NUREG-0858

Comparison Between Field Data and Ultimate Heat Sink Cooling Pond and Spray Pond Models

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

R. Codell

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R. Codell

Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

ABSTRACT

Two previously published reports, NUREG-0693 and NUREG-0733, presented models and methods by which ultimate heat sink cooling ponds and spray ponds used for safety-related water supplies in nuclear power plants could be analyzed for design-basis conditions of heat load and meteorology. These models were only partially verified with field data. The present report compares the NRC models to data collected for NRC by Battelle Pacific Northwest Laboratories on the performance of small geothermally heated ponds and spray ponds. These comparisons generally support the conclusion that the NRC models are useful tools in predicting ultimate heat sink performance.

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SYMBOLS

A = pond surface area, ft^2

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

A_s = cross-sectional area of the spray field, cm^2

C = cloud cover in tenths of the total sky obscured

C_d = drag coefficient for falling drops

C_p = heat capacity of pond water, Btu/(lb °F) or cal/(gm °C)

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

C_1 = Bowen's coefficient, 0.26 mm Hg/°F

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

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 = equilibirium temperature, °F

$F(w)$ = 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

$\dot{H}$ = 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 caused by conduction and convection, Btu/(ft^2 day)

$\dot{H}_E$ = heat loss from the pond surface caused by evaporation, Btu/(day ft^2)

$\dot{H}_{RJ}$ = net rate of heat addition by the plant, 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)

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

L_p = water level in experimental pond siphon tube--pond side, cm

ΔL_p = change in actual pond water level, cm

L_w = water level in experimental pond siphon tube--well side, cm

ΔL_w = change in the well water level, cm
m = mass of drop, gm
ΔM = actual pond water loss, lb
p = atmospheric pressure, mm Hg
Pr = Prandtl number
Q = flow rate of water to spray field, ft^3/sec
r = drop radius, cm
r_i = particular average radius of drop, cm
R_c = cooling range of the sprays, °F
Re = Reynolds number
Sc = Schmidt number
t = time, sec or hr
T = temperature of drop, °C or °K
T_A = air temperature, °F or °C
$T_{A,\infty}$ = temperature of air in which the drop is immersed, °C
T_d = dewpoint temperature, °F
T_s = pond surface temperature, °F
ΔT_v = "virtual" temperature difference between the pond surface water and air above the pond, °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 = absolute velocity of drop relative to air, cm/sec
V_p = pond volume, ft^3
V_o = full pond volume at start of test, ft^3
w = windspeed perpendicular to the pond, either naturally impinging or induced, cm/sec or mph
w_2 = windspeed at height of 2 m above pond, mph
W = flow rate through pond or sprays, ft^3/hr
W_b = flow rate of the blowdown or leakage stream, ft^3/hr
W_{drift} = water loss attributable to drift, ft^3/hr
W_e = evaporation rate, ft^3/hr
W_{spray} = rate of water evaporated from all drops in the spray field, ft^3/hr
λ = heat of vaporization of water, cal/gm or Btu/lb

SYMBOLS (Continued)

ρ = density of water, lb/ft^3 or gm/cm^3

ρ_A = density of air, gm/cm^3

ρ_w = density of water in stilling well, gm/cm^3

ρ_p = density of water in experimental pond, gm/cm^3

COMPARISON BETWEEN FIELD DATA AND ULTIMATE HEAT SINK COOLING POND AND SPRAY POND MODELS

1 INTRODUCTION

The ultimate heat sink is defined as the complex of sources of service or house water supply necessary to operate, shut down, and cool down a nuclear power plant safely.

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 under the conditions leading to the highest water loss.

Water for the ultimate heat sink is frequently supplied directly from large-surface water bodies, such as rivers, lakes, or oceans, for which the relatively small amount of heat from the service water system can be dissipated easily. The ultimate heat sink water can also be supplied from dedicated ponds, spray ponds, and cooling towers. These devices frequently are small in relation to the heat loads imposed on them, and thereby operate at relatively high temperatures.

The design of small, dedicated ponds, spray ponds, and cooling towers must take into account the worst meteorologic conditions that could reasonably be expected to occur simultaneously with the design-basis accident in order to calculate the highest returned-water temperature and water loss. The staff has published NUREG-0693, "Analysis of Ultimate Heat Sink Cooling Ponds" (Ref. 2) and NUREG-0733, "Analysis of Ultimate-Heat-Sink Spray Ponds" (Ref. 3), which give detailed instructions on computer programs used for analyzing small cooling and spray ponds, respectively. The techniques presented in these reports outline the ways in which long-term offsite meteorologic records can be (1) scanned to find the most adverse conditions, (2) correlated to onsite data, (3) analyzed statistically, and (4) used to predict the highest temperature and water loss. Heat and mass transfer relationships used in these models were compared in some cases with available field data and ranged from "realistic" to "conservative." However, verification of the models was far from complete.

In 1977, NRC contracted with Battelle Pacific Northwest Laboratories to undertake a comprehensive field-testing program to collect data on the performance of small cooling and spray ponds.

The first series of cooling pond tests were performed at the Raft River geothermal test site in southern Idaho. Hot water, supplied by geothermal wells, was allowed to cool in a small, excavated, lined pond. Extensive water and atmospheric measurements were taken during a series of tests of the pond. Although a spray facility was planned at the same site, further tests were abandoned after the accidental destruction of the pond liner.

Another geothermal test site, East Mesa in southern California, was chosen for the spray pond tests. A small, lined pond was filled with hot water and steam provided from a geothermal well. Water in the pond was sprayed from an array of spray nozzles. Extensive water and meteorologic measurements were taken during a series of tests with and without the sprays in operation. Further experiments are planned for this facility.

The purpose of this report is to present the available data from the Raft River (cooling pond) and East Mesa (spray pond) tests and compare them with the predictions made using the NRC ultimate heat sink models. These comparisons generally support the conclusion that the NRC models are useful tools in predicting ultimate heat sink performance.

2 HEAT AND MASS TRANSFER RELATIONSHIPS FOR POND SURFACES

2.1 Introduction

Bodies of water exchange heat and mass across the air-water interface by the mechanisms of conduction, convection, radiation, and evaporation. Virtually all heat and mass transfer from cooling ponds is accomplished by these mechanisms. Surface effects are responsible for a portion of the heat and mass transfer in spray ponds also, but are usually minor in comparison to heat and mass transfer from the sprays themselves.

The heat and mass transfer relationships for the pond surfaces as used in the NRC models are developed in two ways:

(1) The "equilibrium temperature" procedure of Brady et al. (Ref. 4) and Edinger et al. (Ref. 5) is used for the NRC surface-cooling pond model (Ref. 2).

(2) The more-rigorous procedure of Ryan and Harleman (Ref. 6) is used to determine the surface cooling in the NRC spray pond model (Ref. 3). The comparison of the pond model with the Raft River pond data is made using both the Brady-Edinger and the Ryan formulas. The East Mesa spray pond data are compared only with the Ryan formulas.

2.2 Development of the Basis for Surface Heat and Mass Transfer From a Pond Surface

A relationship for the rate of net heat flow from the pond surface can be developed by consideration of each heat source and heat loss. It is assumed that all heat exchange with an isolated body of water takes place through its surface. The rate of heat exchange $\dot{H}$ is

$$\dot{H} = \dot{H}_{SN} + \dot{H}_{AN} - \dot{H}_{BR} - \dot{H}_{E} - \dot{H}_{C} + \dot{H}_{RJ} \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}1)$$

in which

$\dot{H}$ = rate of atmospheric heat transfer

$\dot{H}_{SN}$ = net rate of shortwave solar radiation entering the pond

$\dot{H}_{AN}$ = net rate of longwave atmospheric radiation entering the pond, measured directly

$\dot{H}_{BR}$ = net rate of back radiation leaving the pond surface

$\dot{H}_{E}$ = net rate of heat loss caused by evaporation

$\dot{H}_{C}$ = net rate of heat flow from the pond caused by conduction and convection

$\dot{H}_{RJ}$ = net rate of heat addition by the plant

This relationship is illustrated graphically in Figure 2.1.

Of the heat flows into the pond resulting from radiation $\dot{H}_{SN}$ and $\dot{H}_{AN}$, only the net atmospheric radiation can be estimated from meteorologic parameters. The net atmospheric radiation term can be approximated using air temperature T_A and cloud cover C (in tenths). Ryan and Harleman (Ref. 6) developed the following formula for $\dot{H}_{AN}$:

$$\dot{H}_{AN} = 1.2.10^{-13} (T_A + 460)^6 (1 + 0.17C^2) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}2)$$

Three components of the heat-exchange equation, $\dot{H}_{BR}$, $\dot{H}_E$, and $\dot{H}_C$, are functions of the pond surface temperature. The back-radiation term may be expressed using the relation for radiation from a black body (Ref. 4):

$$\dot{H}_{BR} = 4.026 \times 10^{-8}(460 + T_s)^4 \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}3)$$

where T_s is the surface temperature of the pond.

The evaporative heat flow can be estimated by

$$\dot{H}_E = (e_s - e_a)F(w) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}4)$$

in which e_s is the vapor pressure at the temperature of the water surface (mm Hg) and e_a is the vapor pressure of water in the air above the pond (mm Hg). The term F(w) is an empirical function of windspeed in miles per hour, w. The wind function proposed by Brady (Ref. 4) is

$$F(w) = 70 + 0.7w^2 \qquad \text{Btu/(ft}^2\text{ day)/mm Hg} \qquad (2\text{-}5)$$

where w is measured at the 10-ft level.

Brady's wind function is derived empirically from large-lake data. A more accurate, but less conservative, formula was derived by Ryan (Ref. 6) on firmer physical grounds:

$$F(w) = [22.4 (\Delta T_v)^{1/3} + 14w_2] \qquad (2\text{-}6)$$

where

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

and w_2 is expressed in mph measured 2 m above water surface, and

where

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

p = atmospheric pressure, mm Hg

This formula accounts for an expected increase in natural convection with increasing pond temperature, whereas Brady's wind function is not temperature dependent.

The direct solution of Equation 2-1 with terms defined by Equations 2-2, 2-3, 2-4, and 2-6 constitutes the "rigorous" or Ryan formulas for surface heat transfer and evaporation.

2.3 Equilibrium Temperature Heat Transfer Model

The temperature the pond would reach at steady state without external heat inputs and under constant environmental conditions is known as the equilibrium temperature E. The equilibrium temperature is the temperature at which the heat removal from the pond balances the heat addition. This relation is graphically illustrated in Figure 2.2. The equilibrium heat transfer coefficient K is defined as the slope of the heat-removal curve at pond temperature $T_s = E$ for a unit surface area:

$$K = \left.\frac{\partial \dot{H}}{\partial T_s}\right)_E \qquad \text{Btu/(ft}^2\text{ day }^\circ\text{F)} \qquad (2\text{-}7)$$

The Brady heat transfer equation can be derived by a simplification of the vigorous surface heat transfer formulas of the previous section.

The quantity $(e_s - e_a)$ in Equation 2-4 can be replaced by a simple relationship,

$$(e_s - e_a) = \beta\,(T_s - T_d) \qquad \text{mm Hg} \qquad (2\text{-}8)$$

where

$$\beta = 0.255 - 0.0085T^* + 0.00204(T^*)^2 \qquad \text{mm Hg/}^\circ\text{F} \qquad (2\text{-}9)$$

T_d = dewpoint temperature, °F, and

$$T^* = \frac{T_s + T_d}{2}$$

Making the appropriate substitutions into Equation 2-4,

$$\dot{H}_E = \beta\,(T_s - T_d)F(w) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}10)$$

The conduction and convection heat flow can be approximated by

$$\dot{H}_C = C_1\,(T_s - T_A)F(w) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}11)$$

where

C_1 = Bowen's coefficient, 0.26 mm Hg/°F

T_A = air temperature

After considerable manipulation, the heat transfer formulas will reduce to

$$\dot{H} = K(E - T_s) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}12)$$

$$K = 15.7 - (\beta + 0.26)F(w) \qquad \text{Btu/(ft}^2\text{ day)} \qquad (2\text{-}13)$$

$$E = \frac{\dot{H}_{SN}}{K} + \frac{(\beta T_d + 0.26 T_A)}{(\beta + 0.26)} \qquad {}^\circ F \qquad (2\text{-}14)$$

in which

T_s = pond surface temperature, °F

w = windspeed, mph, measured at the 18-ft level

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

T_d = dewpoint temperature, °F

T_A = air temperature, °F

β is defined by Equation 2-10 and F(w) is defined by Equation 2-5.

Details of the derivation can be found in References 2 and 3.

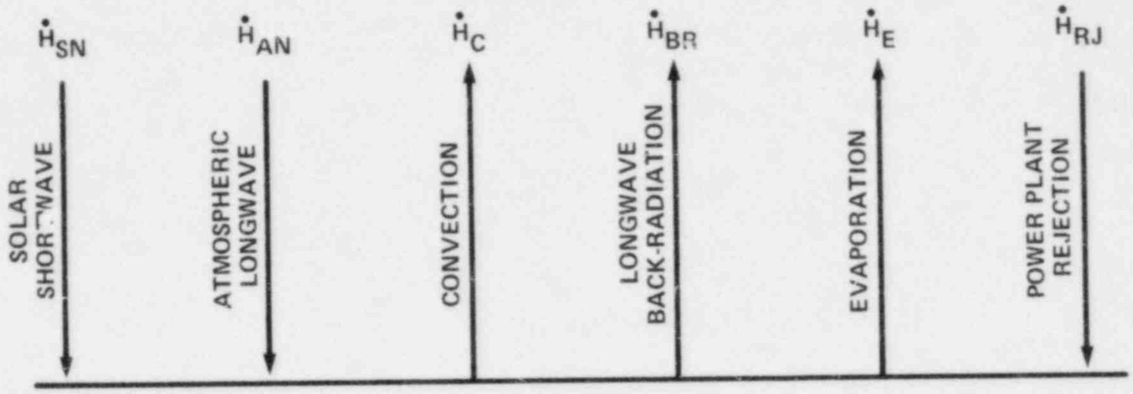

Figure 2.1 Heat loads on a pond

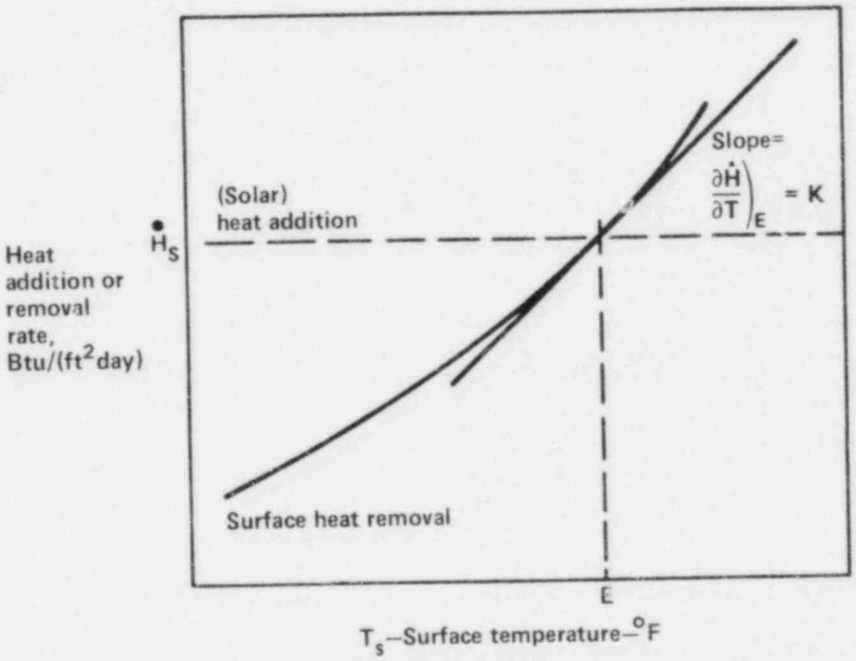

Figure 2.2 Definition of equilibrium coefficients

3 SPRAY POND HEAT AND MASS TRANSFER PERFORMANCE MODELS

3.1 Introduction

A set of models that considers the interaction of sprayed water with air in a spray field has been developed to calculate cooling and water-loss performance.

The performance model is developed in two parts:

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

(2) "Macroscale" submodels that 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 for 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 ultimate heat sink (UHS) system.

