3/HR                         MIXED  64
      DATA HVAP/1040.0/                                                 MIXED  65
      E2=HE*A/(24*HVAP*62.4)                                            MIXED  66
      E2=E2+F1*(FEVAP+FDR)                                              MIXED  67
C     RATE OF VOLUME CHANGE, FT**3/HR                                   MIXED  68
      FB=-BLOW-E2                                                       MIXED  69
      RETURN                                                            MIXED  70
      END                                                               MIXED  71
      SUBROUTINE EQTEMP(T,HR,HE)                                        EQTEMP  2
C     CALCULATE SURFACE HEAT TRANSFER AND EVAPORATION USING             EQTEMP  3
C     FORMULAE OF RYAN ET AL 1973                                       EQTEMP  4
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     EQTEMP  5
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      EQTEMP  6
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   EQTEMP  7
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    EQTEMP  8
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER   26
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     EQTEMP10
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    EQTEMP11
      PAIR=PB*25.4                                                      EQTEMP13
      DTV=(T+460)/(1-.378*PWAT(T)/PAIR)                                 EQTEMP14
     1 -(TA+460)/(1-.378*PWAT(TD)/PAIR)                                 EQTEMP15
      DTV3=0                                                            EQTEMP16
      IF(DTV.LE.0.0) GOTO 1500                                          EQTEMP17
      DTV3=DTV**.33333333                                               EQTEMP18
 1500 FU=(22.4*DTV3+14*W)                                               EQTEMP19
      HE=(PWAT(T)-PWAT(TD))*FU                                          EQTEMP20
      HC=C1*(T-TA)*FU                                                   EQTEMP21
      DATA C1/0.26/                                                     EQTEMP22
      HBR=4.026E-8*(460+T)**4                                           EQTEMP23
      HAN=1.16E-13*(TA+460)**6*(1-CC**2*.17)                            EQTEMP24
      DATA CC/0.0/                                                      EQTEMP25
      HR=HS-HC+HAN-HBR-HE                                               EQTEMP26
      RETURN                                                            EQTEMP27
      END                                                               EQTEMP28
      FUNCTION PWAT(T)                                                  PWAT    2
C     VAPOR PRESSURE OF AIR IN MM HG                                    PWAT    3
C     FOR T IN DEG F                                                    PWAT    4
      TK=(T-32)/1.8+273.1                                               PWAT    5
      PWAT=760*EXP(71.02499-7381.6677/TK-9.0993037*ALOG(TK)             PWAT    6
     1 +.0070831558*TK)                                                 PWAT    7
      RETURN                                                            PWAT    8
      END                                                               PWAT    9
      SUBROUTINE SPRAY(TSPRAY,ETA,FEVAP,FDR)                            SPRAY   2
C     SPRAY POND PERFORMANCE USING REGRESSION EQUATIONS                 SPRAY   3
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     SPRAY   4
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      SPRAY   5
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   SPRAY   6
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    SPRAY   7
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER   27
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     SPRAY   9
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    SPRAY  10
```

Figure B.4 (Continued)

```
      EQUIVALENCE(DB,TA)                                                SPRAY 11
C     HIGH WIND SPEED EFFICIENCY                                        SPRAY 12
      ETA=CH(1)+CH(2)*DB+CH(3)*TW+CH(4)*TSPRAY+CH(5)*W+CH(6)*SQRT(W)    SPRAY 13
C     LWS EFFICIENCY                                                    SPRAY 14
      EL=CL(1)+CL(2)*DB+CL(3)*DB**2+CL(4)*DB**3+CL(5)*TW+               SPRAY 15
     1 CL(6)*TSPRAY+CL(7)*TSPRAY**2                                     SPRAY 16
      IF(ETA.LT.EL) GOTO3                                               SPRAY 17
C     HIGH WIND SPEED EVAPORATION                                       SPRAY 18
      FEVAP=CEH(1)+CEH(2)*DB+CEH(3)*TW+CEH(4)*TSPRAY+                   SPRAY 19
     1 CEH(5)*W+CEH(6)*SQRT(W)                                          SPRAY 20
      GOTO 4                                                            SPRAY 21
C     LOW WIND SPEED EVAPORATION                                        SPRAY 22
    3 FEVAP=CEL(1)+CEL(2)*DB+CEL(3)*DB**2+CEL(4)*DB**3+CEL(5)*TW        SPRAY 23
     1 +CEL(6)*TSPRAY+CEL(7)*TSPRAY**2                                  SPRAY 24
      ETA=EL                                                            SPRAY 25
C     DRIFT LOSS                                                        SPRAY 26
    4 NTBL=(W-WDR0)/DWDR+1                                              SPRAY 27
      IF(NTBL.GE.NDRIFT) NTBL=NDRIFT-1                                  SPRAY 28
      FDR=FDRIFT(NTBL)+((W-WDR0-(NTBL-1)*DWDR)/DWDR)*                   SPRAY 29
     1 (FDRIFT(NTBL+1)-FDRIFT(NTBL))                                    SPRAY 30
C     SET LIMITS ON EVAPORATION AND EFFICIENCY                          SPRAY 31
      IF(FEVAP.LT.CEMIN) FEVAP=CEMIN                                    SPRAY 32
      IF(FEVAP.GT.CEMAX) FEVAP=CEMAX                                    SPRAY 33
      IF(ETA.LT.CMIN) ETA=CMIN                                          SPRAY 34
      IF(ETA.GT.CMAX) ETA=CMAX                                          SPRAY 35
      RETURN                                                            SPRAY 36
      END                                                               SPRAY 37
