WNP-2 SPRAY POND
DRIFT LOSS
REPORT

July, 1985

Prepared by: D. M. Myers
L. C. Mauws
J. D. Husted

Approved by: C. R. Noyes
D. R. Kidder

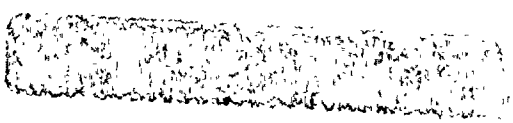

Table of Contents

SPRAY POND DRIFT LOSS REPORT

I. Introduction

In 1979, the Supply System performed a drift loss and thermal performance test to establish the performance parameters to be used in safety analyses of the Ultimate Heat Sink (UHS) Spray Ponds. Reference 1 summarized the results of that testing. During the review prior to issuance of an operating license, the Nuclear Regulatory Commission (NRC) placed a requirement on the Supply System for additional confirmatory drift loss testing prior to the first refueling outage. This report presents the methods and results of that testing. The prime interest of the NRC was in additional data at high wind speeds, since the data taken in 1979 was considered of insufficient quantity to give a high confidence level that analyses were conservative.

II. Summary

A comprehensive drift loss test was performed which covered about eight days of testing. The results of the testing are summarized in Figure 1, which shows drift loss as a function of wind speed. Safety analyses done prior to commercial operation used conservative drift loss assumptions based on testing done by the Supply System in 1979. Figure 1 shows the relationship of the data taken in this test to the drift loss assumption in the safety analyses. The drift loss used in the safety analyses is well above that found in this test, with about a 20% margin above the upper bound of the drift loss data at the design point. This demonstrates that the analyses previously performed are conservative.

III. Theory

During periods of high winds, small water drops in the spray are carried beyond the pond perimeter by the wind. This loss of water or drift must be accounted for in safety analyses since we are required to provide a 30 day water inventory without makeup (Reference 2). In this test, the drift loss is calculated indirectly by measuring total water loss (pond level change) and subtracting other loss mechanism contributions:

$$D = T - (E + S + L)$$

where D = drift loss
T = total loss of inventory
E = evaporative loss in the sprays
S = surface evaporative loss
L = leakage

Total Loss

Total loss was determined by measuring pond level changes with a hook gauge as described in the test description. The spray ponds are 246' square in plan dimension, so a level change of one inch in one pond corresponds to:

$$\frac{(246\ \text{ft})(246\ \text{ft})}{12\ \text{in/ft}} \times 7.48\ \text{gal/ft}^3 = 37722\ \text{gal/in}$$

The total loss in gallons was calculated by adding the level changes of both ponds during the period of measurement (usually 30 minutes), multiplying by 37722 gal/in and dividing by the period in minutes over which the change took place. This results in a total loss flow rate in gpm.

Evaporative Loss From Sprays

The evaporation in the sprays was determined by measuring the water temperature before and after spraying:

$$E = \frac{\dot{m} C_p \Delta T}{h_{fg}} f_{evap} \Rightarrow \frac{E}{\dot{m}} = \frac{C_p \Delta T}{h_{fg}} f_{evap}$$

where $\dot{m}$ = spray mass flow rate, gpm
C_p = specific heat, Btu/lbm^{o}F, assumed value 1.0
ΔT = TH - TC
TH = water temperature before spraying, ^{o}F
TC = average water temperature after spraying, ^{o}F
f_{evap} = fraction of heat dissipation by evaporation
h_{fg} = latent heat of vaporization, Btu/lbm
E = evaporation in sprays, gpm

The average water temperature after spraying was calculated by averaging the thermocouple readings described earlier in the section. For each radial row of thermocouples the spray pattern noted in the test results was used to determine which thermocouples were receiving water. These readings were then averaged, to obtain an average for the row. Each row was then averaged with the others to arrive at an overall cold water temperature, TC.

The fraction of heat dissipation by evaporation was determined beginning with relations from Reference 3. Conductive and convective heat transfer is given as:

$$Q_c = k\pi D_p \left[2. + 0.6\ Pr^{1/3} Re^{1/2}\right]\left[T_d - T_a\right]$$

and evaporative heat transfer is:

$$Q_e = D_v D_p h_g \pi \left[2. + 0.6\ Re^{1/2} Sc^{1/3}\right]\left[\frac{P_{ai}}{R_v T_d} - \frac{P_{ao}}{R_v T_a}\right]$$

where k = thermal conductivity of air mixture,
D_v = diffusivity of vapor in air
D_p = spray drop diameter
h_g = enthalpy of vapor
Pr = Prandtl number
Sc = Schmidt number
Re = Reynolds number
P_{ai} = saturation vapor pressure at T_d
T_d = drop temperature
P_{ao} = vapor pressure in air
T_a = air temperature
R_v = vapor gas constant

If $Q_e/Q_c = R$ and $Q_e + Q_c = Q_s$ where Q_s is sensible heat transferred,

$$Q_e = Q_s - Q_c = Q_s - Q_e/R$$

$$Q_e = \frac{R}{R+1} Q_s$$

$$f_{evap} = \frac{R}{R+1}$$

The latent heat of vaporization, h_{fg}, was determined as a function of temperature from the following equation derived from the steam tables over the temperature range of interest:

$$h_{fg} = 1093.6 - 0.556 (TH + TC) / 2$$

The saturation vapor pressure and ambient vapor pressure in the air were determined from the following equations derived from Reference 4:

$$e_s = 0.007501\ e^z \text{ mmHg}$$

where $z = C_1/TC^* + C_2 + C_3TC^* + C_4TC^{*2} + C_5TC^{*3} + C_6 \ln TC^*$

$C_1 = -5800.2206$

$C_2 = 1.3914993$

$C_3 = -0.04860239$

$C_4 = 0.41764768 \times 10^{-4}$

$C_5 = -0.14452093 \times 10^{-7}$

$C_6 = 6.5459673$

$TC^* = TC \text{ in } {}^oK$

and $e_a = 25.4e^y$

where $y = \dfrac{-30.579 + \sqrt{935.07524 - 7.5572(79.047-DP)}}{3.7786}$

DP = dew point temperature in ${}^oF$

These equations define the parameters needed to calculate the evaporation from the sprays given the meteorological conditions and the hot and cold water temperatures involved in spray cooling.