3.2 Microscale Submodel

The microscale submodel considers the heat, mass, and momentum transfer from a single water drop into the surrounding air. The motion of the drop after it leaves the spray nozzle is approximated by the classic ballistic problem shown in Figure 3.1. Drops leave the nozzle at an 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:

$$\frac{du}{dt} = - \frac{C_d A_d \rho_A (u - u')V}{m} \tag{3-1}$$

$$\frac{dv}{dt} = - \frac{C_d A_d \rho_A (v - v')V}{m} - g \tag{3-2}$$

where

u = velocity of drop in x 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

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

g = acceleration of gravity, cm/sec^2

C_d, a drag coefficient for falling drops, is a function of Reynolds number Re (Ref. 7).

The ballistics model shown in Figure 3.1 is solved with the drag terms set to zero for use in the heat and mass transfer models discussed in the following section. Under these conditions, Equations 3-1 and 3-2 then can be solved for u and v analytically.

The use of the analytical equation rather than the more complicated numerical solutions of equations containing the drag is a considerable simplification and has been shown to be a reasonable approach when applied to the heat transfer formulas discussed in the following section. The equations with the drag terms are solved numerically for the drift-loss model discussed in Section 4.

3.2.1 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. 8):

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

where

T = temperature of the drop, °C

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

ρ = density of water, gm/cm^3

r = radius of drop, cm

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

t = time, sec

The heat and mass transfer coefficients h_c and h_d, respectively, are based on the classic work on pendant drops by Ranz and Marshall (Ref. 9). The heat transfer coefficient h_c has been empirically determined to be functions of the Reynolds number Re, the Prandtl number Pr, and the Schmidt number Sc. All of these dimensionless numbers can be expressed in terms of the drop diameter, drop velocity, and air and water temperatures of the sprays. Further details on the actual thermodynamic relationships used can be found in Reference 3.

3.3 Macroscale Models

The performance of a single isolated spray nozzle might be adequately predicted by the microscale model alone. However, when many spray nozzles are arranged into a spray field, the modification of the atmospheric environment in which the nozzle is immersed because of neighboring spray nozzles must be considered. 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.

Separate macroscale models deal with high- and low-windspeed conditions. The high-speed model assumes that the momentum exchange in the pond resulting from drag and buoyancy is much less important than that caused by 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 pond is self-induced.

Both models are run at the same time in the simulation because 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.

3.3.1 High-Windspeed Submodel

The spray field is represented by a rectangular volume, in which the density of sprayed drops is great, as shown in Figure 3.2. The rectangular volume is divided into 10 equal segments. Each segment is then considered to be a compartment whose air temperature and humidity are determined by the preceding segment.

Ambient air enters the first segment of the spray field at a volumetric rate determined by the windspeed perpendicular to the long axis of the pond w and the cross-sectional area of the spray field A_s.

For a particluar segment, it can be assumed that the humidity and air temperature are determined only by that which 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.

For drops of a particular average radius r_i (cm), the heat entering the segment is proportional to the fraction of drops in that size range,* the flow rate of water into the section, and the difference between the temperature of the drop when it left the nozzle and the temperature when it reached the pond surface.

The temperature of the air leaving one segment and entering the next reflects the added heat and moisture. Calculations continue with the next segment in the sequence through all pond segments. The properties of the air in the first segment are determined by the ambient-air temperature and humidity. The total cooling performance of the spray field is the average cooling from all sections.

3.3.2 Low-Windspeed 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. Because 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 caused by 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 3.3 (Ref. 3 and D. M. Myers, personal communication, 1976). Air enters the segment from all four sides 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.

Details of the high- and low-windspeed models can be found in Reference 3.

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*The final model actually uses a single "average" drop radius that has been determined empirically. Details of the averaging procedure can be found in Reference 3.

**However, at least one spray-equipment manufacturer, Ecolaire (Ref. 10), is marketing an oriented spray-field arrangement to induce circulation of air laterally, thereby increasing spray efficiency by preventing air stagnation.

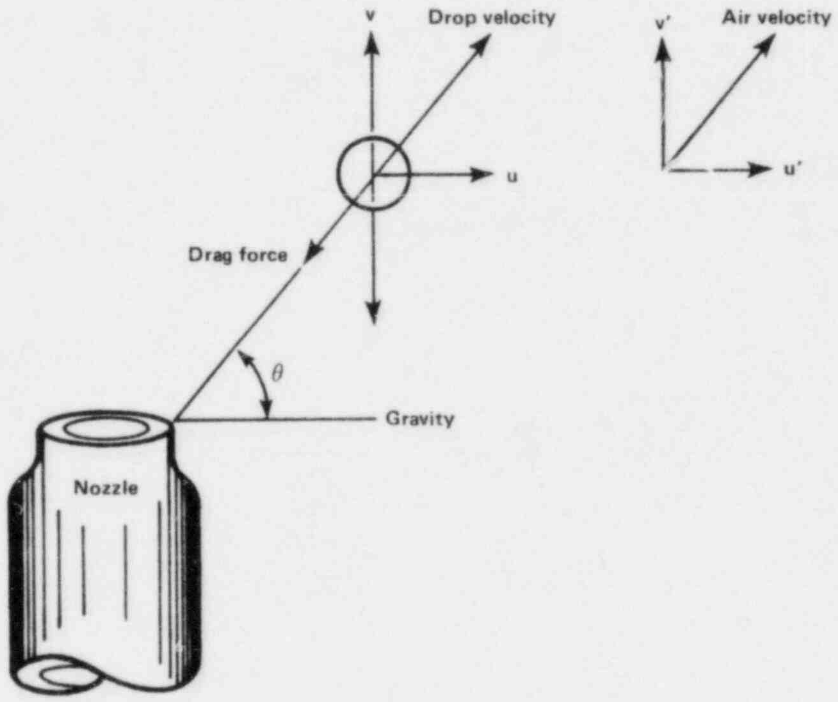

Figure 3.1 Ballistics of a drop leaving a spray nozzle

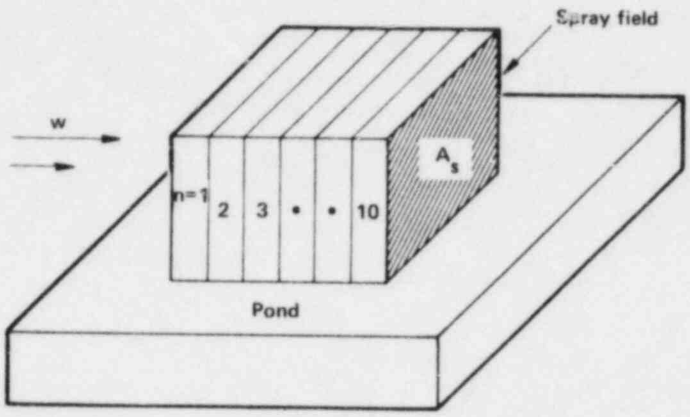

Figure 3.2 Segmentation of spray field for high-windspeed model

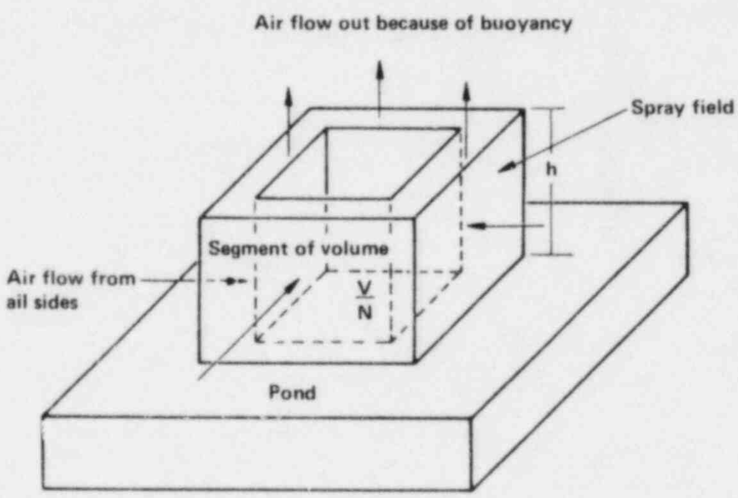

Figure 3.3 Segmentation of spray field for low-windspeed model

4 DRIFT-LOSS MODEL

4.1 Introduction

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.

4.2 Model Assumptions

The model is formulated for a spray pond of conventional design, with the Spraco 1751 nozzle operating at the recommended pressure and height. The trajectories of drops leaving the spray nozzles are simulated by using a ballistics approach in a manner similar to that of the "microscale" submodel of Section 3.2, but for 21 drop diameters that represent the drop-diameter distribution of the Spraco 1751 nozzle. The equations in Section 3.2 for the ballistics of drops apply. No interaction of drops is presumed.

The conservative assumption that all droplets are formed at the apogee of the trajectory of the largest drop diameter is made.

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.

The Spraco 1751 nozzle under a design pressure of 7 psig demonstrates a nozzle velocity of about 24 ft/sec forming 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 (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 downwind direction. The smaller drop diameters would naturally be affected more than the larger ones.

The 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.

Details of the model can be found in Reference 3.

5 POND MODELS

5.1 Introduction

The mixed-tank model depicted in Figure 5.1 presumes that the heated effluent is instantaneously and uniformly mixed throughout the volume of the pond, and that the water in the pond is uniform in temperature. Atmospheric heat transfer from the surface is related to the pond-surface temperature. The surface cooling pond analytical method gives consideration to two other simple hydraulic models: plug flow and stratified (developed in detail in Reference 2).

5.2 Model Equations

5.2.1 Heat Balance

The heat rejected by the sprays is

$$\dot{H}_{spray} = Q\rho C_p R_c \qquad \text{Btu/(ft}^2\text{ day)} \qquad (5\text{-}1)$$

where

Q = net flow through the pond, ft^3 sec

ρ = density of water, lb/ft^3

C_p = heat capacity of pond water, Btu/(lb °F)

R_c = cooling range of the sprays determined from the high-windspeed-low-windspeed (HWS-LWS) model, °F

By combining all heat inputs to and outputs from the pond, and using the relationship between temperature and heat, the following equation is obtained:

$$\frac{dT}{dt} = \frac{\dot{H}_{RJ} - \dot{H} - \dot{H}_{spray}}{\rho C_p V_p} \qquad \text{°F/hr} \qquad (5\text{-}2)$$

where

V_p = pond volume, ft^3

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

The cooling pond temperature relationship would be identical except there would be no spray heat loss

$$\frac{dT}{dt} = \frac{\dot{H}_{RJ} - \dot{H}}{\rho C_p V_p} \qquad (5\text{-}3)$$

5.2.2 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

$$W_e = \frac{A\dot{H}_E}{\rho\lambda} \quad (5\text{-}4)$$

where

A = pond surface area, ft^2

$\dot{H}_E$ = heat loss from the pond surface caused by evaporation, Btu/(hr ft^2)

ρ = density of water, lb/ft^3

λ = heat of vaporization of water, Btu/lb

Combining all terms of the mass balance yields the expression:

$$\frac{dV}{dt} = - W_b - \frac{A\dot{H}_E}{\rho\lambda} - W_{drift} - W_{spray} \quad (5\text{-}5)$$

where

W_{drift} = drift loss, ft^3/hr

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

The cooling pond mass balance (mixed-tank model) would be identical except there would be no spray or drift-water loss.

$$\frac{dV}{dt} = - W_b - \frac{A\dot{H}_E}{\rho\lambda} \quad (5\text{-}6)$$

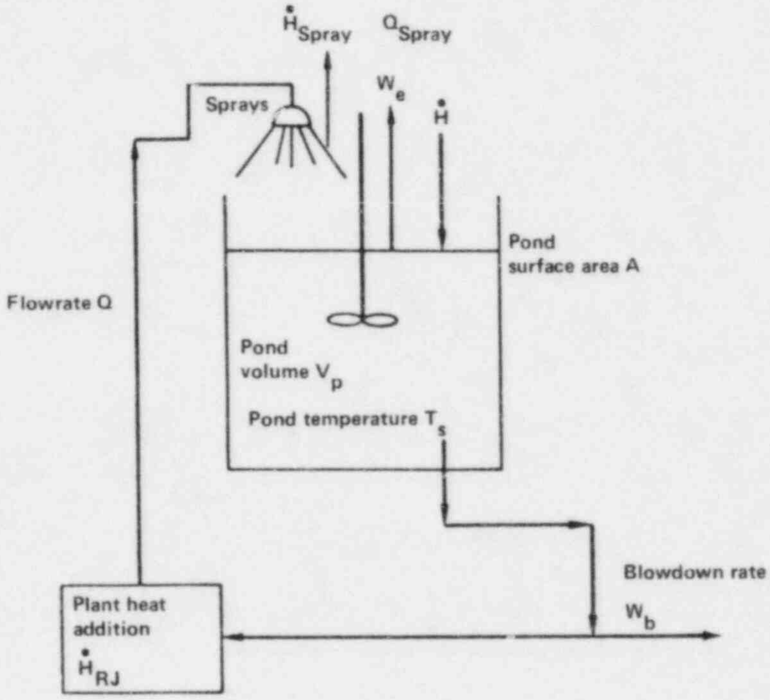

Figure 5.1 Mixed-tank model

6 MODEL-PROTOTYPE COMPARISONS FOR RAFT RIVER AND EAST MESA TESTS

6.1 Introduction

The model-prototype comparisons in this report were undertaken for the sole purpose of demonstrating the reliability and conservatism of the models under conditions for which they would actually be used. With these objectives in mind, it is noted that not all of the meteorologic data that were available in the tests were used because it is unlikely that such data would be available at an actual site. For example, some of the meteorologic data from the offsite reference tower were used even though more representative measurements were available closer to the ponds.

In addition, minor modifications to the heat and mass balances, such as accounting for the sloping sides of the pond and the heat transfer through the ground, were ignored because these factors would not be used in routine application of the model.

Solar radiation was measured close to the pond sites with a pyroheliometer. Only the incident component of solar radiation was used in the model even though both the incident and reflected components were measured.

Windspeed was taken from instruments at the 1.5-m height. Dry-bulb and wet-bulb temperatures were taken at the lowest station on the offsite meteorologic tower, which was 5 m above the tower base. No attempt was made to adjust the meteorologic data to a height specified by either the Ryan (2-m) or Brady (18-ft) surface heat transfer formulas. These adjustments would be risky without a more thorough understanding of the obstacles, vegetation, atmospheric stability, and other factors at the sites. These meteorologic studies could be the subject of further analyses, but the subject will not be explored to a greater degree in this report.

Geothermal water and steam were used to supply heat and water for the tests at both ponds. Although the water contained dissolved minerals, the concentrations would have less than 0.2% effect on any of the thermodynamic properties of pure water. Therefore, it was not necessary to correct any of the heat or mass transfer formulas in the models.

Precipitation was not measured during any of the tests considered at either site. The general weather conditions experienced can be characterized as undisturbed with substantial ground-based convection during the main part of the daylight hours and into the night, with low-level inversion formation in the evening, persisting after dawn. Most of the days were fairly cloudless. Only during some of the Raft River tests did cloudiness affect solar radiation, and this was for short durations only (Ref. 12).

6.2 Specific Description of Experimental Sites

6.2.1 Raft River Cooling Pond

The Raft River cooling pond is shown in Figure 6.1. It is located at a Department of Energy geothermal site near Malta in southern Idaho. Heated water is supplied to this pond from geothermal test wells (Refs. 12 and 13).

Sand and gravel in the basin were excavated by a bulldozer. The bottom is bowl shaped and terminates in almost vertical banks. Nominal pond surface area is 3200 m^2, and the nominal volume is 4300 m^3. Terrain near the pond is essentially flat, with a low mound of sand and gravel left over from the pond excavation. Mountain ranges up to 1 km high rim the site at a distance of several kilometers. Site elevation is 1477 m above mean sea level. Atmospheric pressure during the tests was between 840 and 860 mbars. A more detailed description of the site can be found in Reference 12.

Initial experiments with the Raft River pond demonstrated that seepage was extensive (Ref. 13). This made the direct measurement of evaporative water loss impossible. The pond was subsequently lined with an impermeable membrane that eliminated most or all of the seepage until the liner was severely damaged in an accident.

The pond was equipped with a wide variety of air and water instruments. Thermistors were placed in the pond at several points. Thermistor chains were suspended on three sides of the pond from floats attached to the bottom and from a surface float near the pond center. A string of five thermistors was buried beneath the pond to determine gradients of temperature in the soil. The pond surface elevation was monitored using an array of three hook gauges and stilling wells. Evaporation was also measured independently from a standard evaporation pan mounted in the pond water so that its temperature would be approximately that of the pond. Evaporation-pan temperature was measured with a mercury-in-glass thermometer. Another unheated pan was located on shore. Dry-bulb and wet-bulb thermistors were mounted at three levels above the base on towers located on three shores and on a raft near the pond center. Windspeed/direction sensors were mounted at the 1.5-m level on the raft tower and on the three pond perimeter towers. Net radiation over the water surface was monitored by a net radiometer located on the raft. Three wedge-type rain gauges were located on the pond periphery.

