

# NEBRASKA MODIFIED ROOF POND: 1985 SUMMER PERFORMANCE RESULTS

by  
Drs. Bing Chen, Raymond Guenther, John Maloney, and John Kasher  
and  
Chuck Sloup, Jay Kratochvil, Tom Goetzinger  
Passive Solar Research Group  
University of Nebraska at Lincoln  
University of Nebraska at Omaha  
Omaha, Nebraska

## ABSTRACT

This paper reports on the results of three of the tests performed on the Nebraska modified roof pond. During the summer of 1985, with the test room decoupled from the roof pond itself, several series of tests were initiated. The first experiment (fig. 1) was to test the overall response of the system by forcing the temperature in storage to a preset value and observe its decay/ curve with ponding and spray. The second experiment (fig\* 2) was similar to the first but with ponding only and no spray. Experiment three (fig. 3) observed the discharge of heat from pond with the-pump turned off, in essence a natural decay test without roof pond cooling. Net night sky radiation,, ambient air and pond temperatures, and dew point temperature were measured.

The water in the roof pond was heated electrically to about 500C and then permitted to cool in various ways. With the pump on in experiments 1 and 2 the convection and evaporation losses were considerably larger than the radiative losses; at the elevated water temperatures the evaporative and convective losses were significantly higher than at the lower water temperatures; the convective-evaporative losses when ponding and ponding with spray are comparable. The losses from the system without active cooling strategies are mainly due to evaporation thru or refluxing in the cracks of the floating insulation and to convection\*

## INTRODUCTION

As presented to the Montreal world congress in 1985 (1), the Nebraska Modified Roof Pond is an innovative concept which was designed to provide annual thermal performance in a multitude of climates (see fig. 4). The Nebraska Modified Roof Pond improves performance in the summer cooling mode by incorporating direct evaporation and convection as a cooling component. Ponding occurs at night when water is pumped from the reservoir and distributed over the surface of a cement coated rigid insulation which floats above the water reservoir, At this time the pumped water can also be delivered as a fine spray to test whether or not there is enhanced evaporation. Measurements have shown that evaporation and convection plays a significant role in cooling. The new roof pond does not use moveable roof shutters and water bags. With

the floating layer of insulation it is possible to operate the pond even under freezing conditions,

## 2, EXPERIMENTAL PROCEDURE

### NOMENCLATURE

Td	(°C)	Dewpoint temperature
Ta	(°C)	Ambient temperature
Tw	(°C)	Water temperature in pond
C	(W-H/°C)	Effective heat capacity of the pond
H	(W)	Total power lost by roof pond
Hr	(W)	Radiant power loss by roof pond
Hc	(W)	Conduction losses from pond
Hv	(W)	Evaporation-Convection losses
He	(W)	Electric power from heater or pump
Pv	(mm Hg)	Vapor pressure of water in pond from Tw
Pp	(mm Hg)	Partial pressure of water in air from Td
Kv	(W/mm Hg)	Heat loss coefficient due to evaporation and convection

The heat balance equation for the roof pond is given by

$$(1) -C \frac{dT}{dt} = \text{Heat lost} - \text{Heat gained}$$

The heat gained by the pond occurs by turning on water bed heaters (740 W) or a submersible pump (414 W). Heat is lost from the pond by conduction (Hc) p night sky radiation (Hr) and by a convection-evaporation component (Hv) o

We define net heat lost by the pond (H) as being positive so

$$(2) H = -C \frac{dT}{dt}$$

Thus the heat balance equation can be written as

$$(3) H = Hc + Hr + Hv - He$$

The heat gained He is any one of three values: 0 W (discharge) 414 W (pump on for cooling), and 740 W (during pond charging).

The water temperature in the pond was raised to over 45°C when two water bed heaters (placed near the pond's bottom) were turned on. In experiment 1 the cooling takes place while water is sprayed over the top of the pond throughout the night (ponding and spray); in experiment 2 the water is pumped over the floating pond insulation without spraying (ponding only); in experiment 3 the pond is permitted to cool without active cooling. The results of experiments 1, 2, and 3 are summarized in tables 1, 2 and 3 and displayed in

figures 1, 2 and 3. Table 4 utilizes data from the charging portion of experiment 1 to compute the thermal heat capacity of the roof pond,

Research objectives included: (1) comparing radiant cooling ( $H_r$ ) with convection-evaporation cooling ( $H_v$ ), (2) determining if spraying would provide additional cooling and, (3) computing the ratio of the net heat lost from the pond divided by the difference between water vapor pressure and the partial pressure of the air. This ratio is called the convection-evaporation heat loss coefficient ( $K_v$ ).

$$(4) K_v = H_v / (P_v - P_a)$$

The conduction loss is computed from the thermal conductivities of the materials times  $(T_w - T_a)$ ; the heat capacity can be computed from the slope of the  $T_w$  versus time curve while the heaters were on in experiments 1 and 2 and under conditions where the environmental inputs were minimal as will be discussed below,