Surface Evaporation

Surface evaporation was calculated using the equation given in Reference 1:

$$\dot{m}_{es} = 181.6 \frac{Q_{es}}{\rho h_{fg}}$$

where $\dot{m}_{es}$ = rate of water loss due to surface evaporation, gpm

ρ = density of water, lbm/ft^3

$Q_{es} = (e_s - e_a)(70 + .7U^2)$

e_s = saturated vapor pressure at surface temperature, mmHg

e_a = vapor pressure in air, mmHg

U = wind velocity, mph

h_{fg} = latent heat of vaporization, Btu/lbm

Leakage

A separate leakage test was performed prior to the drift loss test, and the results of that test indicated leakage too low to measure. Therefore, leakage was assumed to be zero for this test. This assumption is conservative because any leakage that does exist is included in drift loss, which would contribute to a conservatively high drift loss.

Drift Loss

Drift loss for each data set was calculated using a computer program to facilitate use of the previously defined relationships. The total loss was computed and the spray evaporation and surface evaporation were subtracted to give drift loss. In the program output, drift loss is given in percent of flow rate. The program and parameter definitions are given in Appendix B.

Results Evaluation

In the safety analysis of the ultimate heat sink spray ponds (FSAR Section 9.2.5), drift loss was assumed to vary as the square of the wind speed in determination

of the design basis wind speed. Based on the 1979 test report (Reference 1), a drift loss of 1.02% was assumed to occur at a wind speed of 6.91 mph. The 6.91 mph wind speed is the root-mean-square (RMS) average of the wind speed for the worst case for water loss meteorology. The RMS wind speed was used because the objective of the analysis is to use average 30 day drift loss, and drift loss was anticipated to be proportional to U^n, where U is wind speed and $1 \leq n \leq 2$. Since the FSAR analyses used $D \propto U^2$, the results of this test confirm the conservatism of the safety analyses already performed if drift loss is equal to or less than 1.02% at 6.91 mph, and the data falls below the bounding curve $D = .02136\ U^2$. This curve is shown in Figure 1.

In order to confirm the conservatism of the safety analyses, the data from the present test is plotted and a least squares curve fit is shown in Section V.

IV. Test Description

A. Procedure

The Ultimate Heat Sink test was performed in accordance with a plant procedure (PPM 8.2.92) prepared specifically for this test and included in Appendix C. The test had two distinct sections, one to establish the leakage rate from the spray ponds and another to determine the drift loss from the spray ponds as a function of wind speed. The test was performed as part of the Power Ascension Test Program.

In order to establish pond leakage rate, the ponds were instrumented to measure pond surface temperature, wind speed, ambient dew point and dry bulb temperatures, and pond level change. The surface temperature and environmental conditions were used to calculate surface evaporation. This calculated value was subtracted from total level change to determine leakage rate. The data was taken over a 12 day period with data for evaporation calculation recorded hourly. This data was averaged by a data logger over the previous hour. Level data was taken twice per day at intervals of adequate duration to allow measurable level changes. Conditions which could affect data validity such as system operation, rain, etc., were recorded.

The drift loss portion of the Ultimate Heat Sink test was performed over a period of eight days with data being taken 24 hours per day. The spray ponds were instrumented as shown in the next section. The instrumentation was selected and located so that data could be recorded for use in calculation of surface evaporation and evaporation from the spray. All data was taken at 30 minute intervals. The data logger averaged the water temperatures, ambient temperature, dew point, wind speed, and direction over the 30 minute periods. The test was performed in late April to coincide with frequent spring winds. Average wind speeds ranged from less than 2 mph to greater than 25 mph, thus providing a good distribution of wind speeds.

B. Instrumentation

Leakage Rate Test

The following parameters were measured in order to establish leakage rate for the spray ponds:

- o Pond Surface Temperature
- o Wind Speed
- o Wind Direction
- o Ambient Temperature
- o Dewpoint
- o Pond Level Change

Surface Temperature was measured at five locations in each pond (see Figure 2). Type T thermocouples were attached to automotive innertubes so the tip was 3"-9" below the surface of the pond. The thermocouples were attached to the data logger described below for readout.

Wind speed and direction were measured at approximately 15 feet above ground between the two ponds with Weather Measure Model W203-HF-3L & W104-2 anemometer vane. This data was recorded on a strip recorder

and the data logger. Ambient temperature and dew point were measured at approximately seven feet above ground at the same location as the wind speed and direction using a Climet Instrument Company ambient/ dewpoint temperature shield with Model No. 015-74 platinum RTD temperature and Model No. 015-12 dew point sensor.

Pond level changes were measured with a hook gauge installed in a stilling well. The level measurements were manually recorded on a data sheet. The data logger used was a Doric Model 235A 100 channel programmable model

Drift Loss Test

The following parameters were measured in addition to the parameters measured for leakage test: Water temperature at spray nozzle discharge and sprayed water temperature returning to the pond. These two parameters were measured using Type T thermocouples. For the hot water temperature measurement at the nozzle, the thermocouples were attached to two spray nozzles with the tip located in the spray. Fifty-six conical catch pans were floated on spray pond A to catch the return water (see Figure 2). Each pan had a thermocouple attached to it with the tip near the drain to measure sprayed water temperature. All instrumentation was calibrated just prior to starting the test. Each thermocouple input to the data logger was calibrated at two points (32 F and 100 F) rather than using a standard Type T thermocouple input. This provided better accuracy for each channel. Photographs of key instrumentation are given in Appendix D.