An existing 16-m tower, located about 150 m from the pond, was equipped with three levels of aspirated dry- and wet-bulb thermistors and two levels of three-component anemometers. This remote tower was to provide undisturbed reference data.

Other instruments included an acoustic sounder for measurements of atmospheric stability, an Eppley pyranometer mounted on the roof of the mobile laboratory, tethered balloons for observations to altitudes of 200 m, and hand-held infrared radiation thermometers to measure interface temperatures.

The performance tests on the Raft River pond were run by filling the pond with hot geothermal water and observing its cooling and water loss from the time that the pond was full. There was no input of heat or water during the test.

Measurements of pond temperature indicated that there were no significant vertical or horizontal temperature gradients during the test. The "mixed-tank" model, therefore, is completely appropriate for the model prototype comparison. It should be noted, however, that the operation of the Raft River pond is dissimilar to the operation of an actual ultimate heat sink cooling pond. In an actual pond, heated water could be added and cooled water could be withdrawn which could lead under certain conditions to stratification and complicated temperature and velocity profiles in the pond. Such phenomena might not be well represented by the mixed-tank pond hydraulic model described in Section 5.

A series of five tests were conducted during this period (Ref. 12). Four of the tests were performed with heated water. The remaining test was performed with unheated water. Table 6.1 lists the parameters of the tests.

A previous set of tests was conducted between April 27 and May 4, 1979 (Ref. 13). These tests were performed before the impermeable pond liner was installed and, therefore, did not accurately account for water loss through infiltration. The results of these tests are not included in the present model-prototype comparison.

6.2.2 East Mesa Spray Pond Site

The East Mesa spray pond is located near El Centro in southern California on the site of a geothermal test station operated by WESTEC Services. Heated water and steam are supplied to the pond from two geothermal wells. The square-shaped pond is approximately 195 ft on each side with sloping walls and a flat bottom. The full pond is about 5 ft deep. It is lined with an impermeable membrane (Ref. 12).

Water is sprayed through 64 Spraco 1751 nozzles located in the center of the pond in the arrangement suggested by the manufacturer as shown in Figure 6.2. Water is supplied to the sprays by two headers, and is pumped at a flow rate of about 3390 gal/min.

The pond was extensively instrumented. Sprayed water temperature was measured at three nozzles. Pond temperature was measured at several places in the pond at various depths. Pond water level was determined by three hook gauges and stilling wells. Ground temperature was measured at several depths beneath the liner with thermistors.

Dry-bulb and wet-bulb temperatures, windspeed, and wind direction were measured at multiple points above and next to the pond and at several elevations on a reference tower located approximately 120 m from the pond. Rain was measured with wedge- and tipping-bucket gauges near the pond. Sprayed water was collected and its temperature determined in funnel spray collectors located in the pond. Drift loss was measured with sensitized paper located at the pond perimeters. Solar radiation was measured with an Eppley pyranometer on the roof of the mobile laboratory and a net radiometer above the sprays. Cloud cover was measured with a whole-sky camera.

Atmospheric pressure determined during the tests varied between 1000 and 1040 mbars.

The performance tests were run on the East Mesa spray pond by filling the pond with hot water and steam provided by the geothermal wells, and then spraying the pond water through the nozzles. There was no input of heat or water during the tests. No measurable thermal stratification of the water in the pond was noted.

A series of four tests were conducted from September 16, 1979 to October 1, 1979. Three of these tests were carried on with the sprays operating and heated water in the pond. For one experiment, the sprays were not turned on for about 75 hours.

6.3 Interpretation of Water-Loss Data

The initial comparisons of the East Mesa and Raft River data with their respective models showed generally excellent agreement for water temperature but less satisfactory agreement for water loss. Because cooling and water loss are so closely related, this disagreement was troublesome. The investigators took great precautions to ensure that the ponds were watertight, yet the prototype ponds apparently lost water at a rate significantly greater than that calculated by the model.

Analyses of the heat and mass budget for the East Mesa and Raft River data were performed by Godbey (Ref. 14), and the apparent discrepancies between the heat and mass budgets were recognized. The problem was identified as possibly resulting from two phenomena:

(1) The temperatures in the pond, siphon tube, and stilling well were all different; therefore, the water level in the stilling well might not be an accurate measure of the pond level.

(2) The pond water contracted as it cooled; thus, it appeared that there was a greater water loss than had actually occurred.

True water losses from the measurements of water level were developed in the present study to take the two phenomena into account. Unfortunately, the temperatures in the stilling wells or siphon tube were not measured; therefore, they had to be estimated.

Figure 6.3 shows schematically the layout of the ponds with respect to the hook gauge and stilling wells. The siphon tube extends from the pond surface, over the berm, and to the stilling well.

It was arbitrarily assumed that the temperature of the water in the siphon tube was that of the pond on the pond side, and that of the well on the well side. The temperature of the well was determined with the cooling pond model using the Ryan heat transfer formulas. The volume and area of the stilling pond were assumed to be 0.0555 ft^3 and 0.0845 ft^2, respectively. The temperature of the well at the start of each run was set to its equilibrium temperature, determined by allowing the temperature of the well to attain steady state with the meteorologic values at the start of the run. The heat capacity or heat transfer of the stilling well walls or the siphon tube was not taken into account.

If the density in the left (well) side is ρ_w and the density in the right (pond) side is ρ_p, the corresponding water levels L_w and L_p are related by the expression

$$\rho_w L_w = \rho_p L_p \tag{6-1}$$

At the start of the measurements, the pond was full and

$$L_p = L_{po}$$

$$T_p = T_{po}$$

$$\rho_p = \rho_{po}$$

$$\rho_p = \rho_{po}$$

A change in the well ΔL_w would indicate an actual pond water level change ΔL_p of approximately

$$\Delta L_p = \frac{\rho_w}{\rho_\rho} (L_{po} + \Delta L_w) - \frac{\rho_{wo}}{\rho_{po}} L_{po} - L_{wo} + L_{po} \tag{6-2}$$

The actual pond water loss ΔM was calculated to be

$$\Delta M = \rho_{po} V_o - \rho_p (V_o - A \Delta L_p) \tag{6-3}$$

where V_o is the full pond volume at the start of the test and A is the pond surface area (assumed constant at full pond volume).

6.4 Model-Prototype Comparisons

6.4.1 Introduction

Data on the Raft River and East Mesa experiments were provided by Hadlock in graphical form (Ref. 15). These data were keypunched manually at half-hour intervals and in some cases interpolated from the graphical record if there was a gap in the data. All wet-bulb and dry-bulb temperature measurements were taken at the 5-m height on the offsite reference tower because the tower better reflected ambient air conditions, unaffected by the operation of the pond. Windspeed was taken at the 1.5-m elevation at the pond location. No attempt was made to correct the meteorologic data to elevations required by the heat transfer formulas. Tables of these data are provided in Appendices A and B.

6.4.2 Raft River Comparison

The model-prototype comparisons for the Raft River site are shown in Figures 6.4 through 6.11. These figures show the results of the cooling pond model using both the Brady-Geyer and Ryan-Harleman heat transfer formulas.

Figure 6.4 shows the measured and predicted pond temperature for the "Idaho Hot 1" experiment of July 30-August 1, 1978. This run was performed with water that was initially about 61.1°C. The Ryan-Harleman formula somewhat overpredicts the cooling but the result is generally close to the observed temperature. The Brady-Geyer formula significantly underpredicts the cooling. Figure 6.5 shows the measured and predicted water use for this case. The measured water use shows an anomalous "dip" in the first few hours. The observed pond water level did not increase in this period; therefore, this dip must be an artifact of the water use correction procedure used to compensate for thermal expansion effects, as described in Section 6.3. The greater cooling shown by the Ryan-Harleman formula is reflected in relatively higher water use compared with that of the Brady-Geyer formula. Agreement between model and prototype is flawed by the noted anomaly, but appears to be better for the Ryan-Harleman model.

Figure 6.6 shows the observed and predicted temperature for the "Idaho Hot 3" experiment of August 8-10, 1978. The results of this comparison are similar to those of the "Idaho Hot 1" experiment. The Ryan-Harleman model somewhat overpredicts and the Brady-Geyer model underpredicts the cooling. Water loss for this experiment is shown in Figure 6.7. Only 26 hours of water-loss data were available in this run. The Ryan-Harleman formula appears to predict water use more closely in this case.

Figure 6.8 shows the observed and predicted temperature for the "Idaho Hot 4" experiment of October 4-6, 1978. Water loss is shown in Figure 6.9. Results are similar to those previously described.

Figure 6.10 shows the observed and predicted temperature for the "Idaho Cool 1" experiment of July 25-27, 1978, which showed temperatures significantly lower than those of the other experiments. Agreement between the data and models is much poorer in this case than for the "hot" experiments, although the Ryan-Harleman model is clearly better. Water use for this experiment is shown in Figure 6.11. Both models predict about the same water use, but underpredict the observed water use.

A comparison was not made with the "Idaho Hot 2" experiment of August 3-5, 1978, because a leak occurred during the test and the water-loss data are, therefore, questionable.

6.4.3 East Mesa Comparison

The model-prototype comparisons for the East Mesa site are shown in Figure 6.12 through 6.19. As with the Raft River comparisons, no attempt was made to correct the meteorologic data for elevations required by the surface heat transfer equations.

Figure 6.12 shows the measured and predicted pond temperature for a portion of the "East Mesa Cool 1" experiment of September 16-18, 1979. This portion of the experiment differs from the other spray pond tests because the sprays were not in operation; therefore, most heat transfer occurred from the pond surface. Agreement between the model and prototype is good. The model appears to be more responsive to diurnal variations in heat transfer than the prototype indicates.

Figure 6.13 shows the model-prototype comparison for water use for the "East Mesa Cool 1" experiment. Agreement is fairly good, but the model somewhat underpredicts water usage.

Figure 6.14 shows the model-prototype comparison for temperature for the "East Mesa Warm 1" experiment of September 22-24, 1979. In this experiment, the sprays were in operation. Agreement is generally excellent, but the model seems to be somewhat more responsive than the prototype. Water use for this experiment is shown in Figure 6.15. Agreement between the model and prototype is excellent.

Figures 6.16 and 6.17 show the model-prototype comparisons for temperature and water use, respectively, for the "East Mesa Warm 2" experiment of September 27-28, 1979. Agreement is generally excellent, but water use is slightly overestimated.

Figures 6.18 and 6.19 show the model-prototype comparisons for temperature and water use, respectively, for the "East Mesa Warm 3" experiment of October 1-2, 1979. Agreement is good, and the model is generally more responsive than the prototype.

6.5 Discussion of Results

6.5.1 Raft River Comparison

The model-prototype comparisons demonstrate that the Brady-Geyer formula consistently predicts temperatures higher than those observed and is, therefore, conservative. Water use is underpredicted by this model, but is of only secondary concern in ultimate heat sink cooling pond analyses because the ponds are virtually always of ample volume for the Regulatory Guide 1.27 requirements (Ref. 1).

6.5.2 East Mesa Comparison

Agreement between the model and prototype measurements is generally excellent. There was a noticeable difference between the performance of the model in the "East Mesa Cool 1" run, where the sprays were off for the first 75 hours of the test, and the other experiments where the sprays were in operation. Far more heat would be lost from the sprays than from the pond surface; therefore, any inadequacy of the surface-cooling formulas would be fairly insignificant and masked by the spray field performance.

6.5.3 Potential Causes of Disagreement Between Models and Prototype Experiments

The comparisons between the models and the prototypes are generally quite good, but discrepancies are noticeable in almost all experiments. Disagreements between the models and prototypes can be attributed to one or more of the following factors:

(1) Inadequacy of the Model Equations To Predict Physical Reality of Surface Heat Transfer and Water Loss

The Ryan-Harleman and Brady-Geyer formulas for heat and mass transfer from water surfaces were mainly derived from physical principles, but in some cases empirical expressions were needed. In particular, the "wind function" for evaporation depended on data collected at large reservoirs where temperatures were generally lower than those encountered in the present case. The Ryan-Harleman formulas depend on an expression that accounts for buoyancy of heated, humidified air; thus, the natural convection above the heated water surface is taken into account. The cooling lakes and reservoirs studied in the Ryan-Harleman case, however, had surface areas of several thousand acres, but the present ponds are smaller than 1 acre. The air circulation over very large ponds is probably significantly different from that over small ponds. It is possible that atmospheric convection cells develop over large cooling reservoirs much more readily than over small ponds. Furthermore, windspeeds over large expanses of water are higher than those over land because of the relative aerodynamic smoothness of water. The two above-mentioned phenomena would generally result in overprediction of cooling when applied to small ponds. Large cooling reservoirs, however, may alter the local climate by humidifying and heating the surrounding air--a phenomenon that would decrease the rate of cooling.

(2) Inadequacy of the Spray Field Equations To Predict Physical Reality of Spray Field Heat and Mass Transfer

The spray field formulas are an admitted simplification of the complicated process of heat and mass transfer occurring in the spray field. The spray field in this case was a nearly square array of nozzles. In the model, it was assumed that the wind was always blowing at right angles to the major axes of the field, when in fact it may have been blowing from an oblique angle. The variation of windspeed in the vertical direction over the height of the spray field cannot be taken into account in this model, nor can the development of a boundary layer near physical obstructions in or near the pond (for example, nozzles, pipes, and pond berm). The model also does not take into account the complicated nature of the drop-diameter distribution, or the possibility that this distribution may change over the spray trajectory because of drop breakup, interference, or wind effects. The model allows only two extremes: a high-windspeed and a low-windspeed condition as described in Section 3. It does not allow a condition where there is a combination of natural and forced convection.

(3) Inappropriateness of the Meteorologic Data

Wet-bulb and dry-bulb temperatures were obtained at the reference meteorologic tower. The tower is 150 m from the pond at Raft River and 120 m from the pond at East Mesa. Only data from the 5-m level of the tower were used. The Ryan-Harleman surface heat and mass transfer relationships depend on data obtained 2 m above the pond surface (Ref. 6). The spray field is about a maximum of 4 m above the water surface; therefore, the appropriate meteorologic data should be specified at the midpoint height of about 2 m also.

Windspeed was measured at the 1.5-m height. Since windspeed generally increases with altitude, the 1.5-m values are probably underestimates of this parameter, and the prediction of a lower rate of cooling and water loss results. Dry-bulb and wet-bulb temperatures may show significant differences with increases in altitude also because of the phenomenon of heating and cooling of the air by the ground surface. Furthermore, the offsite data probably do not include any effect the pond may have on the local climatology.

Extrapolation of the reference tower data to data at a more appropriate altitude probably could be accomplished to some degree, but was not attempted in this study.

(4) Neglect of Heat Transfer and Leakage to Ground

One assumption of the pond models was that heat transfer and leakage underneath the pond would be negligible. In some of the pond experiments, thermistor strings measured temperature gradients through the soil. The heat flux could then be estimated as the product of the gradient and the thermal conductivity of the soil. Estimates by Godbey (Ref. 14) and Hadlock (Ref. 12) indicate that heat transfer through the soil is very small when compared with other mechanisms in the pond.

The impermeable liners of the ponds, if properly constructed, should virtually eliminate seepage. Hadlock noted no direct or indirect evidence of leakage from the ponds except when the liners were damaged (Ref. 12). Furthermore, the models do not show a clear systematic overestimate or underestimate of the observed water losses.

(5) Inaccuracies in Measuring Pond Water Level

Water use during the pond experiments was calculated indirectly from water levels determined by hook gauges and stilling wells as discussed in Section 6.3. The temperature of the water in the stilling well and the connecting tubing had to be calculated because it was not measured. The accuracy of the calculations of these temperatures could not be determined. The water use correction procedure is obviously faulty in the short term as noted in the "Idaho Hot 1" experiment. Diurnal temperature variations in the stilling wells and connecting tubing would tend to be evened out if water loss per 24-hour period were considered rather than water losses over much shorter periods of time.

(6) Uncertainty of Flow Rate Through Spray Nozzles

The rate of flow through the spray nozzles was not measured continuously. Hadlock (personal communication, 1981) indicated that the pump flow rate was known, but it is not clear whether the rated design value was used or flow meters were installed during any periods of the tests. Variations in water temperature, supply voltage, or other factors could lead to uncertainties in this flow rate.