      SUBROUTINE SPRAY2(THOT,ETA,FEVAP,FDR)                             SPRAY2 2
C     RIGOROUS SPRAY POND MODEL                                         SPRAY2 3
      DIMENSION TSEG(11),HUM(11)                                        SPRAY2 4
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     SPRAY2 5
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      SPRAY2 6
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   SPRAY2 7
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    SPRAY2 8
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER  28
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     SPRAY210
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    SPRAY211
      COMMON/DRPSZ/ R                                                   SPRAY212
      EQUIVALENCE(TA,TDRY),(TW,TWET)                                    SPRAY213
      C(Z)=(Z-32.)/1.8                                                  SPRAY214
C     ALPHA IS CONVERGENCE PARAMETER OF LWS MODEL                       SPRAY215
      DATA ALPHA/-0.05/                                                 AUG12  1
C   CONVERT MPH TO CM/SEC                                               SPRAY217
      WIND1=W*44.7                                                      SPRAY218
C    CONVERT FLOW TO CC/SEC                                             SPRAY219
      Q=F1*7.87                                                         SPRAY220
C     DRIFT LOSS                                                        SPRAY221
    4 NTBL=(W-WDR0)/DWDR+1                                              SPRAY222
      IF(NTBL.GE.NDRIFT) NTBL=NDRIFT-1                                  SPRAY223
      FDR=FDRIFT(NTBL)+((W-WDR0-(NTBL-1)*DWDR)/DWDR)*                   SPRAY224
     1 (FDRIFT(NTBL+1)-FDRIFT(NTBL))                                    SPRAY225
C     CALCULATE HUMIDITY                                                SPRAY226
      CALL PSY1(TDRY,TWET,PB,DP,PV,HUMID,ENTHAL,VOLUME,RH)              SPRAY227
      THOT1=C(THOT)                                                     SPRAY228
      TDRY1=C(TDRY)                                                     SPRAY229
      TWET1=C(TWET)                                                     SPRAY230
C      HIGH WIND SPEED MODEL                                            SPRAY231
C     FOR LOW WIND SPEEDS, GOTO LWS MODEL DIRECTLY                      SPRAY232
      IF(W.LT.3.0) GOTO2000                                             SPRAY233
      CALL HWS(THOT1,HUMID,TDRY1,       TWAV,WIND1,Q,R,EVAPS)           SPRAY234
C     HWS EFFICIENCY AND EVAPORATION                                    SPRAY235
      ETA=(THOT1-TWAV)/(THOT1-TWET1)                                    SPRAY236
      FEVAP=EVAPS/Q                                                     SPRAY237
```

Figure B.4 (Continued)

```
 2000 CONTINUE                                                          SPRAY238
C     SKIP LWS MODEL FOR THIS CONDITION TO AVOID COMPUTATIUNAL PROBLEMS SPRAY239
C     HWS EFFICIENCY                                                    SPRAY240
      IF(TDRY.GT.THOT) GOTO 1111                                        SPRAY241
      DATA KOUNT/0/                                                     SPRAY242
      IF(KOUNT.GT.1) GOTO 445                                           SPRAY243
C     INITIALIZE HUMIDITY AND TEMPERATURE IF FIRST RUN                  SPRAY244
      DO 444 L=2,11                                                     SPRAY245
      TSEG(L)=TDRY1+1.0                                                 SPRAY246
  444 HUM(L)=HUMID+.01                                                  SPRAY247
      KOUNT=KOUNT+1                                                     SPRAY248
  445 CONTINUE                                                          SPRAY249
C     LOW WIND SPEED MODEL                                              SPRAY250
      CALL LWS(THOT1,HUMID,TDRY1,TWAV,Q,R,TSEG,HUM,ALPHA,EVAPS)         SPRAY251
C     LWS EFFICIENCY AND EVAPORATION                                    SPRAY252
      ETA2=(THOT1-TWAV)/(THOT1-TWET1)                                   SPRAY253
      FEVAP2=EVAPS/Q                                                    SPRAY254
C     PICK LARGER EFFICIENCY                                            SPRAY255
      IF(ETA.GT.ETA2) GOTO 1002                                         AUG12  2
      ETA=ETA2                                                          SPRAY257
      FEVAP=FEVAP2                                                      SPRAY258
C     LIMITS ON EFFICIENCY AND EVAPORATION                              SPRAY259
 1002 IF(ETA.GT.CMAX) ETA=CMAX                                          SPRAY260
      IF(ETA.LT.CMIN) ETA=CMIN                                          SPRAY261
      IF(FEVAP.LT.CEMIN) FEVAP=CEMIN                                    SPRAY262
      IF(FEVAP.GT.CEMAX) FEVAP=CEMAX                                    SPRAY263
      RETURN                                                            SPRAY264
C     FALL BACK ON REGRESSION MODEL                                     SPRAY265
 1111 CONTINUE                                                          SPRAY266
      CALL SPRAY(THOT,ETA,FEVAP,FDR)                                    SPRAY267
      RETURN                                                            SPRAY268
      END                                                               SPRAY269
      SUBROUTINE LWS(THOT,HUMID,TAIR,TWAV,Q,R,TSEG,HUM,ALPHA,EVAPS)     LWS    2
C     LOW WIND SPEED MODEL                                              LWS    3
      DIMENSION VUP(12),FLOW(12),QT(12),RHO2(12),VH(12)                 LWS    4
      DIMENSION TSEG(11),HUM(11),HOUT(11)                               LWS    5
      DIMENSION HFIL(12),TFIL(12)                                       LWS    6
      DIMENSION TM2(12),TM1(12),HM2(12),HM1(12)                         LWS    7
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     LWS    8
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      LWS    9
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   LWS   10
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    LWS   11