V. Results of Testing

Drift loss testing was performed for approximately eight days with some interuptions such as those necessary to refill the ponds with water to maintain technical specification compliance. Approximately 270 data sets were recorded at 30 minute intervals. Each data set providing useful

data is given in Appendix A. Of the 270 sets, many were discarded from analysis because the average wind speed for that period was low (less than 6 mph). This reduced considerably the data reduction task while maintaining data of significance for the test. Other data sets were discarded if the recorded data was invalid. Invalid data sets occurred during periods such as stilling well level equilibration after being readjusted to a new water level range, or during refilling of the ponds. A total of about 135 data sets were used to determine drift loss characteristics.

The program described in Section III was used to determine drift loss, and the results are summarized in Figure 1. The data demonstrates that the drift loss used in the safety analyses is conservative. Even considering an upper bound of the data, at the design wind speed of 6.91 mph, a margin of about 20% exists between the data and the safety analysis values. This margin increases with increasing wind speed.

During the testing, the plant shut down normally for a maintenance outage. This shutdown resulted in a heat load of about 10^8 Btu/hr being applied initially to the ponds. Drift loss data taken during this heat load period is also shown in Figure 1. No discernable effect was observed on drift loss characteristics due to the heat load. The data follows the same trend as the data taken without heat load.

In summary, the results of this testing confirm the conservatism of drift loss values used in safety analyses performed during plant licensing. A significant amount of new data at high wind speeds was taken which provides the additional assurance required by the NRC.

VI. References

1. K. R. Conn, "1979 Ultimate Heat Sink Spray System Test Results Report," WPPSS-EN-81-01, Washington Public Power Supply System, Richland, Washington.