(7) Thermal Stratification of Pond

The rate of cooling caused by thermal stratification, if present, would be greater than that of a pond that is vertically mixed. Because the Raft River pond was shallow and had no circulation or heat addition, conditions were not suitable for the establishment of stratification. The East Mesa pond had circulation because of the sprays, but because the sprayed water was generally cooler than that of the pond, no stratification could develop.

Direct measurements of pond temperatures indicated that they were nearly homogeneous.

The relatively good agreement between the data and the models indicates that the most important phenomena of heat and mass transfer from the ponds were taken into account. Several of the potential causes of disagreement probably counteract each other; others might have only minor effects on the model accuracy.

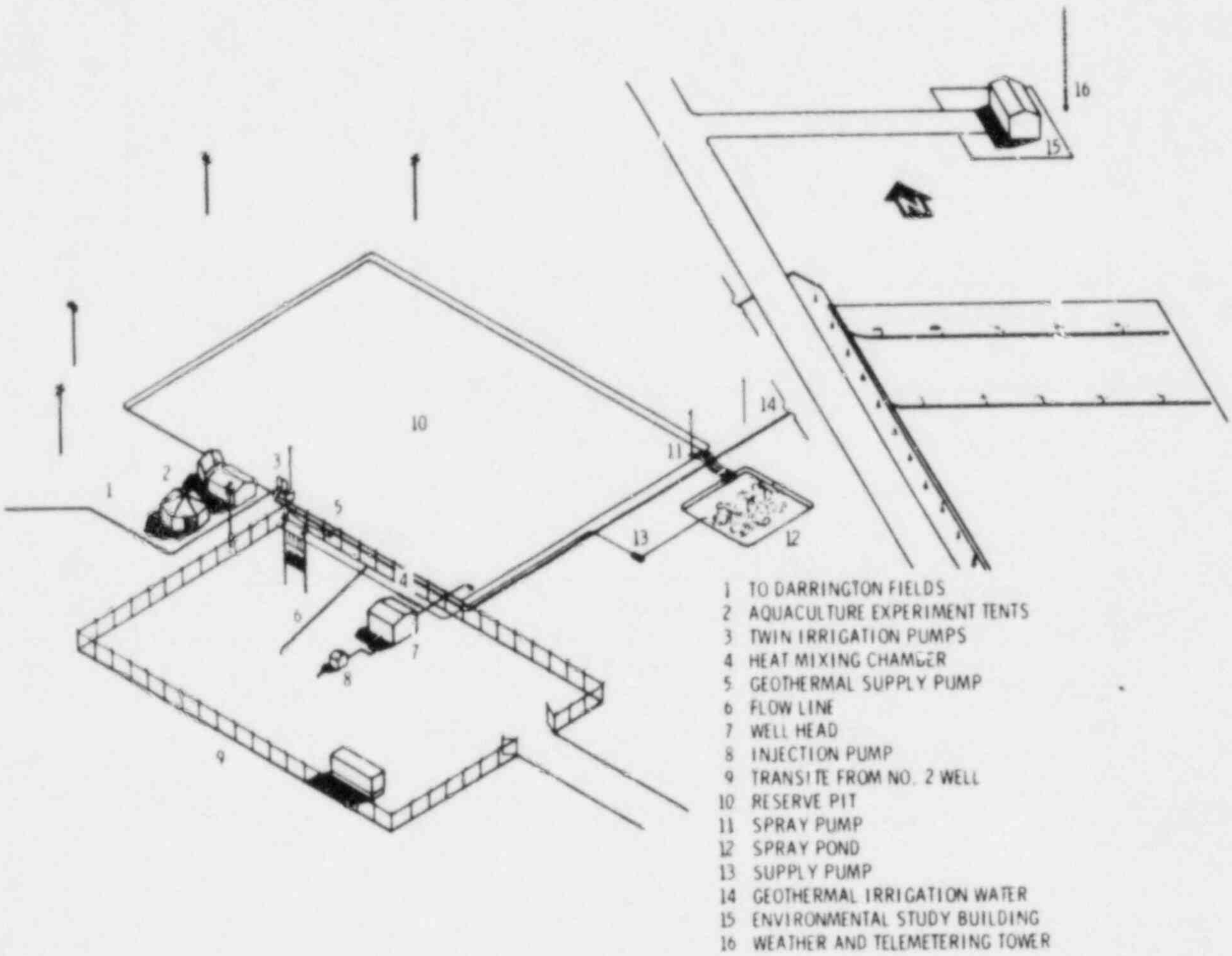

Figure 6.1 An approximate plan of the Raft River Geothermal Site No. 2

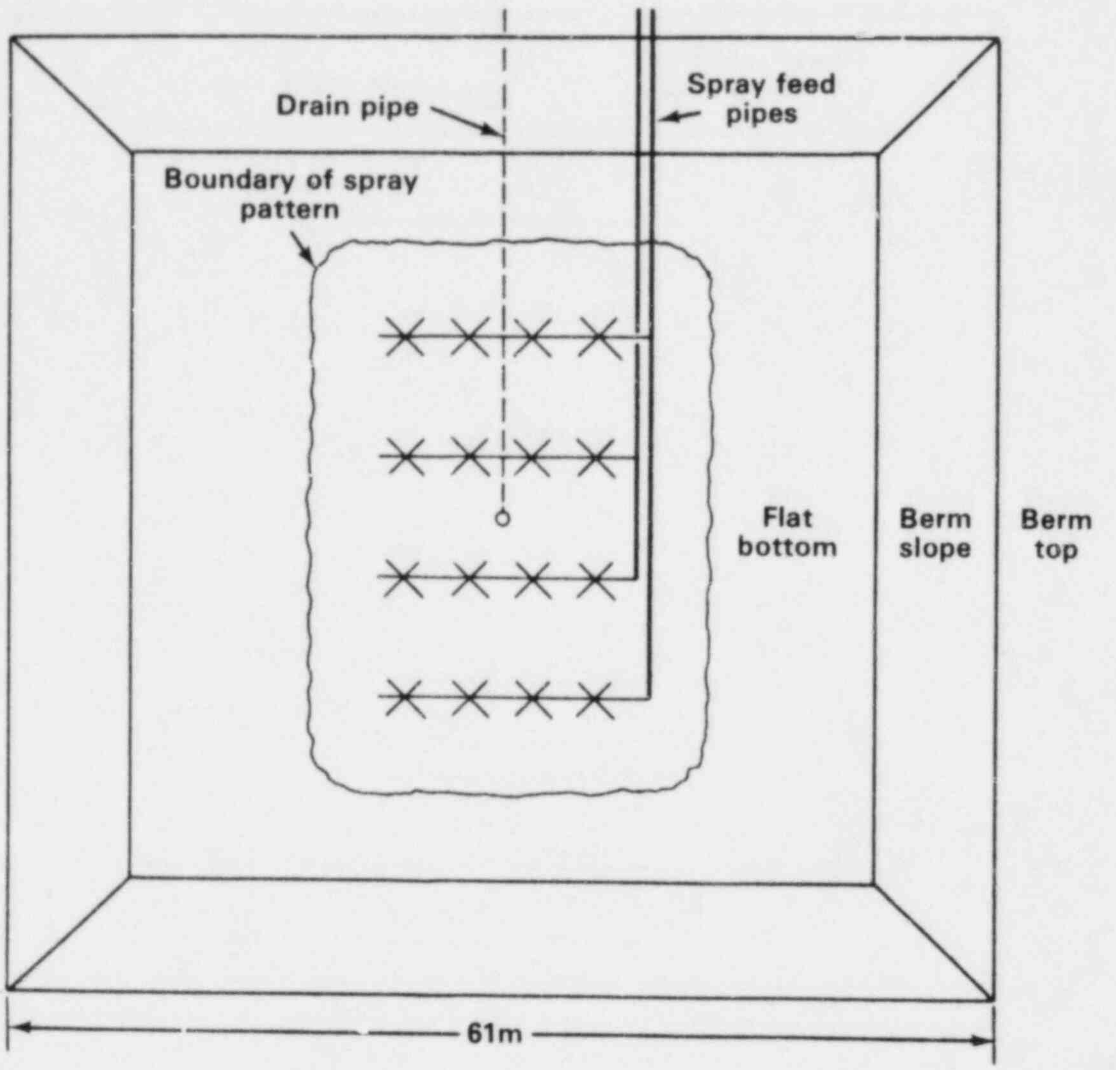

Figure 6.2 Plan drawing of the East Mesa spray pond

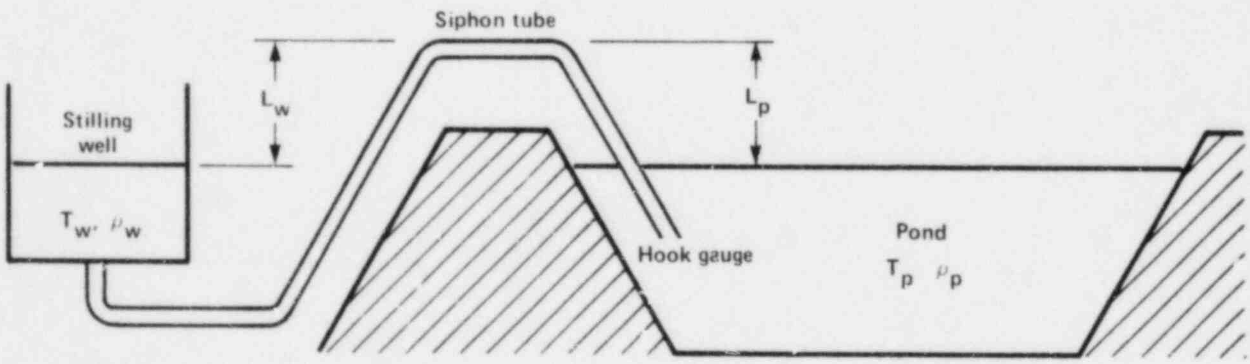

Figure 6.3 Description of stilling well and hook gauge in relation to pond

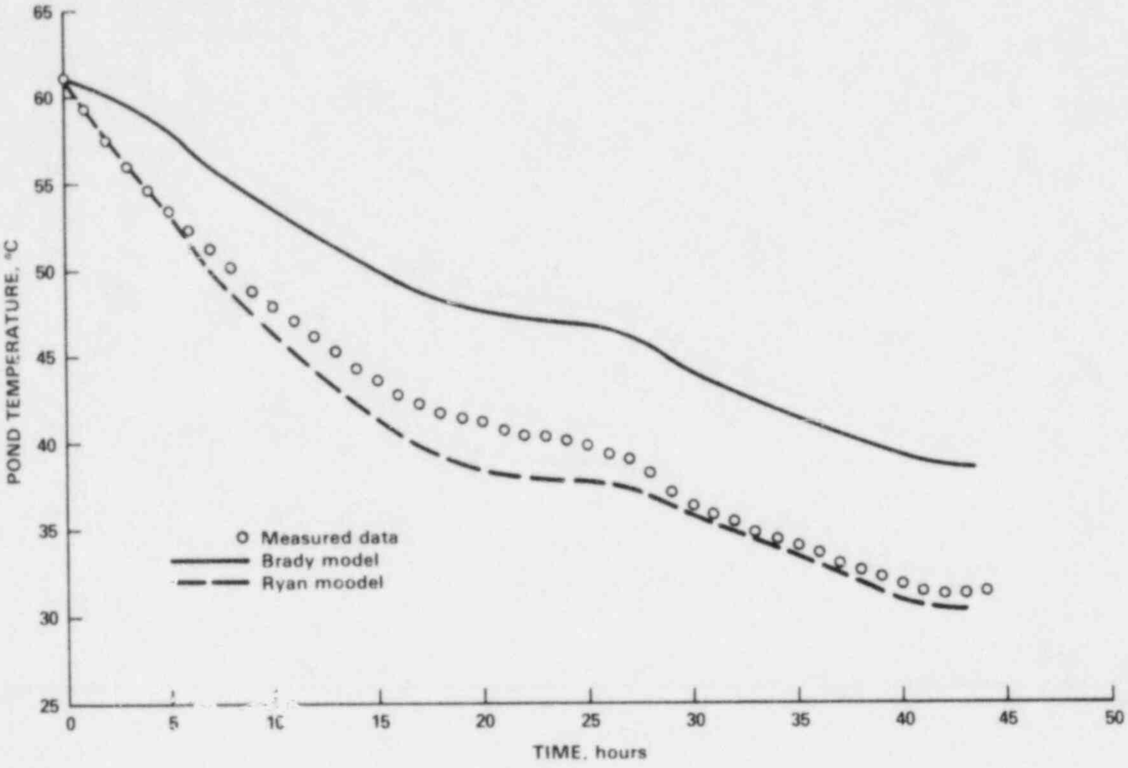

Figure 6.4 Pond temperature for "Idaho Hot 1" experiment

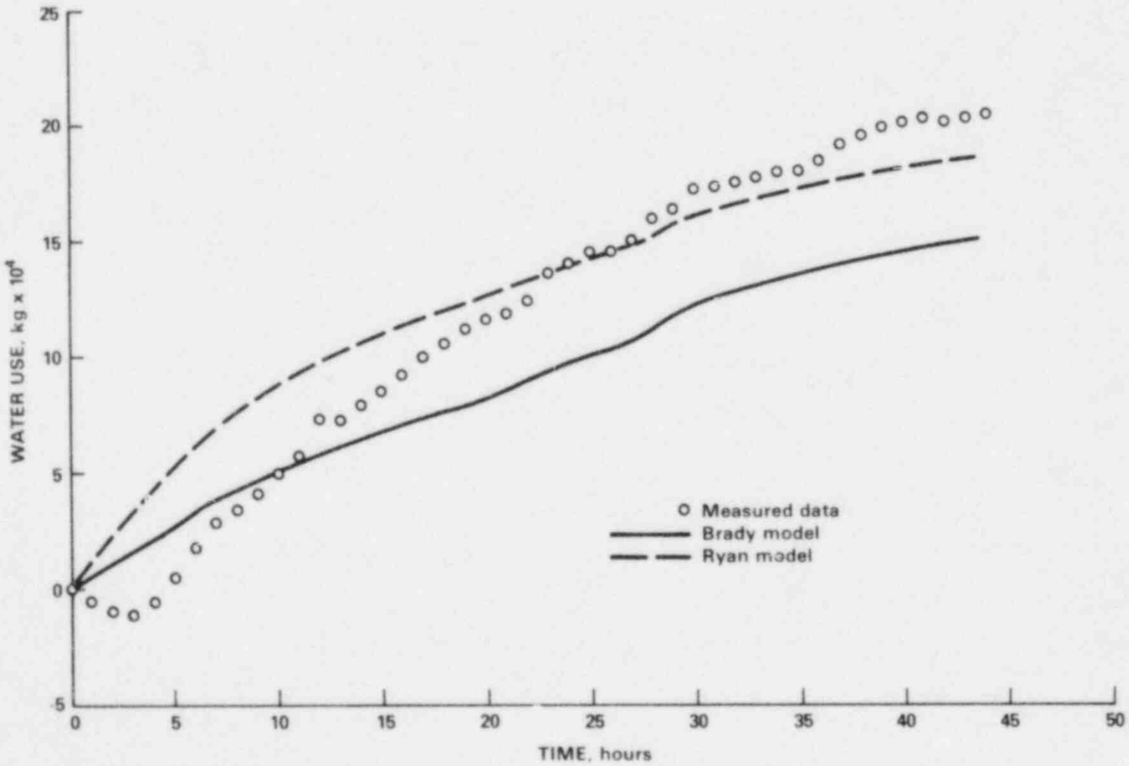

Figure 6.5 Water use fcr "Idaho Hot 1" experiment

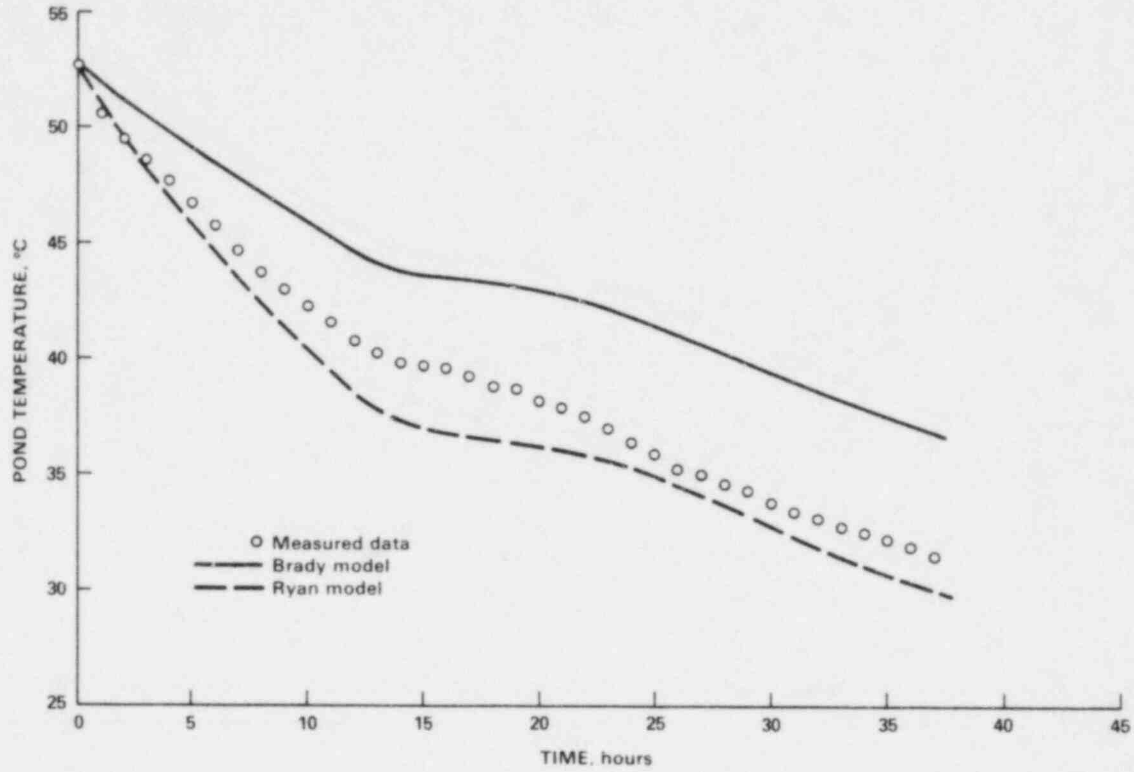

Figure 6.6 Pond temperature for "Idaho Hot 3" experiment

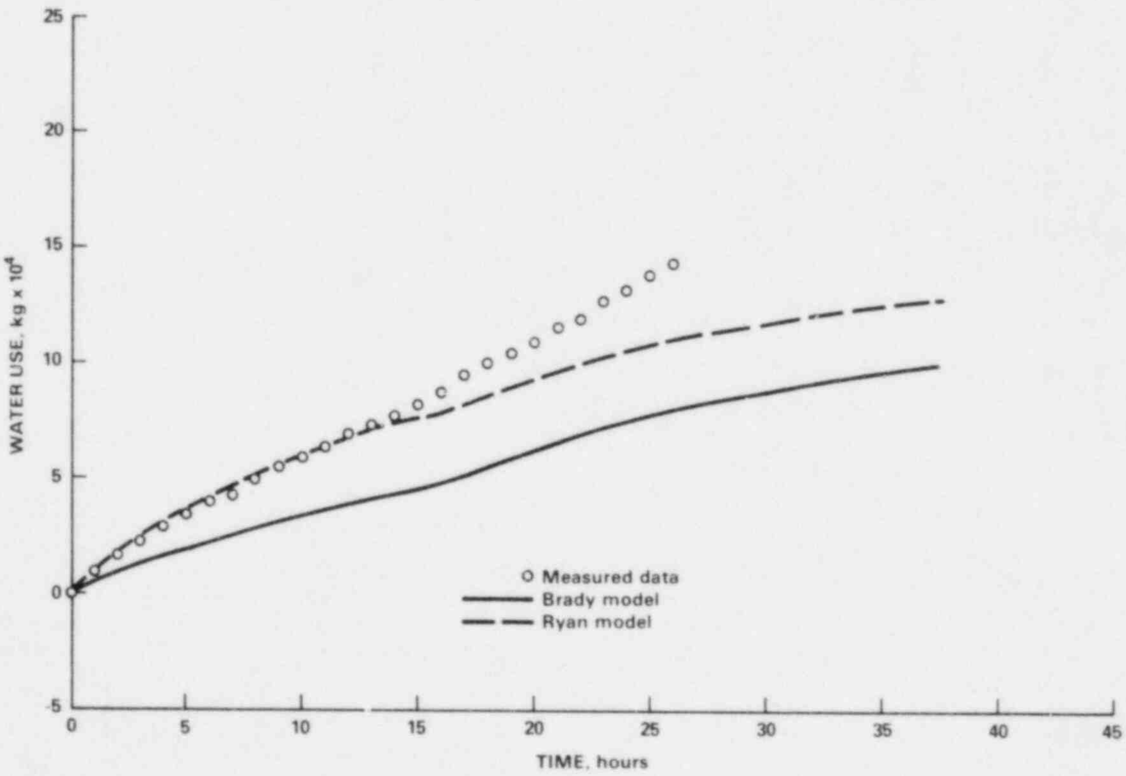

Figure 6.7 Water use for "Idaho Hot 3" experiment

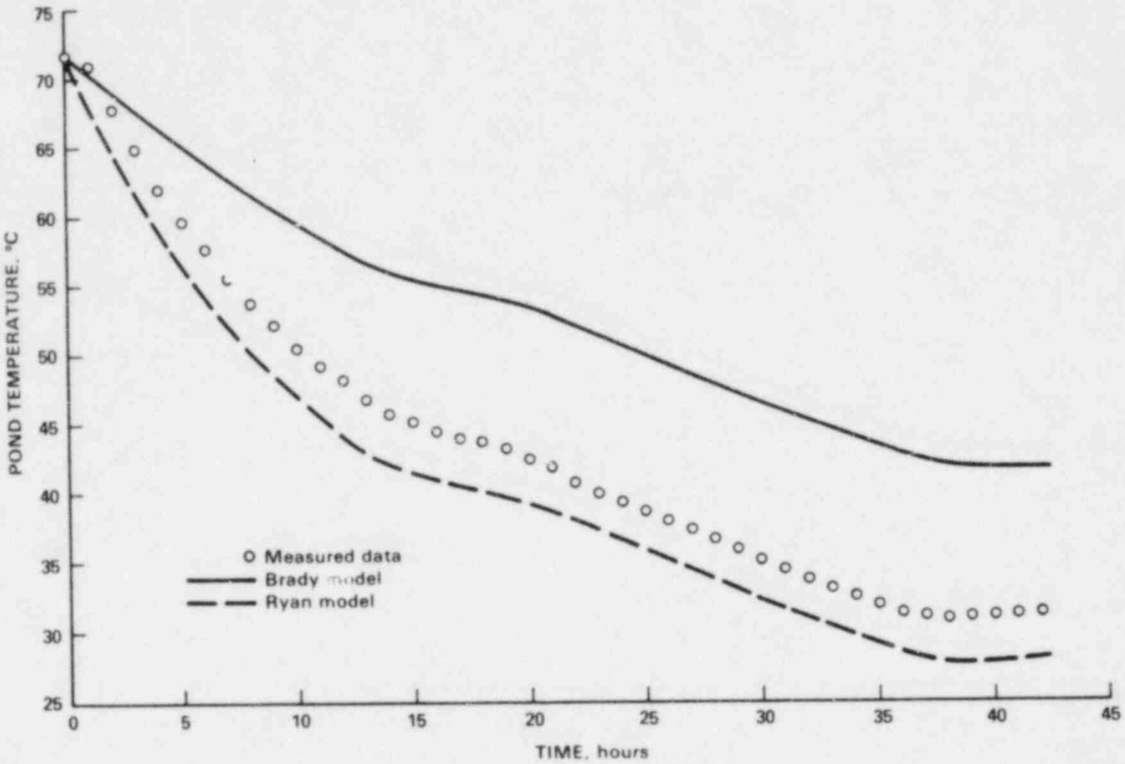

Figure 6.8 Pond temperature for "Idaho Hot 4" experiment

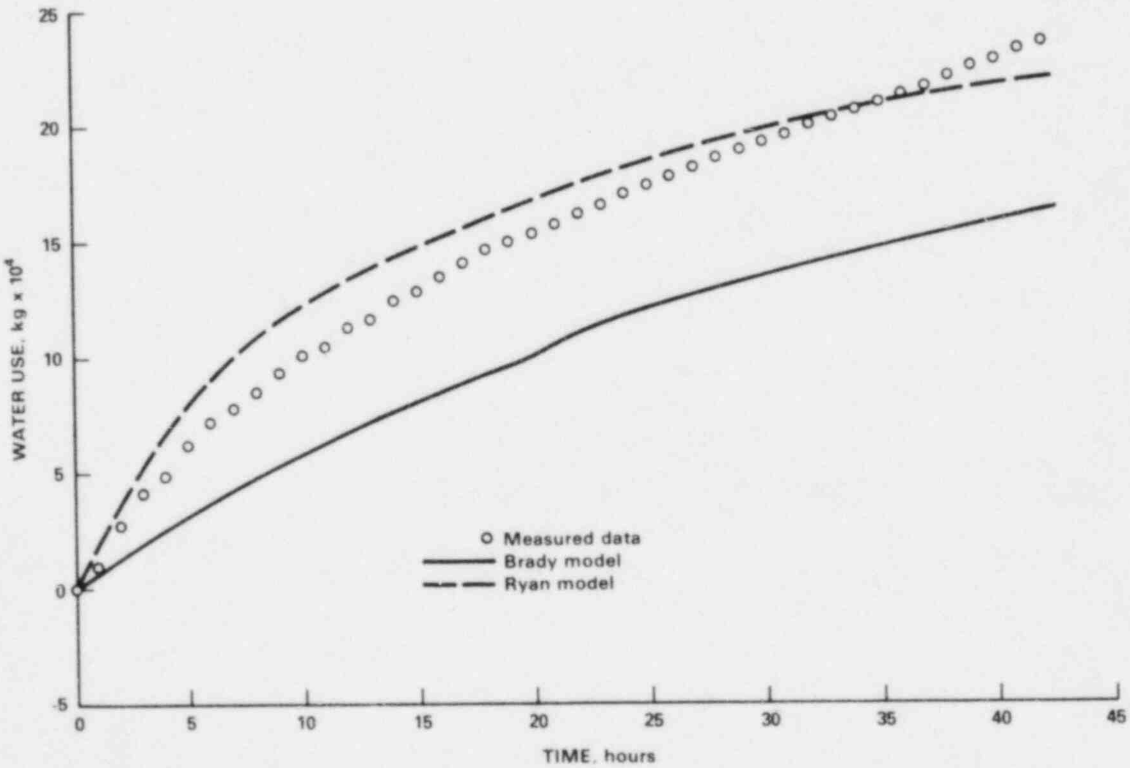

Figure 6.9 Water use for "Idaho Hot 4" experiment

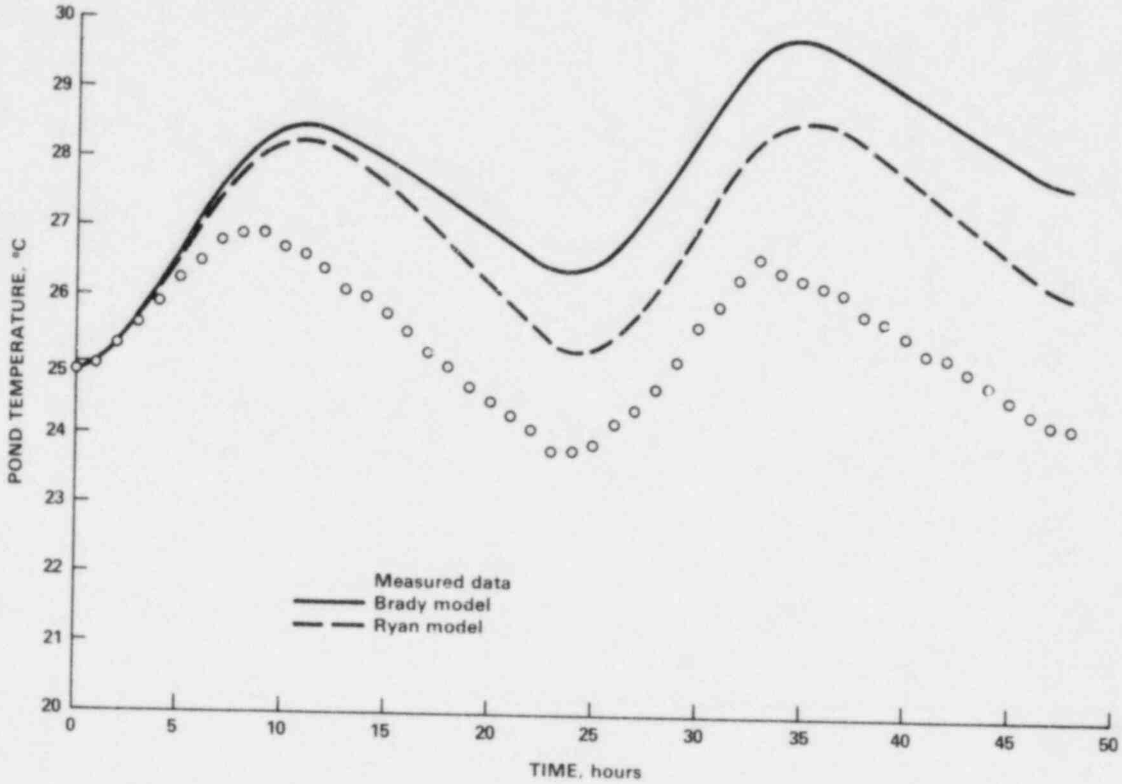

Figure 6.10 Pond temperature for "Idaho Cool 1" experiment

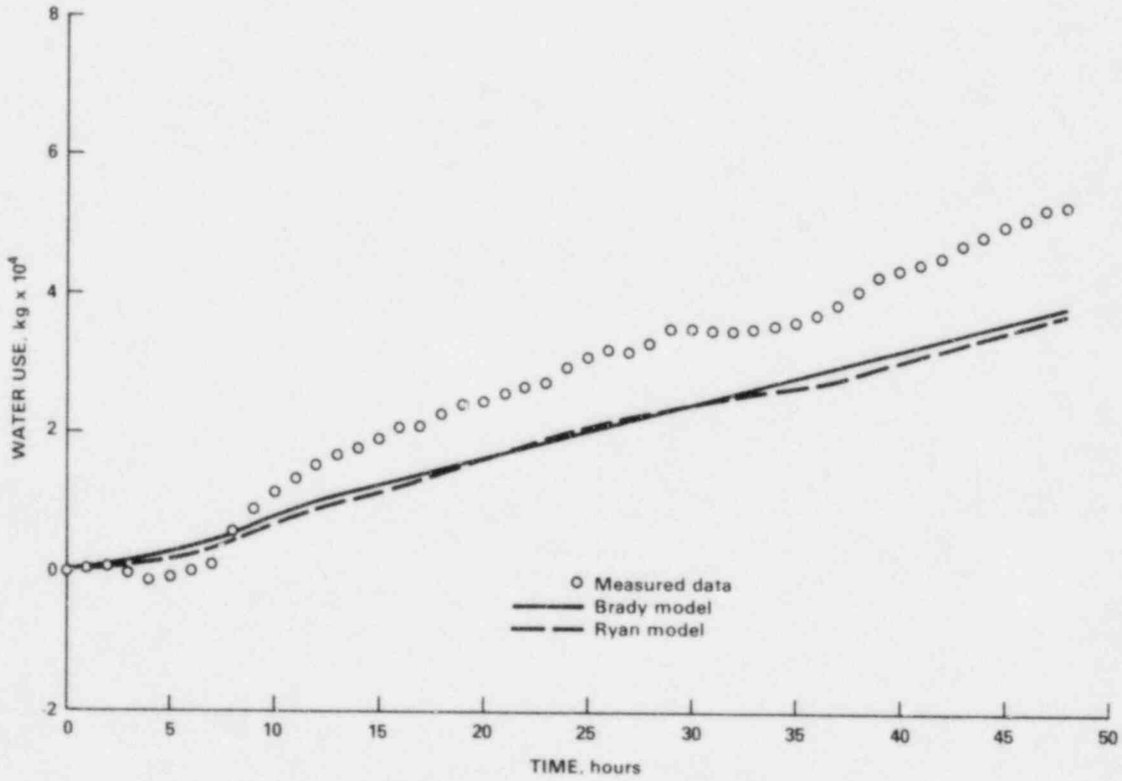

Figure 6.11 Water use for "Idaho Cool 1" experiment

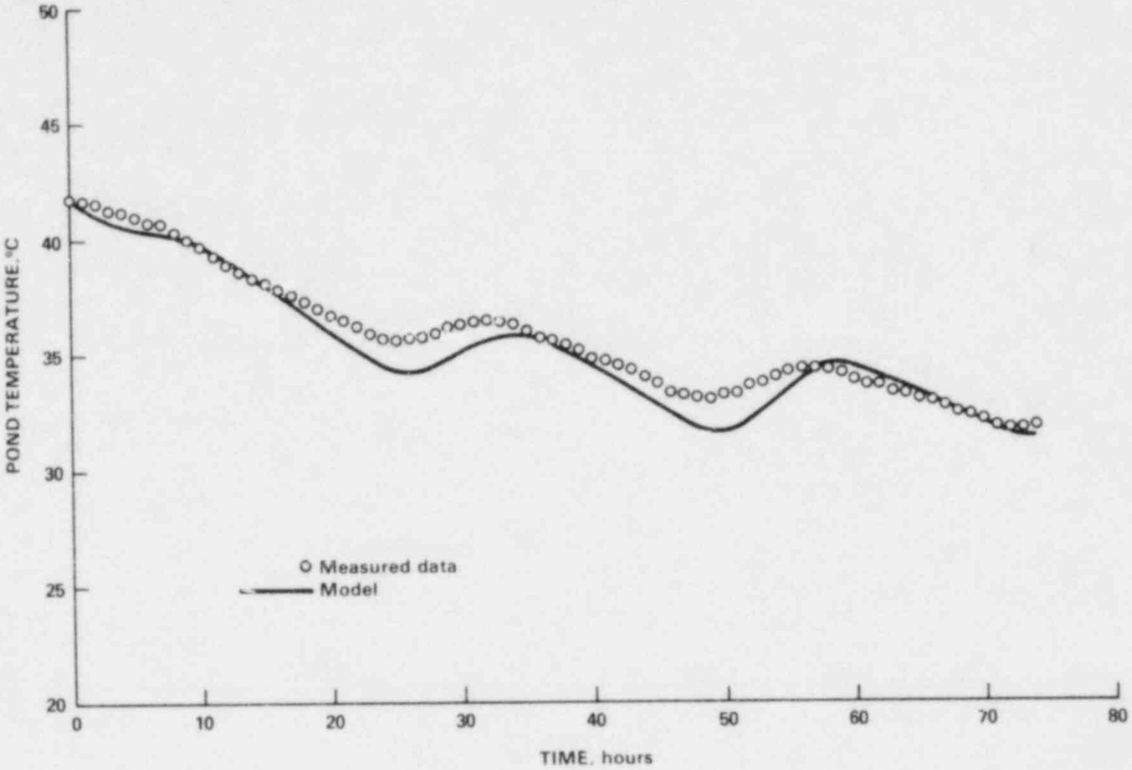

Figure 6.12 Pond temperature for "East Mesa Cool 1" experiment

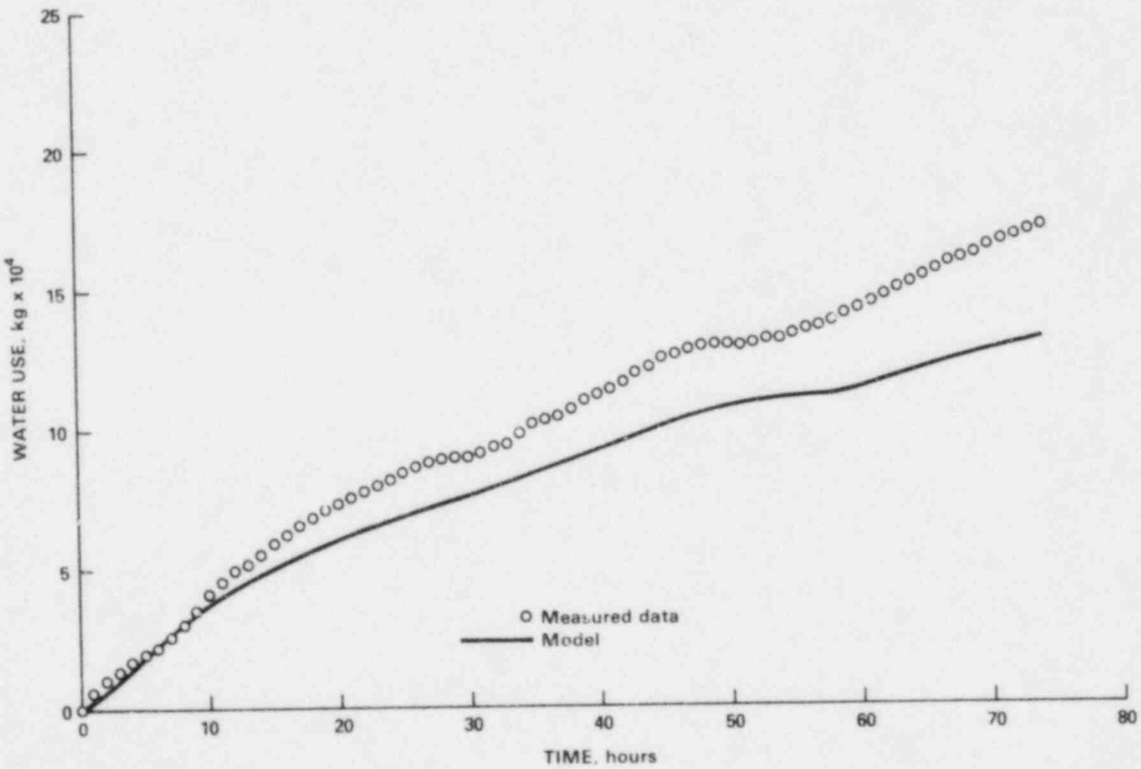

Figure 6.13 Water use for "East Mesa Cool 1" experiment

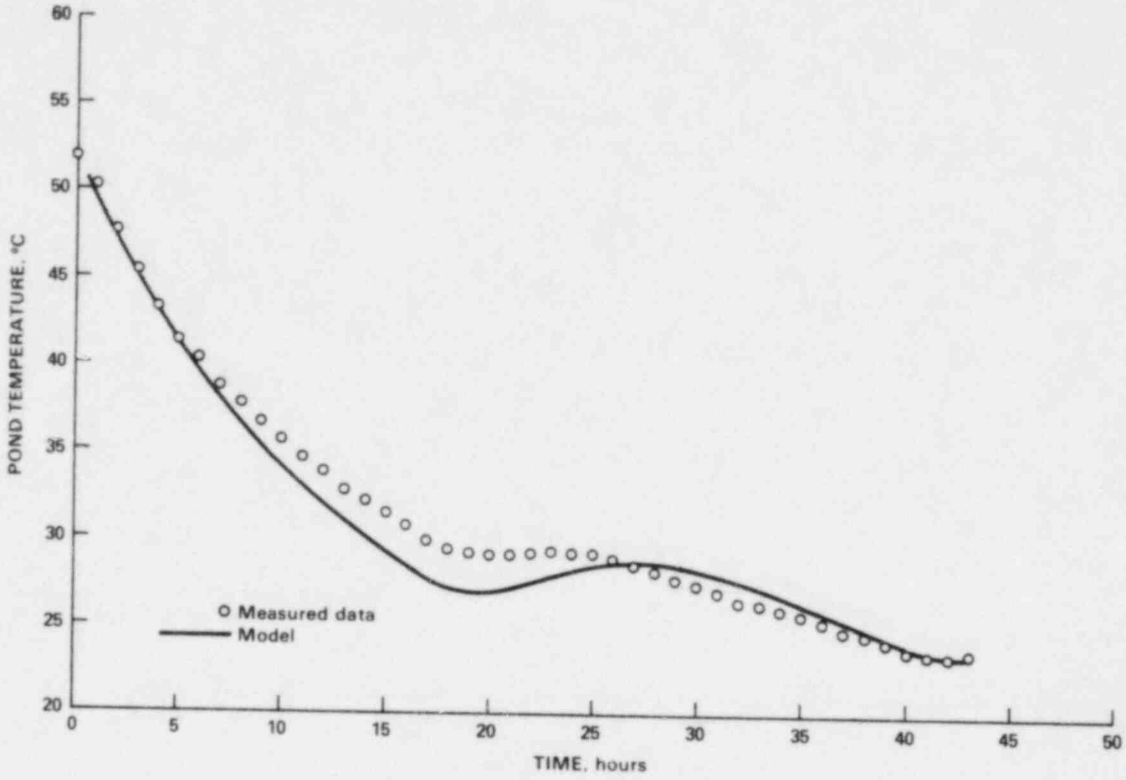

Figure 6.14 Pond temperature for "East Mesa Warm 1" experiment

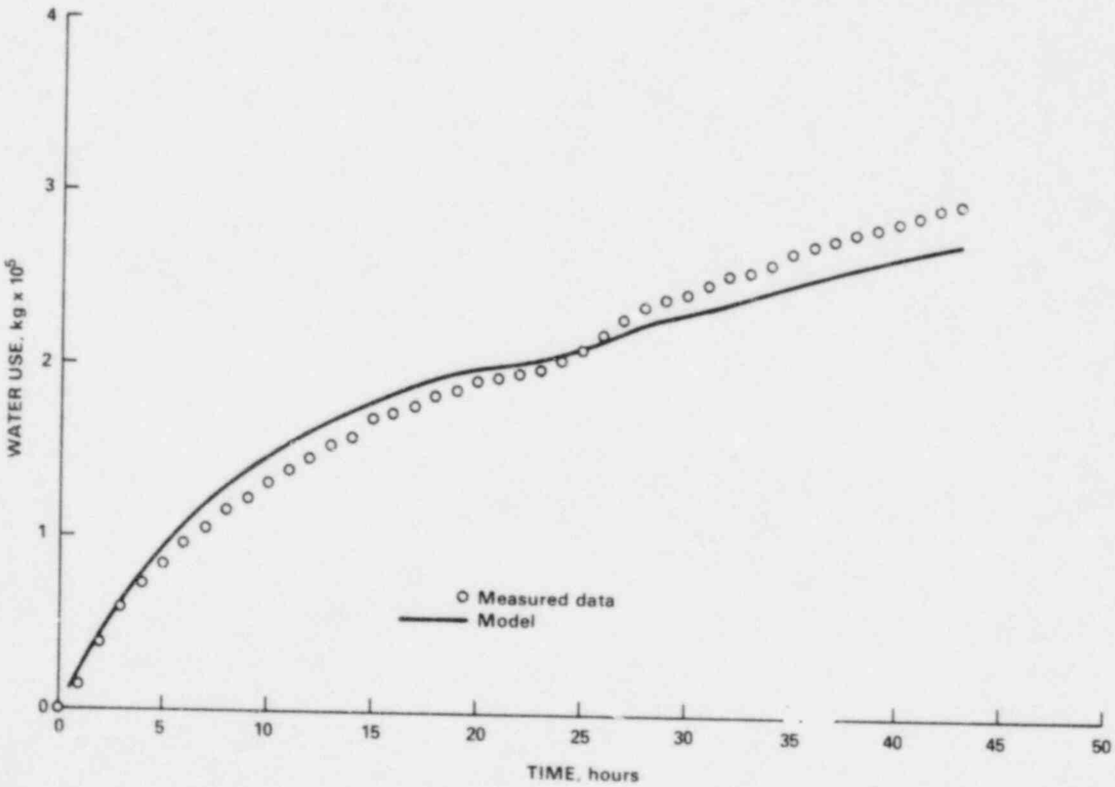

Figure 6.15 Water use for "East Mesa Warm 1" experiment