#### Experiment #1

Referring to figure 1. we note that different parts of the curves have been labelled by A, B, C, and D. In part CD, the water temperature has little change over the period of several days. Changes in ambient temperature have little effect on the water temperature, Also, the water and dewpoint temperatures for the 9/8 and 9/9 initial charging period (which are not shown) are somewhat lower but comparable to those in segment CD. so, it is fair to assume that the ambient conditions have little effect at the beginning of the 9/8 charge period. A straight line fit to 9/9 yielded a slope of  $dT/dt = 0.7330^\circ\text{C}$ . Taking the known electrical power input (740 W), we found a water thermal capacity of 1009.5 W-H/ $^\circ\text{C}$  which compares favorably with our computed value of 998.44 W-H/ $^\circ\text{C}$ .

The conduction losses  $H_c$  during the final charging portion AB are fairly constant and small compared to the overall-net loss from the pond. Considering that the pond is still being charged with 740 W this leaves over 550 W unaccounted for, This remaining heat loss most likely comes from losses through the cracks. The heat loss coefficient ( $K_v$ ) due to evaporation and convection is roughly 7.5 for this portion of the curve.

For the cooling portion BC of the curve (fig.1) . there is an almost exponential drop in water temperature, In order to compute  $dT/dt$  an exponential curve fit was made of the water temperature,

Then the function's derivative is taken and the slope is computed for the appropriate time along the curve. The heat loss coefficient varies from about 54 to 93.7 and increases as the night progresses.

#### Experiment #2

The pond was again heated. Then the pump was turned on at 20:30 but this time without the spray. The pump was turned off in the morning 06:30. For this experiment the process was repeated for the next night in order to obtain information concerning the cooling process with the pond water temperature closer to the ambient. Note that  $H_r$  is lower than the first night and varies considerably as the cloud cover consolidates.

### Experiment #3

Finally, in experiment 3. the pool was heated and permitted to cool on its own. The evaporative-convective heat transfer coefficient remains mostly between 1.87 and 3.06 except towards the end of the experiment where the  $K_v$  rises as high as 6.13.

### 3o DISCUSSION OF RESULTS

The evaporative-convective heat loss coefficients for the first two experiments (while the pumps were on) are very similar. It appears that spraying the water over the pond does not significantly increase the evaporation over ponding. A plausible explanation may be that the spray forms a region of saturated vapor so that the droplets inside this vapor do not contribute significantly to the evaporation. The overall surface area of the region bounded by the spray is not very much different from the surface area of the pond.

Secondly, if one compares the  $K_v$  for the cases where the pump is not running, that the  $K_v$  (7.25-7.86) for the charging portion BC of experiment 1 (table 4) are much higher than the  $K_v$  (1,08.6,13) for the cooling portion of experiment 3 o A hint to what might be happening is gotten if one observes that in experiment 3, this coefficient is anomalously high when the dewpoint temperature is below ambient. This implies that the water must be recondensing and flowing back into the pond, On the other hand, in the part BC of experiment #1, the dewpoint temperature is also below ambient, Yet we still have an anomalously high  $K_v$ . This can be understood if one assumes the liquid is refluxing in the cracks of the material, one can make an approximate description of this process by assuming constant gradients of temperature and of partial pressure within the cracks and matching the temperatures and pressures at both ends of the cracks, Under the circumstances of section AB of experiment 1, there are part of the cracks where the  $T_d$  is greater than the drybulb temperature. Thus, condensation and refluxing should take place. The net exchange of radiation between the roof pond and the night sky behaves as expected. With ponding and spray (experiment 1) done under clear night conditions the radiation loss varies between 159 and 257 watts with an average ambient temperature of about 11°C. With ponding only (experiment 2) the night sky radiation was between 152 and 174 watts and was for the most part clear with an average ambient temperature of about 24°C . For the second night of ponding with completely overcast skies the net radiation-drops to between 55-75 watts,

### Error Analysis

The slopes of the cooling curves are estimated to be within 5% of their actual value and when graphed on semilogarithmic papers yield nearly straight lines, This implies that the

curves are close to exponential. To get the slope, an exponent was fitted through three consecutive temperature data points and then the slope was calculated for the central points. The electrical power readings from the water heaters (740 W) and pump (414 W) are rated to be 2% and 10% respectively; the temperatures are to be within 1°C; the dewpoint temperature is within 0.50C; the variations in the temperatures and dewpoint temperatures yield variations in Pp and Pv of 1.5mm Hg; the pyrrometer is estimated to be 10%; the area of the pond is 2.6 m<sup>2</sup> with 5% error; a conduction loss error of 10%. The variability of the data due to changing weather conditions does not permit us to estimate the reliability of our results except to state that the results for the Kv seem pretty consistent.