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER  29
     5 DUM1(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     LWS   13
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    LWS   14
      DO 491 I=1,12                                                     LWS   15
      TM2(I)=0                                                          LWS   16
      TM1(I)=0                                                          LWS   17
      HM2(I)=0                                                          LWS   18
  491 HM1(I)=0                                                          LWS   19
      TLAST=0                                                           LWS   20
      DATA HVAP,CP,RHO/580.0,1.0,1.0/                                   LWS   21
      ICNT=0                                                            LWS   22
C     DENSITY OF AMBIENT AIR GM/CC                                      LWS   23
      RHO1=(1+HUMID)/((81.86*TAIR+22387)*(.03448+HUMID/18))             LWS   24
      FLOW(11)=0                                                        LWS   25
      QT(1)=0                                                           LWS   26
      FLOW(1)=0                                                         LWS   27
      RHO2(1)=RHO1                                                      LWS   28
      ATOT=ALEN*WID                                                     LWS   29
      TSEG(1)=TAIR                                                      LWS   30
      HUM(1)=HUMID                                                      LWS   31
C     CONCENTRATION OF WATER IN AIR                                     LWS   32
```

Figure B.4 (Continued)

```
      CWA=HUMID/((81.86*TAIR+22387)*(.03448+HUMID/18))
C     BEGIN ITERATIVE SOLUTION
      DO 801 NITER=1,20
      DO 101 J=1,10
      I=12-J
C     DENSITY OF AIR IN EACH SEGMENT GM/CC
      RHO2(I)=(1+HUM(I))/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))
C     HUMID VOLUME, CC/GM BDA
      VH(I)=((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))
  101 CONTINUE
  105 CONTINUE
      DO 1001 J=1,10
      I=12-J
      DRHO=RHO1-RHO2(I)
      ARG=980*DRHO*HT*.5/RHO1
      ICNT=1
      IF(ARG.LT.0.0) GOTO 668
C     UPWARD VELOCITY OF AIR LEAVING EACH SEGMENT
      VUP(I)=SQRT(ARG)
  668 CONTINUE
C     MATERIAL BALANCE ON EACH SEGMENT
      QT(I)=VUP(I)*ATOP(I)/VH(I)
      FLOW(I-1)=FLOW(I)+QT(I)
 1001 CONTINUE
      ICNT=ICNT+1
  104 CONTINUE
C     ENTHALPY OF AIR ENTERING FIRST SEGMENT, CAL/GM BDA
      HOUT(1)=FLOW(1)*(.238*TAIR+HUMID*(HVAP+.45*TAIR))
      TSEG(1)=TAIR
      EVAPS=0
      HUM(1)=HUMID
      SUMTC=0
      DO 201 I=2,11
      TEMP=TSEG(I-1)+273.2
C     VISCOSITY OF AIR, GM/(SEC CM)
      VIS=2.7936E-6*TEMP**.73617
C     DENSITY OF AIR, GM/CC
      RHOA=.353/TEMP
C     DIFFUSION COEFF OF AIR(CM**2/SEC)
      DIFF=5.8758E-6*TEMP**1.8615
C     PRANTL NO
      PRANTL=.93176*TEMP**(-.042784)
C     SCHMIDT NO
      SC=2.2705*TEMP**(-.21398)
C     THERMAL CONDUCTIVITY OF AIR,CM/SEC
      AC=3.9273E-7*TEMP**.88315
      CON4=AC/R
      CON6=2*R*RHOA/VIS
      CON5=DIFF/R
      TDROP=THOT
C     CALCULATE TEMPERATURE AND EVAPORATION OF FALLING DROPS
      CALL DROP(TSEG(I-1),CWA)
C     SENSIBLE HEAT TRANSFER IN SEGMENT
      HSEG=RHO*CP*(Q*ATOP(I)/ATOT)*(THOT-TDROP)
C     EVAPORATION IN SEGMENT
      EVAP1=EVAP*Q*ATOP(I)/(ATOT*VOL)
C     SENSIBLE HE AT LEAVING SEGMENT AND ENTERING NEXT
      HOUT(I)=HSEG+HOUT(I-1)*(1-QT(I-1)/(QT(I-1)+FLOW(I-1)))
C     HUMIDITY IN SEGMENT
      HUM(I)=HUM(I-1)+EVAP1/FLOW(I-1)
C     TEMPERATURE IN SEGMENT
      TSEG(I)=(HOUT(I)/FLOW(I-1)-HUM(I)*HVAP)/(.238+.45*HUM(I))
      EVAPS=EVAPS+EVAP1
```

Figure B.4 (Continued)

```
      CWA=HUM(I)/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))             LWS  96
      SUMTC=SUMTC+TDROP*ATOP(I)                                         LWS  97
  201 CONTINUE                                                          LWS  98
C     AVERAGE TEMPERATURE OF WATER FALLING TO POND SURFACE              LWS  99
      TWAV=SUMTC/ATOT                                                   LWS 100
      IF(NITER.LT.3) GOTO 49                                            LWS 101
      DO 492 I=2,11                                                     LWS 102
C     SECOND ORDER SMOOTHING OPERATOR TO AID CONVERGENCE                LWS 103
      HFIL(I)=ALPHA*(HM2(I)-2*HM1(I)+HUM(I))                            LWS 104
      TFIL(I)=ALPHA*(TM2(I)-2*TM1(I)+TSEG(I))                           LWS 105
  492 CONTINUE                                                          LWS 106
      DO 493 I=2,11                                                     LWS 107
      TSEG(I)=TSEG(I)+TFIL(I)                                           LWS 108
      HUM(I)=HUM(I)+HFIL(I)                                             LWS 109
  493 CONTINUE                                                          LWS 110
   49 DO 494 I=2,11                                                     LWS 111
      TM2(I)=TM1(I)                                                     LWS 112
      TM1(I)=TSEG(I)                                                    LWS 113
      HM2(I)=HM1(I)                                                     LWS 114
  494 HM1(I)=HUM(I)                                                     LWS 115
      IF(ABS((TLAST-TWAV)/TWAV).LT.0.002) GOTO 800                      LWS 116
      TLAST=TWAV                                                        LWS 117
  801 CONTINUE                                                          LWS 118
      WRITE(6,20)                                                       LWS 119
   20 FORMAT(10X,'NO CONVERGENCE AFTER 20 TRIES')                       LWS 120
  800 RETURN                                                            LWS 121
      END                                                               LWS 122
      SUBROUTINE HWS(THOT,HUMID,TAIR,TWAV,WIND,Q,R,EVAPS)               HWS   2
C     HIGH WIND SPEED MODEL                                             HWS   3
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     HWS   4