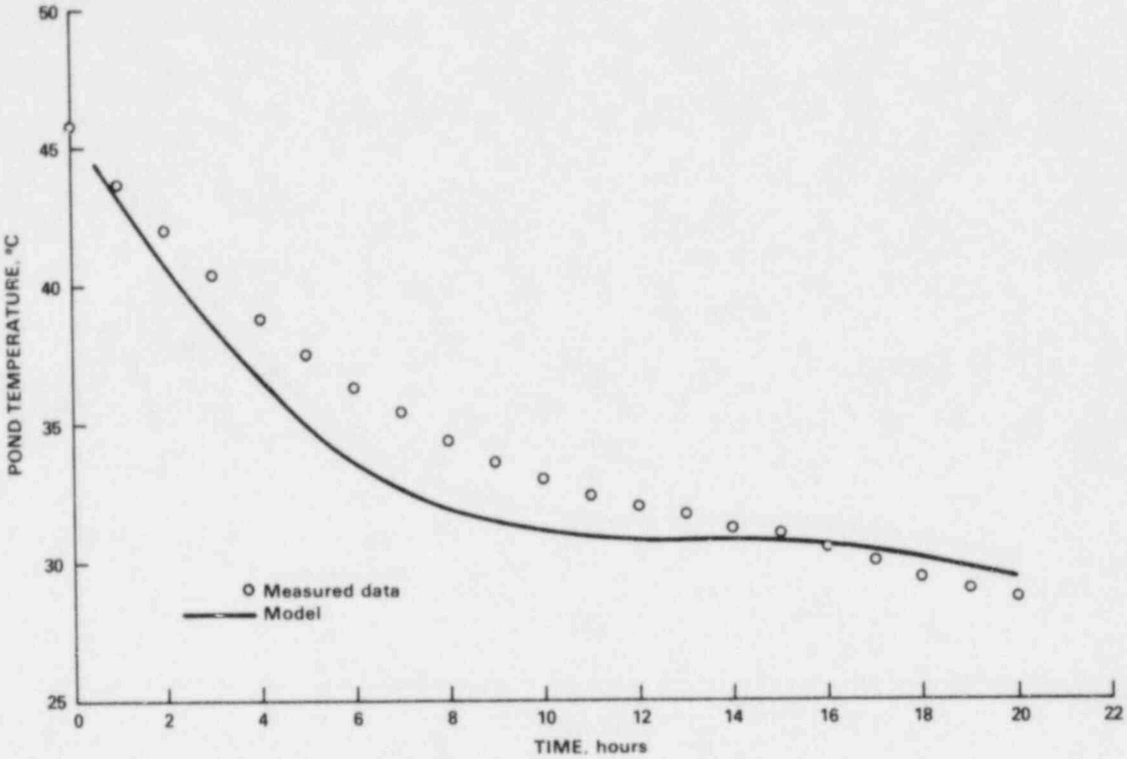

Figure 6.16 Pond temperature for "East Mesa Warm 2" experiment

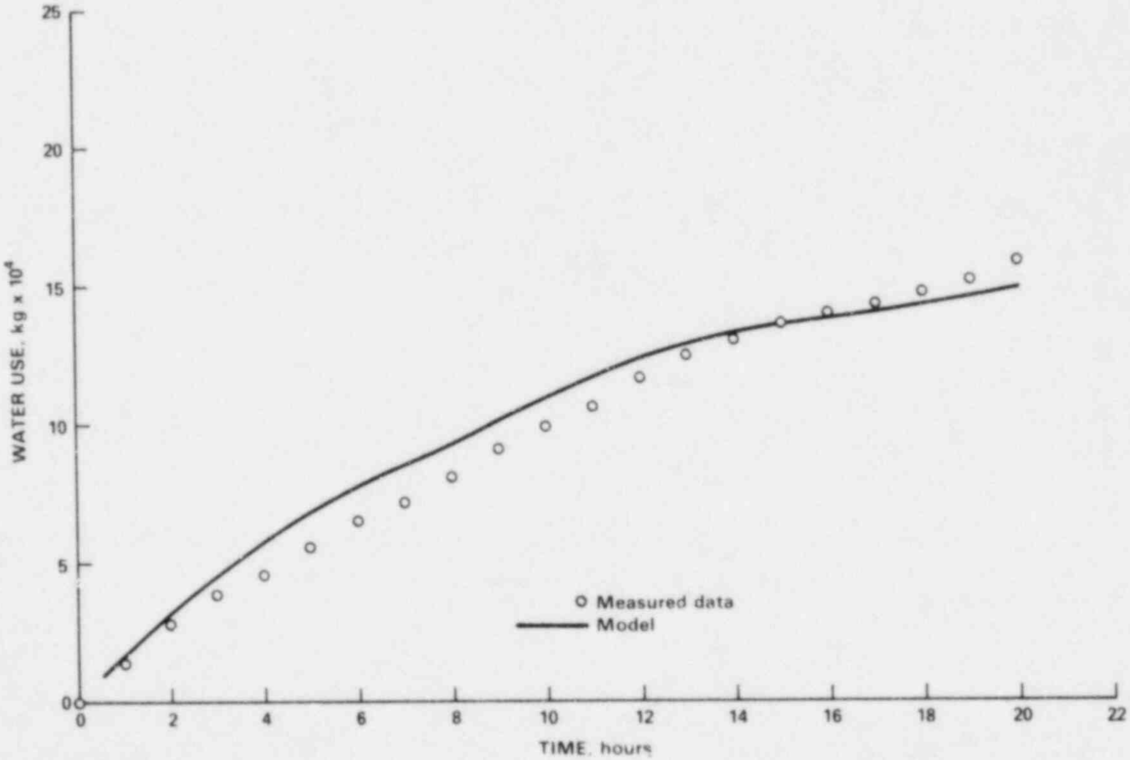

Figure 6.17 Water use for "East Mesa Warm 2" experiment

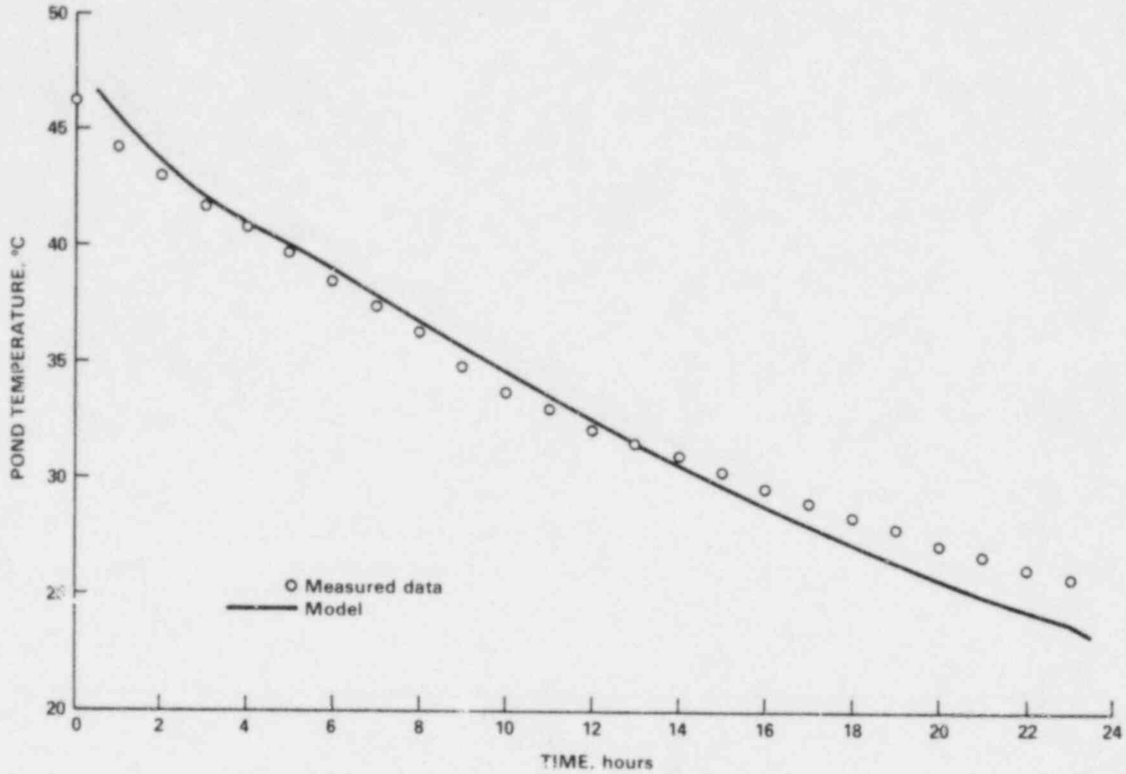

Figure 6.18 Pond temperature for "East Mesa Warm 3" experiment

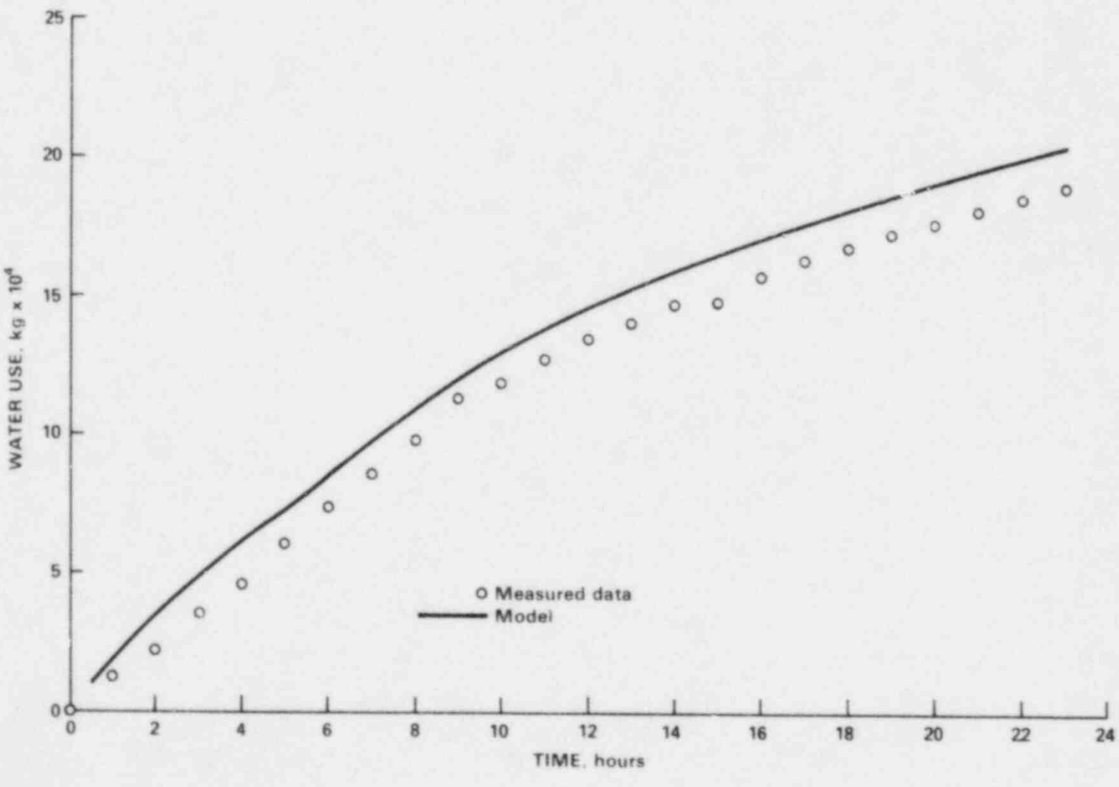

Figure 6.19 Water use for "East Mesa Warm 3" experiment

Table 6.1 Physical description of spray/cooling ponds used in study

Parameter	Raft River	East Mesa
Nominal full-surface area	2840 m^3	3385 m^2
Nominal full volume	3864 m^3	4675 m^3
Nominal depth when full	1.7 m	1.7 m + 0.3 m mud
Altitude	1480 m mean sea level	11 m mean sea level
Atmospheric pressure during tests	840-860 mbars	1000-1020 mbars
Nominal flow rate	0	0.235 m^3/sec
Number of nozzles	-	64

7 CONCLUSIONS

The NRC cooling pond and spray pond models were used to simulate the temperature and water loss of two experimental ponds that were equipped with many instruments to collect performance data. Model-prototype comparisons generally confirm that the NRC models are either accurate or conservative in predicting pond temperature, and generally adequate for water-loss computations.

Although the resulting comparisons are gratifying, they must be viewed with a certain amount of caution. The tests sites in Idaho and California are generally dry, cloudless deserts, and not typical of the climatic conditions at many nuclear power plant sites. The experimental ponds were also somewhat smaller than typical nuclear power plant cooling and spray ponds. Furthermore, the operation of the ponds was not analogous to the operation of cooling and spray ponds used in ultimate heat sink service. This last point would be most important in the case of large cooling ponds that could possibly stratify under the influence of an external heat load.

The results of these comparisons do not, therefore, automatically lead to a conclusion that they will adequately simulate the performance of ultimate heat sink cooling or spray ponds. The adequacy of the models must always be justified on a case-by-case basis. It must be shown that the pond or spray system is within the constraints and assumptions of the models. In the case of cooling ponds, for example, the possible effects of stratification must be taken into account. In spray ponds, the model's suitability for evaluating systems other than conventional vertical nozzle arrays must be addressed carefully. Finally, performance tests with the prototype cooling pond or spray pond should be carried out whenever possible.