2. USNRC, Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants."

3. Ranz and Marshall, "Evaporation from Drops", Chemical Engr. Progress, Vol. 48, No. 3, and Vol. 48, No. 4, 1952.

4. ASHRAE, ASHRAE Handbook - 1981 Fundamentals, page 5.2.

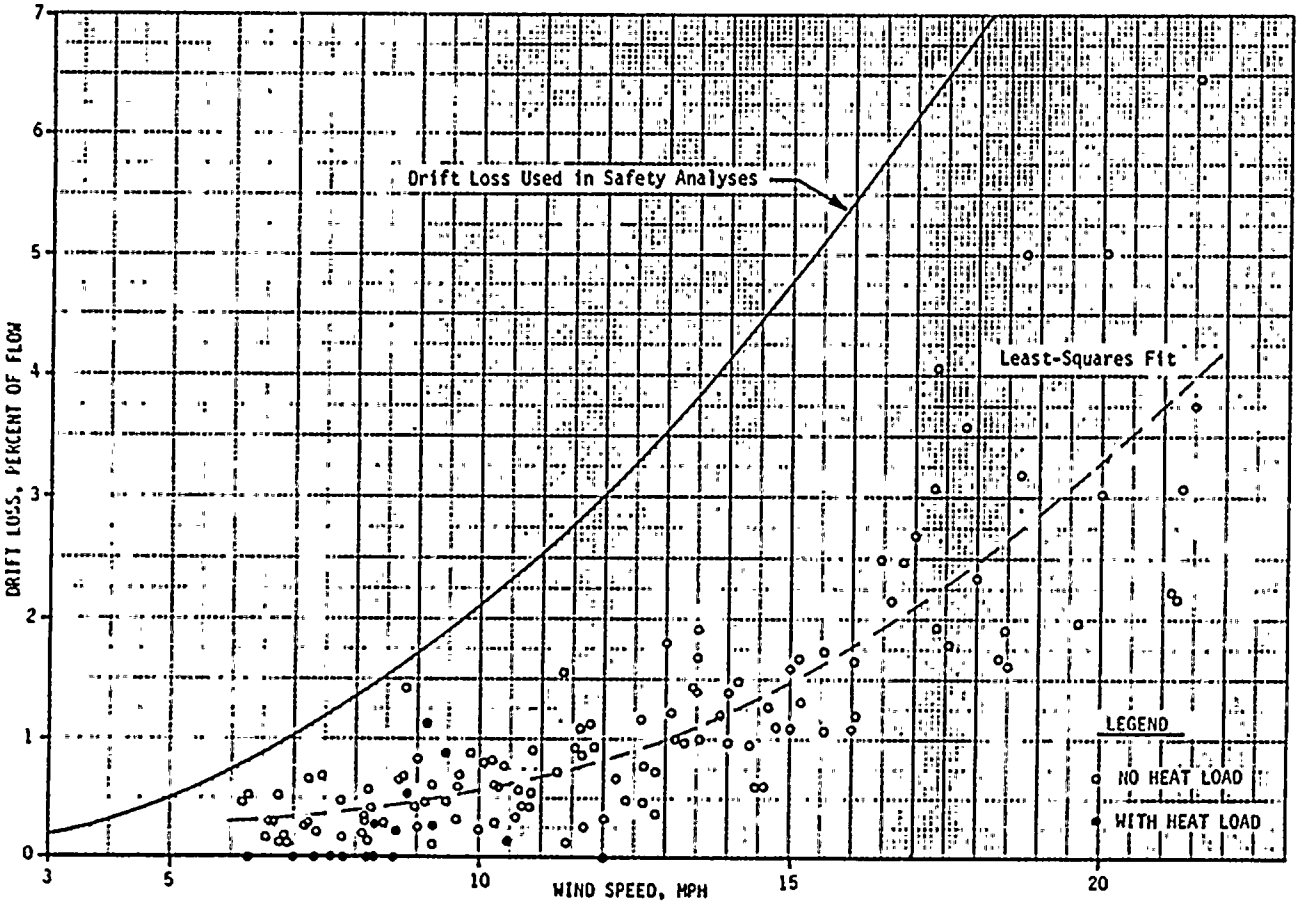

Figure 1 - Drift Loss Characteristics

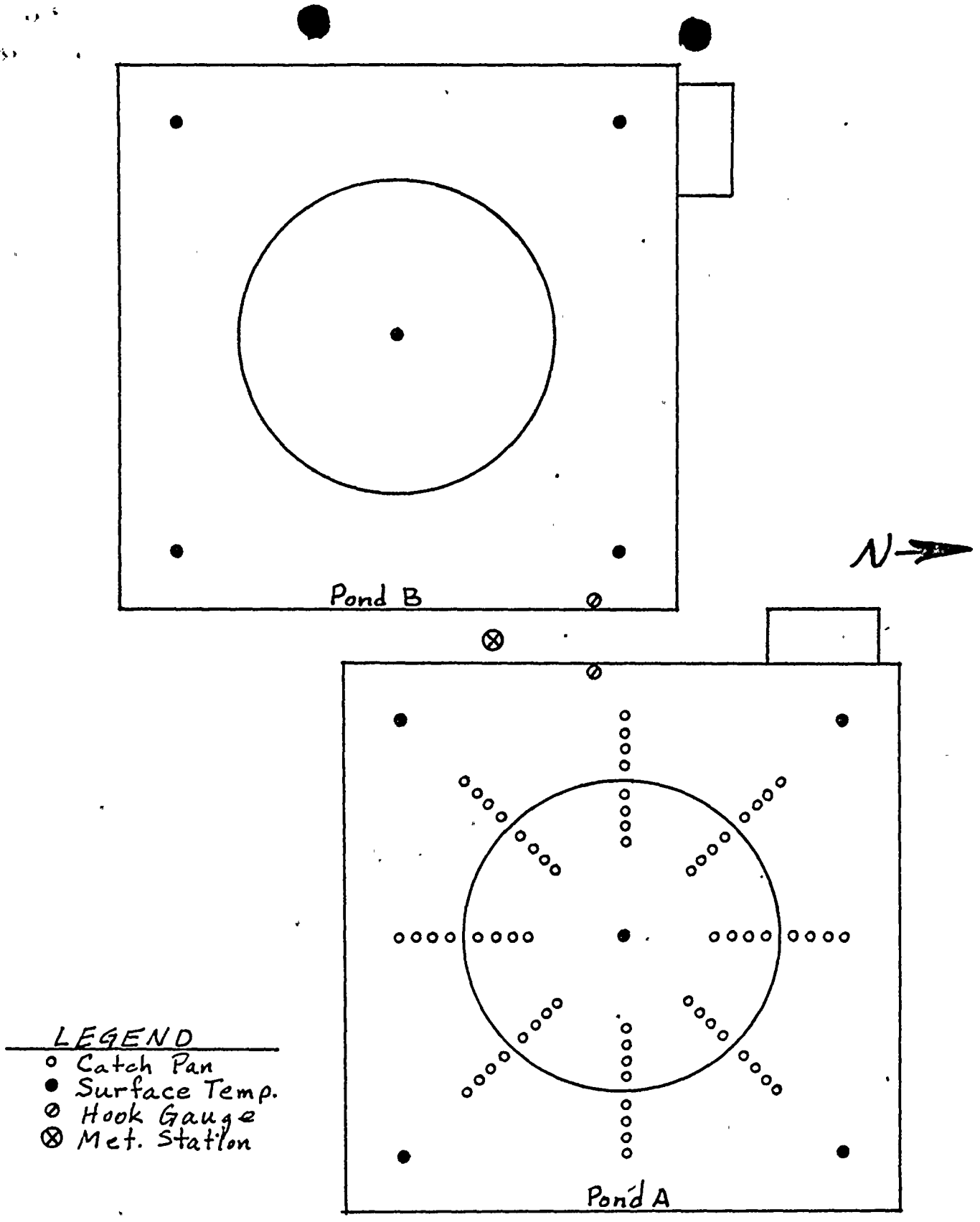

Figure 2. Test Geometry

APPENDIX A
DATA

Parameter Definitions

RECORD - Point number
CW - Cold water temperature after spraying, ^{o}F
HW - Hot water temperature before spraying, ^{o}F
DP - Dew point temperature, ^{o}F
DB - Dry bulb temperature, ^{o}F
W - Wind speed, mph
SA - Surface temperature, Pond A, ^{o}F
SB - Surface temperature, Pond B, ^{o}F
LA - Level change, Pond A, in
LB - Level change, Pond B, in
TIME - Time between readings
SE - Spray evaporation, gpm
DLOSS - Drift loss, % of flow