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      HWS   5
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   HWS   6
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    HWS   7
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER  30
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     HWS   9
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    HWS  10
      DIMENSION TSEG(11),HUM(11),HOUT(11)                               HWS  11
      DATA HVAP,CP,RHO/580.0,1.0,1.0/                                   HWS  12
      CON7=RHO*CP*Q/10                                                  HWS  13
      CON8=Q/(10*VOL)                                                   HWS  14
C     GMS OF BDA ENTERING SPRAY FIELD FROM UPWIND                       HWS  15
      FLO=WIND*ASIDEH/((81.86*TAIR+22387)*(.03448+HUMID/18))            HWS  16
C     ENTHALPY OF AIR ENTERING SPRAY FIELD,CAL/SEC                      HWS  17
      HOUT(1)=FLO *(.238*TAIR+HUMID*(HVAP+.45*TAIR))                    HWS  18
      TSEG(1)=TAIR                                                      HWS  19
      HUM(1)=HUMID                                                      HWS  20
C     CONCENTRATION OF WATER IN AIR                                     HWS  21
      CWA=HUMID/((81.86*TAIR+22387)*(.03448+HUMID/18))                  HWS  22
      EVAPS=0                                                           HWS  23
      SUMTC=0                                                           HWS  24
      DO 1 I=2,11                                                       HWS  25
      TEMP=TSEG(I-1)+273.2                                              HWS  26
C     VISCOSITY OF AIR GM/(CM SEC)                                      HWS  27
      VIS=2.7936E-6*TEMP**.73617                                        HWS  28
C     DENSITY OF AIR GM/CC                                              HWS  29
      RHOA=.353/TEMP                                                    HWS  30
C     DIFFUSION COEFFICIENT OF AIR CM**2/SEC                            HWS  31
      DIFF=5.8758E-6*TEMP**1.8615                                       HWS  32
C     PRANTL NO                                                         HWS  33
      PRANTL=.93176*TEMP**(-.042784)                                    HWS  34
C     SCHMIDT NO                                                        HWS  35
      SC=2.2705*TEMP**(-.21398)                                         HWS  36
C     THERMAL CONDUCTIVITY OF AIR CM/SEC                                HWS  37
```

Figure B.4 (Continued)

```
      AC=3.9273E-7*TEMP**.88315                                         HWS   38
      CON4=AC/R                                                         HWS   39
      CON6=SQRT(2*R*RHOA/VIS)                                           HWS   40
      CON5=DIFF/R                                                       HWS   41
      TDROP=THOT                                                        HWS   42
C     TEMPERATURE AND EVAPORATION OF DROP                               HWS   43
      CALL DROP(TSEG(I-1),CWA)                                          HWS   44
C     SENSIBLE HEAT ENTERING SEGMENT FROM DROPS                         HWS   45
      HSEG=CON7*(THOT-TDROP)                                            HWS   46
C     EVAPORATION FROM ALL DROPS INTO SEGMENT                           HWS   47
      EVAP1=EVAP*CON8                                                   HWS   48
C     ENTHALPY LEAVING SEGMENT AND ENTERING NEXT                        HWS   49
      HOUT(I)=HOUT(I-1)+HSEG                                            HWS   50
C     HUMIDITY OF SEGMENT                                               HWS   51
      HUM(I)=HUM(I-1)+EVAP1/FLO                                         HWS   52
C     AIR TEMPERATURE IN SEGMENT                                        HWS   53
      TSEG(I)=(HOUT(I)/FLO -HUM(I)*HVAP)/(.24+.45*HUM(I))               HWS   54
      EVAPS=EVAPS+EVAP1                                                 HWS   55
C    CWA = CONCENTRATION OF WATER IN AIR, GM/CC                         HWS   56
      CWA=HUM(I)/((81.86*TSEG(I)+22387)*(.03448+HUM(I)/18))             HWS   57
      SUMTC=SUMTC+TDROP                                                 HWS   58
    1 CONTINUE                                                          HWS   59
C     AVERAGE TEMPERATURE OF WATER FALLING TO POND SURFACE              HWS   60
      TWAV=SUMTC/10                                                     HWS   61
      RETURN                                                            HWS   62
      END                                                               HWS   63
      SUBROUTINE DROP(TAIR,CINF)                                        DROP   2
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     DROP   3
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      DROP   4
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   DROP   5
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    DROP   6
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER  31
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     DROP   8
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    DROP   9
C     CALCULATE HEAT AND MASS TRANSFER FROM A DROP                      DROP  10
      EVAP=0                                                            DROP  11
      ICNT=1                                                            DROP  12
C       BEGIN FOURTH ORDER RUNGE-KUTTA INT.OF EQUATIONS                 DROP  13
      DO 1 I=1,NSTDR                                                    DROP  14
      CALL FTDROP(ICNT,TDROP,DTD1,DI1,TAIR,CINF)                        DROP  15
      ICNT=ICNT+1                                                       DROP  16
      TDROP1=TDROP+DT02*DTD1                                            DROP  17
      CALL FTDROP(ICNT,TDROP1,DTD2,DI2,TAIR,CINF)                       DROP  18
      TDROP2=TDROP+DTD2*DT02                                            DROP  19
      CALL FTDROP(ICNT,TDROP2,DTD3,DI3,TAIR,CINF)                       DROP  20