The models and methods discussed in this report are provided to the public as useful tools for ultimate heat sink analyses. A computer tape containing all the programs and sample data sets discussed in NUREG-0693 and NUREG-0733 are available for a nominal fee from the NRC by writing to

Mr. James Shields
Scientific Programming Branch, MPA
Division of ADP Support
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

These models are intended as guidelines only. Their use does not ensure NRC approval, nor are the models required procedures for nuclear power plant licensing. Furthermore, by publishing this guidance, NRC does not wish to discourage independent assessments of ultimate heat sink performance or the furtherance of the state of the art.

8 REFERENCES

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APPENDIX A

RAFT RIVER DATA

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	22.70	15.30	1.10	.81	24.90	7.50
1.0	28.70	18.90	1.10	1.32	25.00	7.43
2.0	29.60	19.40	1.91	1.82	25.30	7.46
3.0	31.50	20.40	1.80	2.22	25.60	7.48
4.0	32.60	21.00	3.50	2.42	25.90	7.50
5.0	33.90	21.60	1.80	2.59	26.25	7.47
6.0	35.30	21.60	3.20	2.61	26.50	7.42
7.0	35.40	21.90	4.30	2.41	26.80	7.39
8.0	35.20	21.70	5.32	2.20	26.90	7.23
9.0	34.40	21.10	4.30	1.77	26.90	7.13
10.0	33.60	20.90	4.22	1.26	26.70	7.05
11.0	32.40	20.30	4.63	.72	26.60	7.00
12.0	30.60	19.10	2.70	.21	26.40	6.95
13.0	25.60	16.20	.70	0.00	26.10	6.91
14.0	23.60	15.20	.42	0.00	26.00	6.89
15.0	19.30	12.30	.70	0.00	25.75	6.85
16.0	16.20	10.80	.50	0.00	25.50	6.80
17.0	14.90	10.20	1.00	0.00	25.20	6.80
18.0	16.30	10.60	.80	0.00	25.00	6.75
19.0	14.80	9.90	.80	0.00	24.70	6.70
20.0	14.20	9.40	.90	0.00	24.50	6.69
21.0	12.50	8.40	.72	0.00	24.30	6.65
22.0	11.70	8.20	1.50	0.00	24.10	6.62
23.0	15.40	10.50	1.20	.28	23.80	6.59
24.0	22.20	15.20	.60	.81	23.80	6.51
25.0	25.00	16.20	2.42	1.34	23.90	5.45
26.0	27.40	17.90	2.71	1.82	24.20	6.40
27.0	29.40	19.40	2.70	2.21	24.40	6.39
28.0	31.20	20.10	3.71	2.41	24.70	6.32
29.0	33.00	21.00	2.30	2.59	25.10	6.22
30.0	33.80	21.60	3.00	2.63	25.60	6.20
31.0	34.70	22.10	2.60	2.49	25.90	6.19
32.0	35.20	22.00	1.70	2.18	26.30	6.18