RECORD	CW	HW	DP	DB	W	SA	SB	LA	LB	TIME	SE	TLOSS	DLOSS
112.40	48.44	53.10	27.24	59.73	14.00	50.90	51.80	0.062	0.069	30.00	66.61	164.72	0.98
112.50	49.06	53.20	27.94	59.63	11.59	50.80	51.80	0.062	0.066	29.00	57.46	166.50	1.10
112.60	48.75	53.20	28.64	59.93	13.43	50.70	51.80	0.075	0.082	28.50	64.55	207.80	1.44
112.70	48.74	53.30	26.68	61.04	15.16	50.70	51.90	0.109	0.096	33.00	68.35	234.33	1.67
112.80	49.24	53.30	30.53	60.79	13.30	50.60	51.90	0.051	0.072	29.00	62.66	159.99	0.97
112.90	48.86	53.30	31.95	59.88	19.99	50.50	51.90	0.171	0.140	32.00	67.81	366.61	3.03
112.10	48.20	53.30	31.00	58.61	21.49	50.40	51.90	0.189	0.251	37.50	72.38	442.60	3.75
113.20	48.53	52.60	41.54	45.68	8.98	49.50	51.10	0.020	0.019	29.00	25.76	50.73	0.25
113.30	48.36	52.50	42.03	45.63	10.62	49.40	51.00	0.039	0.027	30.50	25.81	81.63	0.56
113.40	47.98	52.50	41.34	45.74	11.65	49.30	50.90	0.039	0.052	30.00	29.14	114.42	0.87
113.50	47.68	52.40	40.65	44.89	13.46	49.20	50.90	0.075	0.058	30.00	29.51	167.23	1.40
113.60	49.48	55.50	40.49	47.08	12.63	49.10	50.80	0.061	0.062	30.00	40.35	154.66	1.16
113.70	49.95	56.10	40.35	47.49	10.36	49.20	50.80	0.037	0.062	32.00	41.65	116.70	0.76
113.80	49.84	56.20	40.41	47.32	14.79	49.20	50.70	0.069	0.051	30.00	42.69	150.89	1.10
113.90	49.77	56.30	40.40	47.27	15.54	49.20	50.60	0.065	0.054	30.00	43.72	149.63	1.07
113.10	49.61	57.40	38.87	47.42	18.49	49.20	50.60	0.075	0.082	28.00	53.21	211.51	1.60
113.11	50.30	58.60	38.20	48.69	18.00	49.10	50.50	0.104	0.141	32.00	59.03	288.81	2.34
113.12	50.75	58.50	44.46	50.88	17.34	49.20	50.50	0.092	0.095	29.00	55.98	243.24	1.91
113.13	50.77	58.30	42.16	50.36	16.44	49.30	50.50	0.118	0.119	30.00	54.93	298.00	2.49
113.14	48.80	54.90	42.17	50.29	18.71	49.30	50.50	0.092	0.051	15.00	49.48	359.62	3.17
113.15	49.82	52.00	46.59	53.49	16.81	49.30	50.50	0.171	0.155	45.00	33.26	273.27	2.46
113.16	50.35	52.00	47.67	54.54	17.32	49.30	50.60	0.110	0.178	32.00	38.98	339.50	3.09
113.17	50.42	52.00	47.13	55.53	16.62	49.50	50.70	0.096	0.108	30.00	45.70	256.51	2.16
113.21	46.90	53.10	29.52	48.95	16.07	50.20	51.60	0.038	0.138	38.50	53.78	172.44	1.18
114.17	46.70	51.10	28.51	50.22	7.17	47.30	49.70	0.031	0.018	26.50	42.80	69.75	0.26
114.18	47.30	51.00	29.49	52.90	6.61	47.40	49.70	0.044	0.022	34.50	41.29	72.16	0.30
114.22	47.80	51.10	26.88	56.92	7.18	47.70	49.90	0.035	0.028	32.50	44.63	73.12	0.28
114.23	47.90	51.20	24.47	56.90	10.18	47.70	49.80	0.047	0.062	33.00	42.94	124.60	0.82
114.24	47.60	51.10	27.06	56.69	8.80	47.70	49.80	0.085	0.044	26.00	47.20	187.16	1.42
114.25	48.10	51.10	29.36	56.03	6.27	47.90	49.80	0.020	0.045	27.00	39.11	90.81	0.52
114.28	47.70	51.20	37.81	55.46	7.23	48.00	49.90	0.066	0.046	35.00	55.33	120.71	0.66
114.29	47.30	51.20	36.33	55.47	11.53	47.90	49.70	0.048	0.053	25.00	59.93	152.40	0.94
114.30	47.30	51.10	36.20	54.09	10.07	47.90	49.70	0.063	0.065	37.00	51.00	130.50	0.80
114.35	46.80	50.90	36.30	47.80	13.51	47.70	49.50	0.045	0.149	33.00	34.73	221.76	1.91
114.36	47.00	50.90	35.66	48.60	7.44	47.70	49.40	0.058	0.015	27.00	34.68	101.99	0.68
114.37	47.20	50.80	35.79	48.43	6.54	47.70	49.40	0.012	0.028	30.50	31.55	49.47	0.17
114.38	47.10	50.80	35.98	48.01	7.76	47.60	49.30	0.039	0.026	31.00	31.63	79.09	0.48
114.39	46.90	50.70	34.86	48.07	8.16	47.50	49.20	0.030	0.023	30.00	33.01	66.64	0.33
114.40	46.90	50.60	32.79	48.56	6.83	47.50	49.20	0.024	0.017	30.00	33.30	51.55	0.18
114.41	46.80	50.50	33.13	48.14	6.76	47.40	49.10	0.031	0.038	31.00	32.66	83.96	0.52
115.19	46.10	48.90	25.99	52.50	6.77	45.50	47.70	0.012	0.022	27.50	33.68	46.64	0.12
115.20	46.00	48.90	26.39	53.91	6.19	45.70	47.80	0.051	0.045	42.50	38.68	85.21	0.47
115.31	46.60	49.50	23.88	59.45	7.81	46.60	48.00	0.011	0.034	33.50	52.18	50.67	-0.03
115.32	46.50	49.50	24.00	59.14	8.99	46.60	48.00	0.055	0.046	28.00	53.15	136.07	0.84
115.33	46.40	49.40	23.98	58.78	9.48	46.60	48.00	0.046	0.030	28.50	52.31	100.59	0.48
115.34	46.00	49.40	23.66	57.49	9.24	46.60	47.90	0.041	0.018	33.50	54.63	66.44	0.10
115.35	45.70	49.20	25.21	55.00	8.77	46.50	47.90	0.028	0.056	27.00	49.53	117.36	0.68
115.36	45.60	49.20	26.04	53.24	8.21	46.50	47.90	0.037	0.044	30.00	45.86	101.85	0.56
115.37	45.10	49.20	26.47	51.76	8.66	46.40	47.80	0.047	0.054	33.00	48.66	115.45	0.67
115.38	44.90	49.10	26.15	50.64	10.04	46.30	47.80	0.043	0.013	28.00	46.88	75.44	0.27
115.39	44.50	49.10	25.90	47.76	8.95	46.20	47.70	0.035	0.041	33.00	44.01	86.87	0.42
115.40	44.10	49.00	26.39	44.20	8.10	46.10	47.70	0.019	0.021	25.00	39.50	60.36	0.20
116.50	42.70	48.30	27.72	36.49	7.35	45.30	47.10	0.019	0.024	30.00	32.37	54.07	0.21
116.60	42.90	48.30	28.73	37.93	6.90	45.30	47.10	0.024	0.011	29.50	32.69	44.75	0.11
116.70	43.00	48.10	29.02	37.52	6.65	45.20	47.00	0.027	0.021	30.00	30.20	60.36	0.30
116.80	42.80	48.10	29.49	37.91	7.78	45.10	46.90	0.017	0.023	30.50	31.76	49.47	0.17
116.90	43.30	48.00	30.47	40.04	8.23	45.10	46.90	0.024	0.032	29.00	30.68	72.84	0.42
116.10	43.00	47.90	30.08	41.03	11.25	45.00	46.80	0.044	0.043	31.00	34.08	105.86	0.72