      ICNT=ICNT+1                                                       DROP  21
      TDROP3=TDROP+DTD3*DTDROP                                          DROP  22
      CALL FTDROP(ICNT,TDROP3,DTD4,DI4,TAIR,CINF)                       DROP  23
      TDROP=TDROP+(DTD1+2*(DTD2+DTD3)+DTD4)*DT06                        DROP  24
      EVAP=EVAP+(DI1+2*(DI2+DI3)+DI4)*DT06                              DROP  25
    1 CONTINUE                                                          DROP  26
      RETURN                                                            DROP  27
      END                                                               DROP  28
      SUBROUTINE FTDROP(ICNT,TDRP,DTD,DI,TAIR,CINF)                     FTDROP 2
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     FTDROP 3
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      FTDROP 4
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   FTDROP 5
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    FTDROP 6
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,G(1400,6),HEAT(20),        ITER  32
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     FTDROP 8
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    FTDROP 9
C     RATE OF HEAT AND MASS TRANSFER FROM A DROP                        FTDROP10
      COMMON/RESTOR/ SQV(100)                                           FTDROP11
```

Figure B.4 (Continued)

```
      DATA RG/82.02/                                                    FTDROP12
      TDK=TDRP+273.2                                                    FTDROP13
C     VAPOR PRESSURE OF WATER ATM                                       FTDROP14
      P=EXP(71.02499-7381.6477/TDK-9.0993037*ALOG(TDK)                  FTDROP15
     1 +.0070831558*TDK)                                                FTDROP16
      SRE=CON6*SQV(ICNT)                                                FTDROP17
      HC=CON4*(1+.3*PRANTL**.3333333*SRE)                               FTDROP18
      HD=CON5*(1+.3*SC**.3333333*SRE)                                   FTDROP19
      CDROP=P*18.0/(RG*TDK)                                             FTDROP20
C     RATE OF MASS TRANSFER                                             FTDROP21
      DI=CON3*HD*(CDROP-CINF)                                           FTDROP22
      DATA HVAP/580.0/                                                  FTDROP23
C     RATE OF TEMPERATURE CHANGE                                        FTDROP24
      DTD=-CON1*(DI*HVAP+CON3*HC*(TDRP-TAIR))                           FTDROP25
      RETURN                                                            FTDROP26
      END                                                               FTDROP27
      SUBROUTINE INIT(R,THETA,Y0,VEL0)                                  INIT   2
C     INITIALIZE CONSTANTS AND VELOCITIES OF BALLISTIC DROP             INIT   3
      COMMON CH(6),CL(7),CEH(6),CEL(7),NDRIFT,WDR0,DWDR,FDRIFT(20),     INIT   4
     1 CEMIN,CEMAX,CMIN,CMAX,VOL,AM,CON1,CON2,CON3,CON4,CON5,CON6,      INIT   5
     2 VIS,RHOA,DIFF,AK,H,EVAP,DT06,DT02,TDROP,U0,V0,SC,PRANTL,NSTDR,   INIT   6
     3 ATOP(12), ASIDE(12),K1,E,E2,BETA,TSKIP,QBASE,FBASE,M1,M2,BTA,    INIT   7
     4 BTD,BHS,BW,IMET,BLOW,F1,Q1,TD,TA,HS,W,Z(8400  ),HEAT(20),        ITER  33
     5 FLOW(20),TH(20),NMET,NH,A,DTMET,TW,PR,DTDROP                     INIT   9
     6 ,ASIDEH,HT,WID,ALEN,PB,ISPRAY                                    INIT  10
      COMMON/RESTOR/SQV(100)                                            INIT  11
      VOL=(3.1415926*4/3)*R**3                                          INIT  12
      DATA G/980.0/                                                     INIT  13
      DATA HVAP,CP,RHO/580.0,1.0,1.0/                                   INIT  14
      A=3.1415926*R**2                                                  INIT  15
      CON1=1.0/VOL                                                      INIT  16
      CON2=HVAP*12.566371*R**2                                          INIT  17
      CON3=12.566371*R**2                                               INIT  18
      V0=VEL0*SIN(THETA)                                                INIT  19
      U0=VEL0*COS(THETA)                                                INIT  20
C     TIME FOR DROP TO HIT SURFACE OF WATER                             INIT  21
      TFALL=V0/G+SQRT((V0/G)**2+2*Y0/G)                                 INIT  22
      DTDROP=TFALL/NSTDR                                                INIT  23
      DT06=DTDROP/6                                                     INIT  24
      DT02=DTDROP/2                                                     INIT  25
      NUM=NSTDR*2+10                                                    INIT  26
      DO 1 I=1,NUM                                                      INIT  27
      T=(I-1)*DT02                                                      INIT  28
C     VELOCITY OF DROP                                                  INIT  29
      V=SQRT(U0**2+(V0-980*T)**2)                                       INIT  30
    1 SQV(I)=SQRT(V)                                                    INIT  31
      RETURN                                                            INIT  32
      END                                                               INIT  33
      SUBROUTINE PSY1(DB,WB,PB,DP,PV,W,H,V,RH)                          PSY1   2
C     THIS ROUTINE CALCULATES' VAPOR PRESSURE PV, HUMIDITY RATIO W,     PSY1   3
C         ENTHALPY H, VOLUME V, RELATIVE HUMIDITY RH, AND               PSY1   4
C         DEW POINT TEMPERATURE DP\                                     PSY1   5
C         WHEN THE DRY BULB TEMPERATURE DB, WET BULB TEMPERATURE WB,    PSY1   6
C         AND BAROMETRIC PRESSURE PB ARE GIVEN                          PSY1   7
C     UNITS' DB, WB, + DP )F>\ PB, + PV )IN OF HG>\ W)= WATER VAPOR     PSY1   8
C         PER = DRY AIR>\ H )BTU/= OF DRY AIR>\ V )FT**3/= OF DRY       PSY1   9
C         AIR\ RH IS A FRACTION, NOT (                                  PSY1  10
      C(F)=(F-32.0E0)/1.8E0                                             PSY1  11
      PVP=PVSF(WB)                                                      PSY1  12