33.0	35.00	22.20	2.20	1.79	26.60	6.17
34.0	34.40	21.40	2.00	.86	26.40	6.15
35.0	32.00	20.70	1.50	.36	26.30	6.15
36.0	31.00	19.60	.50	.15	26.20	6.13
37.0	26.90	17.60	1.40	0.00	26.10	6.10
38.0	24.20	15.20	1.60	0.00	25.80	6.05
39.0	21.40	13.50	1.29	0.00	25.70	6.00
40.0	22.00	13.70	.10	0.00	25.50	5.98
41.0	21.00	13.30	.50	0.00	25.25	5.95
42.0	23.70	15.30	.52	0.00	25.20	5.93
43.0	18.80	12.40	1.13	0.00	25.00	5.87
44.0	18.80	12.60	1.00	0.00	24.80	5.83
45.0	17.80	12.50	1.12	0.00	24.60	5.78
46.0	16.70	11.70	.60	0.00	24.40	5.75
47.0	17.60	12.60	.80	.25	24.25	5.70
48.0	26.10	17.70	1.90	.77	24.20	5.68

Table A.1 Data for "Idaho Cool 1" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	32.20	20.60	2.12	2.50	61.10	10.29
1.C	33.70	21.70	2.01	2.56	59.30	10.29
2.0	33.50	21.20	2.21	2.12	57.50	10.27
3.0	32.90	21.20	1.62	1.38	56.00	10.20
4.0	32.40	21.60	1.41	.81	54.60	9.89
5.0	31.80	19.90	2.71	.51	53.40	9.45
6.0	30.50	19.30	4.01	.18	52.30	8.94
7.0	24.00	16.30	1.62	.03	51.20	8.50
8.0	20.70	14.40	1.01	0.00	50.20	8.25
9.0	19.90	13.30	1.71	0.00	48.80	7.92
10.0	17.60	11.80	1.01	0.00	47.90	7.55
11.0	15.50	11.50	1.62	0.00	47.10	7.25
12.0	15.40	10.40	1.32	0.00	46.20	6.63
13.0	15.50	11.30	1.71	0.00	45.30	6.60
14.0	13.70	10.00	.61	0.00	44.30	6.30
15.0	12.90	9.00	1.41	0.00	43.60	6.05
16.0	10.90	8.50	.99	0.00	42.80	5.75
17.0	12.80	9.50	.71	.19	42.25	5.45
18.0	18.90	13.70	1.20	.72	41.70	5.20
19.0	23.80	16.50	.71	1.27	41.40	4.95
20.0	25.50	17.40	2.02	1.79	41.20	4.75
21.0	27.60	18.20	3.62	2.01	40.70	4.60
22.0	29.50	19.20	3.51	2.44	40.40	4.35
23.0	31.10	20.00	3.62	2.60	40.30	3.87
24.0	32.40	20.50	3.31	2.62	40.10	3.66
25.0	32.60	20.90	1.92	1.88	39.80	3.45
26.0	31.60	20.70	1.73	.93	39.30	3.39
27.0	34.70	21.70	3.70	1.75	39.00	3.20
28.0	34.30	20.90	6.51	1.19	38.20	2.81
29.0	32.10	19.60	5.40	.64	37.10	2.62
30.0	29.20	18.50	4.53	.71	36.30	2.30
31.0	27.50	17.20	1.22	0.00	35.80	2.25
32.0	25.20	16.10	1.42	0.00	35.40	2.18
33.0	25.90	16.10	3.31	0.00	34.80	2.09
34.0	18.30	12.30	1.31	0.00	34.40	2.00
35.0	17.80	12.30	.40	0.00	34.00	1.98
36.0	18.80	12.10	.71	0.00	33.60	1.82
37.0	18.10	11.20	1.92	0.00	33.00	1.55
38.0	15.70	9.40	2.51	0.00	32.60	1.40
39.0	13.50	8.60	.63	0.00	32.20	1.28
40.0	13.40	8.00	1.32	0.00	31.80	1.18
41.0	17.10	10.40	.32	.26	31.40	1.11
42.0	22.10	13.30	.31	.81	31.25	1.15
43.0	24.20	15.40	1.40	1.34	31.30	1.08
44.0	25.90	15.70	2.20	1.85	31.40	1.00