116.11	44.00	49.60	30.24	40.73	9.22	45.00	46.70	0.034	0.042	29.50	36.82	97.18	0.61
116.12	43.60	48.00	30.75	41.74	8.15	45.10	46.70	0.020	0.029	30.00	31.19	61.61	0.30
116.13	43.70	47.90	31.10	42.67	8.22	45.00	46.70	0.026	0.010	30.00	31.28	45.27	0.13
116.14	43.60	47.80	31.17	44.07	10.31	44.90	46.70	0.046	0.032	31.50	34.22	93.41	0.59
116.15	43.60	47.70	30.39	44.43	11.41	44.90	46.60	0.030	0.009	31.50	34.39	46.70	0.11
116.16	43.80	47.80	30.54	45.41	9.62	44.80	46.60	0.030	0.028	30.50	35.41	71.73	0.36
116.17	44.10	47.70	30.55	46.91	10.06	44.80	46.60	0.037	0.040	26.00	35.06	111.72	0.77
116.18	44.50	47.60	30.60	48.52	10.84	44.80	46.60	0.032	0.072	32.00	33.58	122.60	0.90
116.20	44.70	47.70	30.18	52.50	14.17	44.80	46.60	0.081	0.076	31.00	44.77	191.04	1.48
116.22	45.10	47.70	30.26	54.31	17.33	44.90	46.60	0.242	0.286	45.00	45.56	442.60	4.06
116.23	45.40	47.80	31.46	54.74	17.80	45.00	46.60	0.180	0.182	34.50	44.92	395.81	3.59
116.24	45.80	47.90	31.68	56.20	18.78	45.10	46.70	0.176	0.164	24.00	45.61	534.39	5.01
116.25	46.50	48.00	32.13	57.74	20.13	45.20	46.70	0.250	0.243	35.00	38.03	531.34	5.05
116.26	48.20	48.20	34.53	60.29	21.52	45.40	46.80	0.242	0.235	28.50	0.00	631.35	6.47
117.10	48.50	48.60	42.07	56.13	14.65	46.20	47.20	0.037	0.076	31.50	6.91	135.32	1.31
117.20	48.10	48.60	42.15	53.84	10.80	46.30	47.20	0.034	0.012	30.00	13.74	57.84	0.45
117.30	48.20	48.60	42.78	53.58	14.35	46.30	47.20	0.037	0.044	29.00	11.56	105.36	0.96
117.40	48.10	48.50	43.16	53.82	13.89	46.40	47.20	0.059	0.050	30.50	16.97	134.81	1.21
117.50	47.90	48.50	42.97	52.05	11.68	46.50	47.20	0.016	0.012	28.00	12.17	37.72	0.26
117.60	47.60	48.50	42.77	50.93	13.53	46.50	47.20	0.036	0.056	31.00	14.01	111.95	1.00
117.70	47.90	48.50	43.13	52.36	12.63	46.50	47.20	0.036	0.010	29.00	13.98	59.83	0.47
117.80	47.90	48.50	43.67	51.90	12.17	46.60	47.20	0.028	0.019	29.50	13.61	60.10	0.47
117.90	47.90	48.50	44.08	52.17	11.98	46.60	47.20	0.002	0.010	30.00	17.78	15.09	-0.03
117.11	47.80	48.50	48.23	50.62	11.85	46.80	47.30	0.060	0.085	60.50	0.00	90.41	0.93
117.12	48.30	48.60	47.22	52.67	9.66	46.90	47.30	0.027	0.027	30.00	0.00	67.90	0.70
117.13	48.70	48.70	47.00	54.46	12.03	47.00	47.30	0.015	0.010	30.00	0.00	31.43	0.32
117.14	49.10	48.80	47.15	55.13	13.50	47.10	47.40	0.074	0.062	31.00	2.89	165.49	1.68
117.15	49.60	48.90	47.04	56.78	17.54	47.20	47.50	0.053	0.085	29.00	6.62	179.50	1.78
117.16	50.00	49.00	47.09	59.75	17.02	47.40	47.60	0.129	0.084	30.00	6.67	267.83	2.69
117.17	50.70	49.10	47.32	61.21	15.55	47.60	47.70	0.073	0.068	30.00	10.34	177.29	1.72
117.18	51.30	49.30	47.77	61.84	9.65	47.90	47.90	0.017	0.040	31.00	12.57	69.36	0.59
117.19	51.20	49.30	48.59	60.28	9.11	48.10	48.00	0.015	0.027	29.50	8.98	53.71	0.46
117.20	52.30	49.60	50.04	66.13	15.17	48.30	48.20	0.061	0.047	31.00	5.73	131.42	1.30
117.21	52.30	49.90	49.81	67.76	16.02	48.50	48.30	0.060	0.065	28.50	5.90	165.45	1.65
117.22	52.30	50.00	47.07	68.70	19.64	48.80	48.40	0.098	0.088	34.00	15.26	206.36	1.97
117.23	52.30	50.10	45.21	68.68	21.22	49.10	48.50	0.098	0.096	31.00	25.56	236.07	2.16
117.24	53.20	50.40	47.02	69.66	21.15	49.30	48.60	0.111	0.079	30.00	23.17	238.91	2.22
117.28	53.90	51.30	47.13	75.11	18.38	50.90	49.70	0.071	0.078	31.00	19.13	181.31	1.66
117.30	52.60	51.60	40.98	72.50	21.30	51.20	50.10	0.121	0.147	30.00	36.13	336.98	3.07
117.31	52.30	51.60	40.66	71.64	18.46	51.20	50.20	0.114	0.059	30.00	30.90	217.53	1.90
117.32	52.30	51.60	40.97	71.05	14.45	51.30	50.30	0.042	0.035	31.50	32.17	92.21	0.60
117.33	52.30	51.70	41.57	70.45	12.86	51.30	50.40	0.025	0.026	30.00	26.73	64.13	0.37
117.34	52.00	51.80	40.81	69.73	14.58	51.30	50.50	0.031	0.024	28.00	15.11	74.10	0.59
117.35	51.80	51.90	40.06	68.67	13.14	51.40	50.60	0.034	0.041	29.00	0.00	97.56	0.99
117.38	51.40	52.10	42.24	62.31	6.23	51.40	50.80	0.000	0.013	35.00	29.49	14.01	-0.17
117.42	50.50	52.30	41.61	56.68	8.43	51.30	51.10	0.030	0.017	31.00	27.41	57.19	0.30