      WSTAR=0.622*PVP/(PB-PVP)                                          PSY1  13
      IF (WB.GT.32.0) GO TO 105                                         PSY1  14
      PV=PVP-5.704E-4*PB*(DB-WB)/1.8                                    PSY1  15
      GO TO 110                                                         PSY1  16
```

Figure B.4 (Continued)

```
  105 CDB=C(DB)
      CWB=C(WB)
      HL=597.31+0.4409*CDB-CWB
      CH=0.2402+0.4409*WSTAR
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
      PV=PB*EX/(1.+EX)
  110 W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1.0+7000.0*W/4360.0)/PB
      H=0.24*DB+(1061.0+0.444*DB)*W
      IF (PV.GT.0.0) GO TO 115
      PV=0.0
      DP=0.0
      RH=0.0
      RETURN
  115 IF (DB.NE.WB) GO TO 120
      DP=DB
      RH=1.0
      RETURN
  120 DP=DPF(PV)
      RH=PV/PVSF(DB)
      RETURN
      END
      FUNCTION PVSF(X)
      DIMENSION A(6),B(4),P(4)
      DATA A/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.49149/
      DATA B/-9.09718,-3.56654,0.876793,0.0060273/
      T=(X+459.688)/1.8
      IF (T.LT.273.16) GO TO 100
      Z=373.16/T
      P(1)=A(1)*(Z-1.0)
      P(2)=A(2)*ALOG10(Z)
      Z1=A(4)*(1.0-1.0/Z)
      P(3)=A(3)*(10.0**Z1-1.0)
      Z1=A(6)*(Z-1.0)
      P(4)=A(5)*(10.0**Z1-1.0)
      GO TO 105
  100 Z=273.16/T
      P(1)=B(1)*(Z-1.0)
      P(2)=B(2)*ALOG10(Z)
      P(3)=B(3)*(1.0-1.0/Z)
      P(4)=ALOG10(B(4))
  105 SUM=0.0
      DO 110 I=1,4
  110 SUM=SUM+P(I)
      PVSF=29.921*10.0**SUM
      RETURN
      END
      FUNCTION DPF(PV)
C     THIS ROUTINE CALCULATES DEW-POINT TEMPERATURE FOR A GIVEN
C         VAPOR PRESSURE PV
      DP(A,B,C,Y)=A+(B+C*Y)*Y
      Y=ALOG(PV)
      IF (PV.GT.0.1836) GO TO 100
      DPF=DP(71.98,24.873,0.8927,Y)
      RETURN
  100 DPF=DP(79.047,30.579,1.8893,Y)
      RETURN
      END
```

Figure B.4 (Continued)

```
      PROGRAM COMET2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     SPRAY POND DATA COMPARISON MODEL
C     COMPARE WATER USAGE AND TEMPERATURE FOR TWO SETS OF METEOROLOGY
C     RICHARD CODELL - US NRC, WASHINGTON DC, DECEMBER 1979
C
C
C     TW1= WET BULB TEMPERATURE FOR DATA SET 1
C     TA1= DRY BULB TEMP. FOR DATA SET 1   (F)
C     W1= WIND SPEED FOR DATA SET 1   (MPH)
C     H1= RATE OF INSOLATION FOR DATA SET 1   (BTU/FT**2/DAY)
C     TW2= WET BULB TEMPERATURE FOR DATA SET 2
C     TA2= DRY BULB TEMP. FOR DATA SET 2   (F)
C     W2= WIND SPEED FOR DATA SET 2   (MPH)
C     H2= RATE OF INSOLATION FOR DATA SET 2   (BTU/FT**2/DAY)
C     PB1 = BAROMETRIC PRESSURE, DATA SET 1(INCHES MERCURY)
C     PB2 = BAROMETRIC PRESSURE, DATA SET 2(INCHES MERCURY)
C
      COMMON HE,  FEVAP,FDR,WDRO,NDRIFT,DWDR,FDRIFT(20),CH(6),CL(7),
     1 CEH(6),CEL(7),HEAT,CON1,CON2,CON3,DTSPRY,DTIME,QSPRAY,V,TD
      DATA QX,QY,QX2,QY2,QCROSS/5*0.0/
      DATA ERR/1.0E-30/
      DATA SX,SY,SX2,SY2,SCROSS/5*0./
      NAMELIST /INLIST/ DTIME,V,A,QSPRAY,HEAT,NDRIFT,WDRO,DWDR,FDRIFT
      PRINT 95
   95 FORMAT(1H1,20X,'DIFFERENCES IN STEADY STATE TEMPERATURES AND WATER
     1 USE FOR SUBJECT SPRAY POND',/20X,'USING MONTHLY AVERAGE VALUES OF
     2 WET BULB,DRY BULB,WIND SPEED,AND SOLAR RADIATION FROM ONSITE
     3',/20X'AND OFFSITE MET STATIONS',///)
      DTIME=0.0
      HEAT=5.0E8
      NDRIFT=2
      WDRO=0
      DWDR=2
      FDRIFT(1)=.0000001
      FDRIFT(2)=.0000001
C     COEFFICIENTS FOR MULTIPLE REGRESSION MODELS OF SPRAY EFFICIENCY
C     AND EVAPORATION LOSS GENERATED BY PROGRAM SPRCO
      READ(5,555) CH,CL,CEH,CEL
  555 FORMAT(4E15.8)
      READ(5,INLIST)
C     ESTIMATE ITERATION TIME IF NOT SPECIFIED
      IF(DTIME.GT.0.0) GOTO 40
      DTIME=10.0*HEAT/(62.4*V)
   40 CONTINUE
      WRITE(6,50) DTIME,V,A,QSPRAY,HEAT,WDRO,DWDR
   50 FORMAT(//20X,'TIMESTEP IN ITERATION DTIME = ',F10.3,' HOURS'/
     1 20X,'VOLUME OF POND, V = ',F12.1,' FT**3'/
     1 20X,'SURFACE AREA OF POND, A = ',F12.1,' FT**2'/
     2 20X,'RATE OF SPRAYING, QSPRAY = ',F12.1,' FT**3/SEC'/
     3 20X,'STEADY HEAT LOAD, HEAT = ',F12.1,' BTU/HR'/
     5 20X,'LOWER LIMIT OF WIND IN DRIFT TABLE WDRO = ',F10.2,' MPH'/
     6 20X,'INCREMENT IN DRIFT TABLE,DWDR = ',F10.2,' MPH'//)
      WRITE(6,52)
   52 FORMAT(//,15X,'DRIFT LOSS TABLE',/,T18,'WIND SPEED, MPH',T34,'DRIF
     1T LOSS FRACTION',/)
      DO 51 I=1,NDRIFT
      WSP=(I-1)*DWDR+WDRO
   51 WRITE(6,53) WSP,FDRIFT(I)
   53 FORMAT(T20,F10.2,T40,F11.8)
      DTSPRY=HEAT/(QSPRAY*3600*62.4)
      CON1=A/(1498*V)
      CON2=A/(1497600)
      CON3=62.4*3600
```

Figure B.5 Listing of program COMET2

```
      READ(5,499) I
  499 FORMAT(I2)
      DO 2 J=1,I
      READ(5,500) TW1,TA1,W1,H1,PB1,TW2,TA2,W2,H2.PB2
  500 FORMAT(10F8.0)
C
C     IF DATA ARE MISSING IN SECOND SET, SET EQUAL TO VALUE IN 1ST SET
C
      IF(TW2.EQ.0.0)TW2=TW1
      IF(TA2.EQ.0.0)TA2=TA1
      IF(W2.EQ.0.0)W2=W1
      IF(H2.EQ.0.) H2=H1
      IF(PB2.EQ.0.0)PB2=PB1
C
C     CALCULATE STEADY STATE TEMPERATURE AND EVAPORATION RATE
C     FOR EACH DATA SET
C
      E1=E(TA1,W1,H1,PB1,TW1)
      EVAP1=30*HE/(62.4*HVAP)
      EVAP1=EVAP1+30*(FDR+FEVAP)*QSPRAY*86400/A
      EVAP1=EVAP1*A
      E2=E(TA2,W2,H2,PB2,TW2)
      DATA HVAP/1040.0/
      EVAP2=30*HE/(62.4*HVAP)
      EVAP2=EVAP2+30*(FDR+FEVAP)*QSPRAY*86400/A
      EVAP2=EVAP2*A
      DE=E2-E1
      DEVAP=EVAP2-EVAP1
      WRITE(6,99)
      WRITE(6,101) TW1,TA1,W1,H1,PB1,E1,EVAP1
      WRITE(6,200) TW2,TA2,W2,H2,PB2,E2,EVAP2
   99 FORMAT(T21,'WET BULB',T37,'DRY BULB',T51,'WIND SPEED',/T22,
     1 'SOLAR RAD.'T84,'PB',T97,'POND TEMP',T114,'EVAPORATION',/T22,
     2 '(DEG. F)',T36,'(DEG.F)',T54,'(MPH)',T80,'INCHES HG',T64,
     3 '(BTU/FT**2/DY)',T96,'(DEG. F)',T112,'      FT**3'//)
  101 FORMAT( 5X,'DATA SET 1',F12.2,5F15.2,F20.2,/)
  200 FORMAT( 5X,'DATA SET 2',F12.2,5F15.2,F20.2,/)
      WRITE(6,102) DE,DEVAP
  102 FORMAT(T77,'E2-E1 = ', F6.3,5X,'EVAP2-EVAP1 = ',F12.1)
C
C     CALCULATE SUMS FOR CORRELATION COEFFICIENTS
C
      SX=SX+E1
      SX2=SX2+E1**2
      SY=SY+E2
      SY2=SY2+E2**2
      SCROSS=SCROSS+E1*E2
      QX=QX+EVAP1
      QX2=QX2+EVAP1**2
      QY=QY+EVAP2
      QY2=QY2+EVAP2**2
      QCROSS=QCROSS+EVAP1*EVAP2
C
C     DIFFERENCES IN EQUILIBRIUM TEMP DUE TO EACH PARAMETER.