Table A.2 Data for "Idaho Hot 1" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	32.40	19.75	4.20	.82	52.70	6.50
1.0	30.40	17.50	3.20	.40	50.60	5.99
2.0	24.70	13.90	1.80	0.00	49.50	5.65
3.0	17.80	9.90	1.20	0.00	48.60	5.38
4.0	14.40	7.50	.92	0.00	47.70	5.10
5.0	12.80	7.00	1.40	0.00	46.75	4.86
6.0	12.90	7.20	1.90	0.00	45.80	4.60
7.0	12.20	6.70	1.50	0.00	44.70	4.44
8.0	11.10	6.10	2.00	0.00	43.75	4.14
9.0	11.20	6.10	1.60	0.00	43.00	3.90
10.0	11.10	6.00	1.20	0.00	42.30	3.70
11.0	9.90	5.20	1.60	0.00	41.60	3.50
12.0	9.10	4.90	1.80	.01	40.80	3.25
13.0	15.80	9.40	1.50	.49	40.25	3.07
14.0	22.20	13.60	1.40	1.00	39.80	2.90
15.0	26.90	16.00	.70	1.50	39.70	2.70
16.0	28.90	16.90	2.90	1.95	39.60	2.48
17.0	30.00	17.80	3.90	2.30	39.25	2.15
18.0	31.90	19.00	3.70	2.51	38.80	1.90
19.0	33.40	19.90	4.40	2.52	38.70	1.70
20.0	33.10	19.75	4.20	1.71	38.20	1.46
21.0	33.50	20.20	4.00	1.65	37.90	1.19
22.0	34.60	20.70	4.40	1.73	37.50	1.02
23.0	34.00	20.30	3.70	1.25	37.00	.70
24.0	32.60	19.90	3.40	.75	36.40	.50
25.0	31.00	19.20	3.40	.35	35.90	.26
26.0	27.10	17.00	1.80	0.00	35.25	.05
27.0	21.90	14.30	1.20	0.00	35.00	0.00
28.0	21.90	14.20	.50	0.00	34.60	0.00
29.0	17.00	11.60	.40	0.00	34.30	0.00
30.0	15.20	10.60	1.20	0.00	33.80	0.00
31.0	14.80	10.00	1.30	0.00	33.40	0.00
32.0	16.40	11.00	1.00	0.00	33.10	0.00
33.0	18.00	12.40	1.20	0.00	32.75	0.00
34.0	18.00	12.20	.50	0.00	32.50	0.00
35.0	18.10	13.70	.70	0.00	32.20	0.00
36.0	19.90	13.30	1.40	0.00	31.90	0.00
37.0	19.20	12.90	2.10	.25	31.50	0.00

Table A.3 Data for "Idaho Hot 3" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	12.00	6.00	.70	.03	71.70	13.35
1.0	9.00	4.20	1.30	.03	70.90	12.92
2.0	6.70	2.70	1.30	.03	67.80	11.95
3.0	5.40	2.10	1.30	.03	64.90	11.15
4.0	3.50	.90	1.40	.03	62.00	10.60
5.0	3.30	.90	1.40	.03	59.70	9.90
6.0	3.00	.50	1.40	.03	57.70	9.35
7.0	2.00	0.00	1.30	.03	55.60	8.95
8.0	1.00	-.30	1.50	.03	53.80	8.53
9.0	.40	-.50	1.80	.03	52.20	8.10
10.0	.80	-.60	1.30	.03	50.50	7.68
11.0	.40	-.50	1.50	.03	49.20	7.44
12.0	2.00	0.00	1.90	.05	48.20	7.05
13.0	6.30	2.90	1.80	.54	46.80	6.82
14.0	12.50	6.60	.50	1.11	45.75	6.45
15.0	15.60	8.60	1.00	1.59	45.20	6.28
16.0	18.00	9.70	1.80	1.90	44.50	6.00
17.0	19.50	10.50	1.30	2.06	44.00	5.75
18.0	20.40	11.20	1.60	2.01	43.75	5.52
19.0	22.50	11.60	1.60	1.93	43.25	5.35
20.0	23.00	11.90	2.80	1.66	42.50	5.15
21.0	22.70	11.90	3.10	1.22	41.90	4.95
22.0	21.80	11.60	3.00	.71	40.80	4.70
23.0	17.70	9.60	1.70	.18	40.00	4.50
24.0	14.10	7.10	.50	.02	39.40	4.30
25.0	10.40	4.70	1.90	.02	38.70	4.13
26.0	8.00	3.60	1.40	.02	38.00	3.95
27.0	6.70	2.90	1.20	.02	37.40	3.79
28.0	5.00	1.90	1.60	.02	36.70	3.60
29.0	5.20	2.00	1.90	.02	36.00	3.45
30.0	4.20	1.50	1.40	.02	35.20	3.29
31.0	3.50	.70	1.40	.02	34.50	3.14
32.0	4.00	1.30	1.60	.02	33.80	2.95
33.0	2.70	.80	1.50	.02	33.20	2.80
34.0	1.50	.70	.80	.02	32.60	2.65
35.0	1.80	.70	1.90	.02	32.00	2.50
36.0	1.30	.70	1.40	.07	31.40	2.35
37.0	7.00	3.00	2.00	.55	31.20	2.22
38.0	13.40	6.90	1.50	1.10	31.00	2.05
39.0	18.00	9.50	.50	1.57	31.10	1.90
40.0	20.40	11.20	1.50	1.86	31.20	1.80
41.0	22.30	11.90	1.30	2.08	31.30	1.63
42.0	24.00	12.70	1.50	2.08	31.40	1.50

Table A.4 Data for "Idaho Hot 4" experiment

APPENDIX B

EAST MESA DATA

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	25.30	18.60	.20	.18	41.80	14.69
1.0	27.40	20.00	.90	.88	41.70	14.50
2.0	29.10	21.00	1.50	1.64	41.60	14.35
3.0	31.00	21.80	1.90	2.26	41.30	14.20
4.0	32.10	22.20	3.30	2.73	41.20	14.05
5.0	32.90	22.40	2.80	3.02	41.00	13.90
6.0	34.00	23.20	2.30	3.00	40.75	13.77
7.0	34.70	23.50	2.90	2.96	40.70	13.60
8.0	35.80	24.00	3.40	2.61	40.30	13.40
9.0	35.70	23.80	2.50	2.08	40.00	13.20
10.0	35.60	24.00	2.80	1.39	39.70	13.00
11.0	34.80	23.50	.60	.61	39.30	12.85
12.0	32.40	22.30	2.30	.10	38.90	12.73
13.0	29.90	21.30	.80	0.00	38.60	12.68
14.0	28.70	20.60	1.10	0.00	38.30	12.58
15.0	27.20	19.80	.50	0.00	38.10	12.48
16.0	26.00	19.40	.80	0.00	37.80	12.39
17.0	25.60	19.20	.70	0.00	37.60	12.30
18.0	24.50	18.70	.90	0.00	37.30	12.22
19.0	25.30	18.50	1.00	0.00	37.00	12.13
20.0	22.30	17.60	.30	0.00	36.70	12.06
21.0	21.40	17.40	.50	0.00	36.50	12.00
22.0	21.40	16.90	.60	0.00	36.25	11.93
23.0	21.00	16.80	.40	0.00	35.90	11.85
24.0	21.80	17.60	.30	.20	35.70	11.79
25.0	27.00	20.20	.40	.86	35.60	11.70
26.0	29.10	20.80	.80	1.59	35.70	11.63
27.0	30.00	21.60	.90	2.22	35.75	11.56
28.0	32.30	22.60	.40	2.70	35.90	11.49
29.0	33.40	22.70	.80	3.00	36.20	11.44
30.0	34.80	23.80	1.00	3.09	36.30	11.39
31.0	35.10	24.00	2.10	2.95	36.40	11.30
32.0	35.30	24.40	2.00	2.71	36.50	11.21
33.0	35.30	24.30	1.50	2.06	36.40	11.15
34.0	35.50	24.10	1.30	1.35	36.30	11.03
35.0	34.70	24.10	1.30	.58	36.00	10.92
36.0	32.00	22.70	.70	0.00	35.70	10.90
37.0	28.90	21.20	.40	0.00	35.60	10.90
38.0	27.40	20.20	.60	0.00	35.40	10.85
39.0	27.60	20.00	1.30	0.00	35.20	10.77
40.0	25.90	19.20	.80	0.00	34.80	10.71
41.0	25.00	18.80	.80	0.00	34.70	10.67
42.0	24.20	18.50	1.30	0.00	34.50	10.60
43.0	24.00	18.40	1.40	0.00	34.30	10.51
44.0	23.60	18.20	1.60	0.00	34.00	10.45
45.0	23.30	17.80	1.40	0.00	33.70	10.35
46.0	22.70	17.60	1.40	0.00	33.30	10.30
47.0	21.80	17.20	.70	0.00	33.20	10.25
48.0	21.50	17.00	.50	.17	33.10	10.22

Table B.1 Data for "East Mesa Cool 1" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
49.0	25.20	19.90	.60	.86	33.00	10.20
50.0	28.20	21.80	1.00	1.56	33.20	10.20
51.0	31.30	23.30	.50	2.18	33.25	10.18
52.0	35.30	24.50	.90	2.66	33.60	10.12
53.0	36.30	24.30	1.50	2.96	33.70	10.03
54.0	38.00	25.50	1.40	3.05	34.00	9.99
55.0	38.20	25.60	.80	2.93	34.20	9.89
56.0	38.30	25.70	.60	2.56	34.30	9.81
57.0	39.00	25.70	.50	2.04	34.30	9.75
58.0	39.20	26.00	.90	1.34	34.25	9.69
59.0	37.10	25.20	2.90	.56	34.10	9.62
60.0	34.20	23.50	1.50	0.00	33.80	9.58
61.0	31.50	21.90	.30	0.00	33.60	9.54
62.0	29.80	21.30	.50	0.00	33.60	9.51
63.0	28.60	20.90	.40	0.00	33.30	9.45
64.0	27.80	20.30	.70	0.00	33.20	9.41
65.0	27.30	20.10	1.30	0.00	33.00	9.36
66.0	27.30	19.90	1.20	0.00	32.90	9.30
67.0	27.70	20.20	1.10	0.00	32.70	9.23
68.0	26.80	19.70	.70	0.00	32.40	9.19
69.0	26.50	19.40	.80	0.00	32.30	9.15
70.0	25.80	19.20	.80	0.00	32.10	9.07
71.0	24.20	19.00	.40	0.00	31.80	9.00
72.0	24.40	19.20	.70	.16	31.70	8.96
73.0	26.90	21.70	.30	.80	31.70	8.91
74.0	30.60	24.60	1.60	1.54	31.80	8.85

Table B.1 (Continued)

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	38.70	25.30	.80	2.95	51.90	14.10
1.0	40.40	25.90	.30	2.67	50.30	13.55
2.0	41.30	26.10	1.80	2.25	47.70	12.59
3.0	40.70	25.80	1.90	1.62	45.40	11.80
4.0	40.20	25.50	1.10	.92	43.30	11.25
5.0	37.50	24.10	1.90	.18	41.40	10.80
6.0	33.60	22.20	.60	0.00	40.40	10.42
7.0	31.90	21.80	.80	0.00	38.80	10.09
8.0	30.90	22.10	1.20	0.00	37.80	9.75
9.0	29.10	22.10	.50	0.00	36.70	9.50
10.0	27.80	21.70	.40	0.00	35.70	9.19
11.0	28.10	21.30	1.00	0.00	34.70	8.93
12.0	25.50	20.10	.70	0.00	33.90	8.70
13.0	24.80	19.70	.50	0.00	32.80	8.42
14.0	23.30	18.80	.40	0.00	32.20	8.27
15.0	22.90	18.70	.50	0.00	31.50	7.92
16.0	21.70	18.40	.40	0.00	30.80	7.80
17.0	21.80	18.70	.70	0.00	29.90	7.64
18.0	23.60	19.80	.80	.41	29.40	7.45
19.0	29.00	22.70	.70	1.14	29.20	7.32
20.0	31.10	23.60	.40	1.81	29.10	7.13
21.0	33.60	25.20	.40	2.34	29.10	7.03
22.0	35.80	26.00	.80	2.75	29.20	6.90
23.0	37.50	26.20	.70	2.95	29.30	6.78
24.0	39.50	21.10	.40	2.84	29.20	6.55
25.0	40.80	26.70	1.20	2.49	29.20	6.32
26.0	41.40	26.80	1.30	1.96	28.90	6.00
27.0	41.30	26.20	1.90	1.22	28.50	5.70
28.0	39.60	26.10	1.10	.45	28.20	5.48
29.0	36.60	25.10	.60	0.00	27.70	5.35
30.0	32.30	23.40	.70	0.00	27.40	5.28
31.0	30.10	22.80	.60	0.00	27.00	5.13
32.0	28.20	21.70	.80	0.00	26.40	4.98
33.0	27.70	19.90	.50	0.00	26.30	4.94
34.0	26.80	20.50	.80	0.00	26.00	4.82
35.0	26.50	19.30	.70	0.00	25.70	4.63
36.0	25.40	18.50	.80	0.00	25.30	4.50
37.0	23.70	18.40	.50	0.00	24.80	4.40
38.0	22.80	17.80	.50	0.00	24.60	4.30
39.0	22.20	17.90	.80	0.00	24.20	4.20
40.0	22.50	17.90	.60	0.00	23.70	4.09
41.0	22.10	17.20	.70	.15	23.50	3.99
42.0	25.10	19.10	.60	.94	23.40	3.85
43.0	31.50	23.50	.80	1.75	23.60	3.78

Table B.2 Data for "East Mesa Warm 1" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	24.90	18.10	.20	0.00	45.80	13.97
1.0	24.00	18.00	.30	0.00	43.70	13.38
2.0	22.20	17.30	.20	0.00	42.00	12.83
3.0	21.80	16.90	.20	0.00	40.40	12.40
4.0	20.50	16.20	.70	0.00	38.80	12.08
5.0	21.00	16.40	.70	.15	37.50	11.69
6.0	24.50	18.80	.40	.71	36.30	11.32
7.0	28.90	22.30	1.00	1.45	35.40	11.05
8.0	32.30	23.70	3.30	1.95	34.40	10.70
9.0	34.00	24.50	3.40	2.50	33.60	10.32
10.0	35.30	24.50	3.40	2.79	33.00	10.00
11.0	36.70	24.80	2.10	2.86	32.40	9.70
12.0	37.30	25.00	2.30	2.75	32.00	9.32
13.0	37.80	25.30	.20	2.44	31.70	9.00
14.0	38.30	25.60	1.00	1.61	31.20	8.75
15.0	37.70	25.20	.30	.94	31.00	8.55
16.0	37.00	24.80	.30	.34	30.50	8.40
17.0	33.80	24.70	.40	0.00	30.00	8.30
18.0	32.00	23.50	.50	0.00	29.40	5.15
19.0	30.40	22.20	.30	0.00	29.00	8.02
20.0	29.30	21.20	.10	0.00	28.70	7.83

Table B.3 Data for "East Mesa Warm 2" experiment

TIME HOURS	DRY BULB DEG.C	WET BULB DEG.C	WIND SP. M/S	TOT.SOL.RAD. MW	OBS.POND T DEG.C	OBS.POND HT. CM
0.0	28.20	20.90	1.10	1.43	46.25	13.75
1.0	30.30	22.20	.50	2.05	44.20	13.20
2.0	32.40	22.80	.50	2.48	43.00	12.79
3.0	34.80	23.30	.30	2.74	41.70	12.27
4.0	37.00	24.40	.40	2.85	40.80	11.85
5.0	38.70	24.60	.90	2.74	39.70	11.30
6.0	39.20	25.00	1.70	2.36	38.50	10.80
7.0	39.30	25.00	1.90	1.81	37.40	10.35
8.0	38.80	24.70	1.30	1.14	36.30	9.92
9.0	36.80	23.80	1.70	.39	34.80	9.40
10.0	32.80	21.30	.70	0.00	33.70	9.20
11.0	30.30	21.30	1.30	0.00	33.00	8.95
12.0	28.40	20.20	.60	0.00	32.10	8.71
13.0	26.10	18.80	.50	0.00	31.50	8.53
14.0	25.50	19.50	.50	0.00	31.00	8.34
15.0	24.00	18.10	.80	0.00	30.30	8.29
16.0	23.20	17.50	.40	0.00	29.60	8.00
17.0	24.50	18.40	1.00	0.00	29.00	7.82
18.0	21.50	16.80	.10	0.00	28.40	7.67
19.0	20.70	16.80	.60	0.00	27.90	7.51
20.0	21.20	16.50	.80	0.00	27.20	7.38
21.0	20.20	15.50	.40	0.00	26.70	7.23
22.0	19.30	15.40	.20	0.00	24.20	7.09
23.0	20.50	16.30	.60	.55	25.80	6.95

Table B.4 Data for "East Mesa Warm 3" experiment

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Two previously published reports, NUREG-0693 and NUREG-0733, presented models and methods by which ultimate heat sink cooling ponds and spray ponds used for safety-related water supplies in nuclear power plants could be analyzed for design-basis conditions of heat load and meteorology. These models were only partially verified with field data. The present report compares the NRC models to data collected for NRC by Battelle Pacific Northwest Laboratories on the performance of small geothermally heated ponds and spray ponds. These comparisons generally support the conclusion that the NRC models are useful tools in predicting ultimate heat sink performance.

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Ultimate Heat Sink
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COMPARISON BETWEEN FIELD DATA AND ULTIMATE HEAT SINK COOLING POND AND SPRAY POND MODELS

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