RECORD	CW	HW	DP	DB	W	SA	SB	LA	LB	TIME	SE	TLOSS	DLOSS
123.20	56.50	62.60	31.12	66.10	12.19	55.80	56.00	0.072	0.093	46.00	67.81	135.31	0.66
123.40	54.40	61.40	32.89	60.79	11.33	55.70	56.20	0.131	0.059	32.00	70.36	223.97	1.55
123.50	54.50	61.30	32.24	61.83	10.70	55.60	56.20	0.036	0.063	32.50	70.68	114.91	0.43
123.60	54.50	61.00	32.45	61.67	10.24	55.50	56.20	0.033	0.045	30.50	67.66	96.47	0.27
123.70	53.80	60.80	32.43	60.89	10.58	55.40	56.20	0.039	0.046	29.50	72.26	108.69	0.35
123.80	52.90	60.70	31.50	59.31	12.65	55.30	56.10	0.070	0.049	30.00	77.55	149.63	0.71
123.90	52.20	60.50	31.37	56.57	15.09	55.10	56.10	0.062	0.086	30.00	76.39	186.10	1.08
123.10	52.20	60.30	30.44	54.73	12.82	55.00	56.00	0.069	0.048	30.50	70.47	144.70	0.73
123.11	51.80	60.20	30.34	53.31	10.82	54.90	56.00	0.051	0.042	28.00	70.38	125.29	0.53
124.27	47.80	55.10	31.11	49.04	11.88	50.80	53.90	0.059	0.064	27.00	59.94	171.84	1.12
124.28	48.80	55.10	32.64	50.97	10.25	50.80	53.90	0.032	0.061	30.50	54.94	115.02	0.59
124.29	49.40	54.90	32.05	53.04	9.86	50.80	54.00	0.055	0.058	30.50	52.19	139.76	0.88
124.30	49.30	55.60	31.68	54.25	15.94	50.70	53.90	0.027	0.112	30.50	62.21	171.91	1.09
124.31	50.10	57.20	31.90	55.26	14.94	50.70	53.80	0.101	0.099	33.00	69.20	228.62	1.60
124.32	50.40	57.20	32.14	56.10	13.99	50.80	53.80	0.071	0.087	29.00	68.24	205.52	1.38
124.33	50.70	57.10	30.76	57.99	13.08	50.90	53.80	0.074	0.075	29.50	68.95	190.53	1.22
124.34	50.70	57.10	29.81	57.71	12.93	51.00	53.90	0.091	0.095	28.50	67.84	246.19	1.80
124.36	63.20	83.50	30.33	57.97	7.34	51.70	54.10	0.059	0.051	30.00	152.53	138.31	-0.17
124.37	61.90	78.20	31.31	58.47	7.58	52.40	54.00	0.080	0.021	31.00	125.22	122.90	-0.04
124.38	59.60	74.90	30.92	58.42	9.45	52.70	53.90	0.083	0.077	29.00	120.21	208.12	0.88
124.39	58.20	71.40	31.31	58.52	10.45	52.80	53.90	0.051	0.053	32.00	106.68	122.60	0.14
124.40	57.90	68.80	30.62	58.16	7.82	53.00	53.90	0.053	0.061	30.00	89.36	143.34	0.54
124.41	56.50	66.90	30.20	59.11	8.67	53.20	53.90	0.052	0.030	27.50	89.61	112.48	0.21
124.42	54.30	61.60	31.93	57.97	9.16	53.30	53.90	0.060	0.082	30.00	66.79	178.55	1.13
124.43	50.70	55.20	29.74	59.73	8.28	53.20	53.90	0.028	0.011	30.00	55.38	49.04	-0.09
124.45	55.30	64.80	29.52	61.67	8.30	53.60	54.20	0.044	0.052	30.00	90.77	120.71	0.29
124.50	58.00	67.00	33.37	60.01	7.78	53.80	54.10	0.033	0.024	30.50	77.68	70.50	-0.09
124.51	56.70	65.40	31.36	58.62	9.24	53.80	54.10	0.047	0.036	30.50	74.97	102.65	0.26
124.52	56.00	64.40	33.09	56.64	8.59	53.90	54.10	0.029	0.021	30.00	69.89	62.87	-0.09
124.53	54.10	60.60	33.06	54.26	6.99	54.00	54.10	0.019	0.026	30.00	53.89	56.58	0.01
124.54	50.50	55.40	32.64	52.57	6.28	53.80	54.00	0.028	0.023	30.50	43.97	63.08	0.18
124.55	51.40	59.20	31.60	51.07	8.17	53.60	54.10	0.011	0.015	30.00	61.74	32.69	-0.32