C
      DTW=E(TA1,W1,H1,PB1,TW2)-E1
      DTA=E(TA2,W1,H1,PB1,TW1)-E1
      DW=E(TA1,W2,H1,PB1,TW1)-E1
      DH=E(TA1,W1,H2,PB1,TW1)-E1
      DPB=E(TA1,W1,H1,PB2,TW1)-E1
      DTOT=DTW+DTA+DW+DH+DPB
      WRITE(6,5)
    5 FORMAT(//10X, 'DIFFERENCES IN E BETWEEN DATA SET 2 AND DATA SET 1
     1BY PARAMETER',/)
```

Figure B.5 (Continued)

```
      WRITE(6,6)DTW
    6 FORMAT(10X,'DIFFERENCE DUE TO WET BULB = ',T50,F10.3,' DEG. F')
      WRITE(6,7)DTA
    7 FORMAT(10X,'DIFFERENCE DUE TO DRY BULB TEMP. = ',T50,F10.3,' DEG.
     1F')
      WRITE(6,8) DW
    8 FORMAT(10X,'DIFFERENCE DUE TO WIND SPEED = ',T50,F10.3,' DEG. F')
      WRITE(6,9)DH
    9 FORMAT(10X,'DIFFERENCE DUE TO INSOLATION = 'T50,F10.3,' DEG. F')
      WRITE(6,11) DPB
   11 FORMAT(10X,'DIFFERENCE DUE TO BAROMETRIC PRESSURE = ',T50,F10.3,
     1 ' DEG F')
      WRITE(6,10)DTOT
   10 FORMAT(10X,'SUMMATION OF INDIVIDUAL DIFFERENCES = ',T50,F10.3,' DE
     1G. F',//,1X,130('*'),///)
    2 CONTINUE
C
C     CORRELATION ANALYSIS
C
      SXX=I*SX2-SX**2
      SYY=I*SY2-SY**2
      SXY=I*SCROSS-SX*SY
      RSQ=(SXY**2+ERR)/(SXX*SYY+ERR)
      QXX=I*QX2-QX**2
      QYY=I*QY2-QY**2
      QXY=I*QCROSS-QX*QY
      QRSQ=(QXY**2+ERR)/(QXX*QYY+ERR)
      SERR=SQRT(((SXX*SYY)-SXY**2)/(I*(I-2)*SXX))
      QSERR=SQRT(((QXX*QYY)-QXY**2)/(I*(I-2)*QXX))
      WRITE(6,300) RSQ,SERR
      WRITE(6,310) QRSQ,QSERR
  300 FORMAT(10X,'SAMPLE R SQUARED FOR EQUILIBRIUM TEMP. = ',F10.3,
     1 10X,'STANDARD ERROR = ',F10.3,' DEG.F')
  310 FORMAT(10X,'SAMPLE R SQUARED FOR EVAPORATION = ', F10.3,
     1 10X,'STANDARD ERROR = ',F10.3,'FT**3')
      SXXI=SX /I
      SYYI=SY /I
      BIAS=SYYI-SXXI
      WRITE(6,250) SXXI,SYYI,BIAS
  250 FORMAT(10X,'AVERAGE E, DATA SET 1 = ',F12.3,/,10X,'AVERAGE E, DATA
     1 SET 2 = ',F12.3,/,10X,'AVERAGE E2 - AVERAGE E1 = ',F12.4)
      EBIAS=(QY-QX)/I
      WRITE(6,251) EBIAS
  251 FORMAT(10X, 'AVERAGE EVAP2 - AVERAGE EVAP1 = ',F12.4)
      STOP
      END
      FUNCTION E(TA,W,H,PB,WB)
C
C     CALCULATES THE STEADY STATE TEMPERATURE BY
C     AN ITERATIVE PROCESS, WITH SPRAY HEAT LOSS, EVAPORATION, AND
C     DRIFT DETERMINED BY REGRESSION COEFFICIENTS FROM PROGRAMS
C     #SPRAYCO# AND #DRIFT#
C
      COMMON HE,  FEVAP,FDR,WDRO,NDRIFT,DWDR,FDRIFT(20),CH(6),CL(7),
     1 CEH(6),CEL(7),HEAT,CON1,CON2,CON3,DTSPRY,DTIME,QSPRAY,V,TD
      ES=100
C    CONVERT ATM PRESSURE TO MM
      PAIR=PB*760.0/29.92
C     CALCULATE DEW POINT TEMPERATURE
      CALL PSY1(TA,WB,PB,TD,PV,HUMRAT,ENTHAL,HUMVOL,RH)
C     BEGIN ITERATIVE SOLUTION FOR POND TEMPERATURE
      DO 1 I=1,50
      TSPRAY=ES+DTSPRY
C     SURFACE HEAT TRANSFER AND EVAPORATION FROM RYAN, 1973
```

Figure B.5 (Continued)

```
      DTV=(ES+460)/(1.-.378*PWAT(ES)/PAIR)-
     1  (TA+460)/(1.0-.378*PWAT(TD)/PAIR)
      DTV3=0
      IF(DTV.LE.0.0) GOTO 1500
      DTV3=DTV**.33333333
 1500 FU=22.4*DTV3+14*W
      HC=0.26*(ES-TA)*FU
      HBR=4.026E-8*(460+ES)**4
      HE=(PWAT(ES)-PWAT(TD))*FU
      HAN=1.16E-13*(TA+460)**6*(1.0-CC**2*.17)
C    CONSERVATIVE VALUE FOR CLOUD COVER
      DATA CC/0.0/
      HR=H-HC+HAN-HBR-HE
C     HWS EFFICIENCY
      ETA=CH(1)+CH(2)*TA+CH(3)*WB+CH(4)*TSPRAY+CH(5)*W+CH(6)*SQRT(W)
C     LWS EFFICIENCY
      EL=CL(1)+CL(2)*TA+CL(3)*TA**2+CL(4)*TA**3+CL(5)*WB+
     1 CL(6)*TSPRAY+CL(7)*TSPRAY**2
      IF(ETA.LT.EL) ETA=EL                                              001520
      IF(ETA.LT.0.0) ETA=0.0
      IF(ETA.GT.1.0) ETA=1.0
C     SPRAY HEAT LOSS
      HSPRAY=HEAT-QSPRAY*CON3*ETA*(TSPRAY-WB)                           001530
      DTEMP=HR*CON1+HSPRAY/(62.4*V)
      T1=ES                                                             001550
      ES=ES+DTEMP*DTIME                                                 001560
      IF(ABS(T1-ES).LT.0.002) GO TO 2
    1 CONTINUE                                                          001580
    2 CONTINUE                                                          001590
      E=ES
      IF(ETA.EQ.EL) GOTO 3                                              001600
C     HIGH WIND SPEED EVAPORATION
      FEVAP=CEH(1)+CEH(2)*TA+CEH(3)*WB+CEH(4)*TSPRAY+                   001620
     1 CEH(5)*W+CEH(6)*SQRT(W)
      GOTO 4                                                            001640
C     LOW WIND SPEED EVAPORATION
    3 FEVAP=CEL(1)+CEL(2)*TA+CEL(3)*TA**2+CEL(4)*TA**3+CEL(5)*WB
     1 +CEL(6)*TSPRAY+CEL(7)*TSPRAY**2
C     DRIFT LOSS
    4 NTBL=(W-WDR0)/DWDR+1                                              001670
      IF(NTBL.GE.NDRIFT) NTBL=NDRIFT-1                                  001680
      FDR=FDRIFT(NTBL)+((W-WDR0-(NTBL-1)*DWDR)/DWDR)*                   001690
     1 (FDRIFT(NTBL+1)-FDRIFT(NTBL))                                    001700
      IF(FEVAP.LT.0.0) FEVAP=0.0
      IF(FEVAP.GT.1.0) FEVAP=1.0
      RETURN                                                            001710
      END                                                               001720
      FUNCTION PWAT(T)
      TK=(T-32.0)/1.8+273.1
      PWAT=760*EXP(71.02499-7381.6677/TK-9.0993037*ALOG(TK)+
     1' .0070831558*TK)
      RETURN
      END
      SUBROUTINE PSY1(DB,WB,PB,DP,PV,W,H,V,RH)                          001970
C     THIS ROUTINE CALCULATES' VAPOR PRESSURE PV, HUMIDITY RATIO W,     001980
C         ENTHALPY H, VOLUME V, RELATIVE HUMIDITY RH, AND               001990
C         DEW POINT TEMPERATURE DP(                                     002000
C         WHEN THE DRY BULB TEMPERATURE DB, WET BULB TEMPERATURE WB,    002010
C         AND BAROMETRIC PRESSURE PB ARE GIVEN                          002020
C     UNITS' DB, WB, + DP )F]( PB, + PV )IN OF HG]( W)= WATER VAPOR     002030
C         PER = DRY AIR]( H )BTU/= OF DRY AIR]( V )FT**3/= OF DRY       002040
C         AIR( RH IS A FRACTION, NOT (                                  002050
      C(F)=(F-32.0E0)/1.8E0                                             002060
```

Figure B.5 (Continued)

```
      PVP=PVSF(WB)                                                      002070
      WSTAR=0.622*PVP/(PB-PVP)                                          002080