APPENDIX B

Program Listings and Parameter Definition

Parameter

BOWEN - Fraction of heat transfer in the sprays by evaporation.
CW - Water temperature after spraying, ^{o}F
DB - Ambient dry bulb temperature, ^{o}F
DLOSS - Drift loss fraction of flow, in % of flow
DP - Dewpoint, ^{o}F
FLOW - Spray flow rate, gpm
HFG - Latent heat of vaporization, Btu/lbm
HW - Hot water temperature before spraying, ^{o}F
HWA - Average water temperature in spray, ^{o}F
LA - Water level change in pond A, in
LB - Water level change in pond B, in
NUM - Data set number
PATM - Vapor pressure in ambient air, mmHg
PWS - Saturation vapor pressure at HWA, mmHg
SA - Surface temperature, pond A, ^{o}F
SB - Surface temperature, pond B, ^{o}F
SE - Evaporation in the sprays, gpm
TC - HWA in ^{o}K
TIME - Time period for data set
TLOSS - Total loss from ponds, gpm
W - Wind speed, mph

```
OK,
SLIST NEWBOWEN.FTN
C       THIS PROGRAM CALCULATES DRIFT LOSSES FROM TEST DATA
C        WRITTEN IN JULY, 1985- D. MYERS
C
      REAL LA,LB,NUM,K1
      DATA C1,C2,C3,C4,C5,C6/-5800.2206,1.3914993,-.04860239,
     C.41764768E-4,-.1445209E-7,6.5459673/
      DATA K1,PRN,VIS,RHO,DIA,VR,RV/4.17E-6,.9,.373E-6,.072,
     C6.56E-3,15.,85.5/
      READ(5,*)FLOW
      WRITE(1,1)
   10 READ(5,*,END=99)NUM,CU,HW,DP,DB,W,SA,SB,LA,LB,TIME
      HWA=(HW+CU)/2.
      TC=.55556*(HWA-32.)+273.15
      PWS1=C1/TC+C2+C3*TC+C4*TC**2+C5*TC**3+C6*ALOG(TC)
      PWS=(EXP(PWS1))*.007501
       ALSQ=SQRT(935.87524-7.5572*(79.047-DP))
      AL=(-30.579+ALSQ)/3.7786
      PATM=EXP(AL)*25.4
      HFG=1093.06-.556*(HW+CU)/2.
      HG=HFG+HWA-32.
      REN=SQRT(DIA*RHO*VR/(VIS*32.2))
      PAI=2.785*PWS
      PAD=PATM*2.785
      DV=4.0737E-8*(((DB+460.)**2.5)/(DB+901.))
      HWAR=HWA+460.
      DBR=DB+460.
      SCN=(VIS*32.2/(RHO*DV))**.333333
      RATION=DV*HG*(2.+.6*REN*SCN)*((PAI/(RV*HWAR))-(PAD/(RV*DBR)))
      RATIOD=K1*(2.+.6*PRN*REN)*(HWA-DB)
      R=RATION/RATIOD
      BOWEN=R/(R+1)
      SE=FLOW*(HW-CU)*BOWEN/HFG
      TS=.55556*(SB-32.)+273.15
      PWS1S=C1/TS+C2+C3*TS+C4*TS**2+C5*TS**3+C6*ALOG(TS)
      PWSS=.007501*EXP(PWS1S)
      DES=(PWSS-PATM)*(70+.7*W**2)
      QHV=1093.06-.556*SB
      SURF=181.6*(DES/(62.4*QHV))
      IF(SE.LT.0.)SE=0.
      TLOSS=(LA+LB)*37722./TIME
      DLOSS=((TLOSS-SE-SURF)/FLOW)*100.
      WRITE(1,2)NUM,CU,HW,DP,DB,W,SA,SB,LA,LB,TIME,SE,TLOSS,DLOSS
    2 FORMAT(F6.2,2X,7(2X,F6.2),2(2X,F6.3),2(2X,F6.2),4X,F6.2,2X,F6.2)
    1 FORMAT(2X,'RECORD',4X,'CU',6X,'HU',6X,'DP',6X,'DB',6X,'U'
     C,6X,'SA',6X,'SB',6X,'LA',6X,'LB',6X,'TIME',5X,'SE',6X,'TLOSS',
     C4X,'DLOSS')
      GO TO 10
   99 STOP
      END
```