      IF (WB.GT.32.0) GO TO 105                                         002090
      PV=PVP-5.704E-4*PB*(DB-WB)/1.8                                    002100
      GO TO 110                                                         002110
  105 CDB=C(DB)                                                         002140
      CWB=C(WB)                                                         002150
      HL=597.31+0.4409*CDB-CWB                                          002160
      CH=0.2402+0.4409*WSTAR                                            002170
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622                                  002180
      PV=PB*EX/(1.+EX)                                                  002190
  110 W=0.622*PV/(PB-PV)                                                002200
      V=0.754*(DB+459.7)*(1.0+7000.0*W/4360.0)/PB                       002210
      H=0.24*DB+(1061.0+0.444*DB)*W                                     002220
      IF (PV.GT.0.0) GO TO 115                                          002230
      PV=0.0                                                            002240
      DP=0.0                                                            002250
      RH=0.0                                                            002260
      RETURN                                                            002270
  115 IF (DB.NE.WB) GO TO 120                                           002280
      DP=DB                                                             002290
      RH=1.0                                                            002300
      RETURN                                                            002310
  120 DP=DPF(PV)                                                        002320
      RH=PV/PVSF(DB)                                                    002330
      RETURN                                                            002340
      END                                                               002350
      FUNCTION PVSF(X)                                                  002580
      DIMENSION A(6),B(4),P(4)                                          002590
      DATA A/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.49149/     002600
      DATA B/-9.09718,-3.56654,0.876793,0.0060273/                      002610
      T=(X+459.688)/1.8                                                 002620
      IF (T.LT.273.16) GO TO 100                                        002630
      Z=373.16/T                                                        002640
      P(1)=A(1)*(Z-1.0)                                                 002650
      P(2)=A(2)*ALOG10(Z)                                               002660
      Z1=A(4)*(1.0-1.0/Z)                                               002670
      P(3)=A(3)*(10.0**Z1-1.0)                                          002680
      Z1=A(6)*(Z-1.0)                                                   002690
      P(4)=A(5)*(10.0**Z1-1.0)                                          002700
      GO TO 105                                                         002710
  100 Z=273.16/T                                                        002720
      P(1)=B(1)*(Z-1.0)                                                 002730
      P(2)=B(2)*ALOG10(Z)                                               002740
      P(3)=B(3)*(1.0-1.0/Z)                                             002750
      P(4)=ALOG10(B(4))                                                 002760
  105 SUM=0.0                                                           002770
      DO 110 I=1,4                                                      002780
  110 SUM=SUM+P(I)                                                      002790
      PVSF=29.921*10.0**SUM                                             002800
      RETURN                                                            002810
      END                                                               002820
      FUNCTION DPF(PV)                                                  002830
C     THIS ROUTINE CALCULATES DEW-POINT TEMPERATURE FOR A GIVEN         002840
C          VAPOR PRESSURE PV                                            002850
      DP(A,B,C,Y)=A+(B+C*Y)*Y                                           002860
      Y=ALOG(PV)                                                        002870
      IF (PV.GT.0.1836) GO TO 100                                       002880
      DPF=DP(71.98,24.873,0.8927,Y)                                     002890
      RETURN                                                            002900
  100 DPF=DP(79.047,30.579,1.8893,Y)                                    002910
      RETURN                                                            002920
      END                                                               002930
```

Figure B.5   (Continued)

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This report develops models which can be utilized in the design of certain types of spray ponds used in ultimate heat sinks at nuclear power plants, and ways in which the models may be employed to determine the design basis required by U.S. Nuclear Regulatory Commission Regulatory Guide 1.27.

The models of spray-pond performance are based on heat and mass transfer characteristics of drops in an environment whose humidity and velocity have been modified by the presence of the sprays. Drift loss from the sprays is estimated by a ballistics model.

The pond performance model is used first to scan a long-term weather record from a representative meteorological station in order to determine the periods of most adverse meteorology for cooling or evaporation. The identified periods are used in subsequent calculations to actually estimate the design-basis pond temperature. Additionally, methods are presented to correlate limited quantities of onsite data to the longer offsite record, and to estimate the recurrence interval of the design-basis meteorology chosen.

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