#### 4o CONCLUSIONS

1. Given a significant temperature difference between pond and air temperatures, the major heat loss component appears to be due to convection and evaporation, Under these conditions spraying does not significantly improve overall cooling performance
2. Even as pond temperatures approach ambient temperature the net heat loss from the pond is still dominated by convection and evaporation.
3. Night sky radiation drops off significantly with increasing cloud cover. Even under conditions of high humidity evaporation and convection appear to predominate the cooling of the roof pond .

#### 5. FUTURE WORK

Although portions of experiments that fixed pond temperatures were attempted in 1985 the power heaters were too small to maintain higher fixed water temperatures. Larger heaters will be installed to provide direct information on measured cooling when the pond is coupled to the test room.

Lumped into a single term, (Hv) the cooling impact due to evaporation and convection should be studied in greater detail. Evaporation data was not analyzed due to a malfunctioning

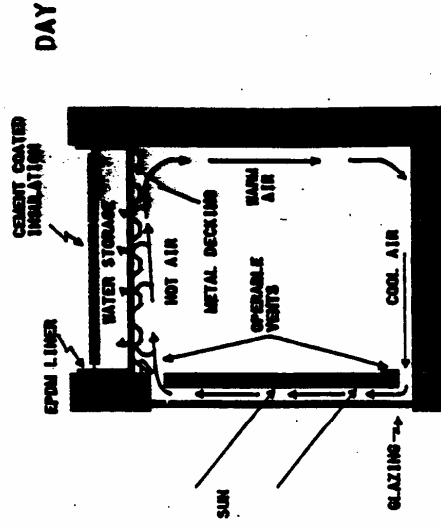
WEATHERtronics evapograph, hence the reason for the combined convection- evaporation coefficient. The air speed measurements should be averaged values when sampled rather than instantaneous,

Water levels in the roof pond should be minimized to reduce building. structural- loads without adversely sacrificing thermal performances Although winter performance is not discussed in this paper it is currently being studied and will be reported upon at a future conference.

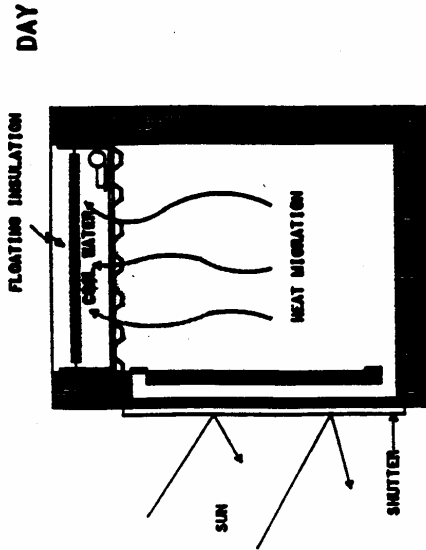
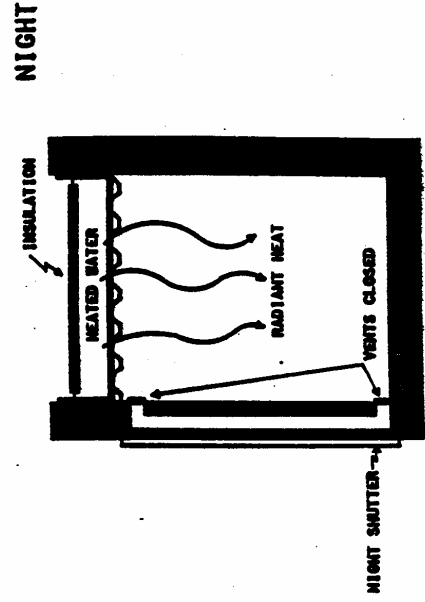
## REFERENCES

1. Chen, B. et al, "Performance results of the Nebraska Modified Roof Pond in a Severe Cooling and Heating Environment", Solar World Congress Montreal 1985,

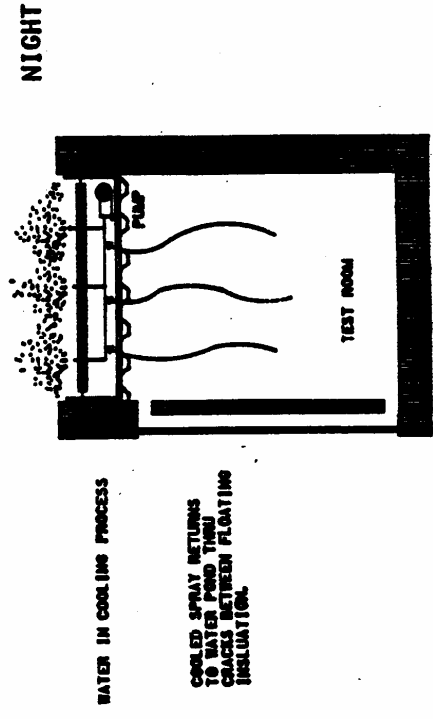
2o Marlatt,, W. P. et al,, Roof Pond Systems, Rockwell International California (1984).



**ROOF POND  
WINTER MODE**

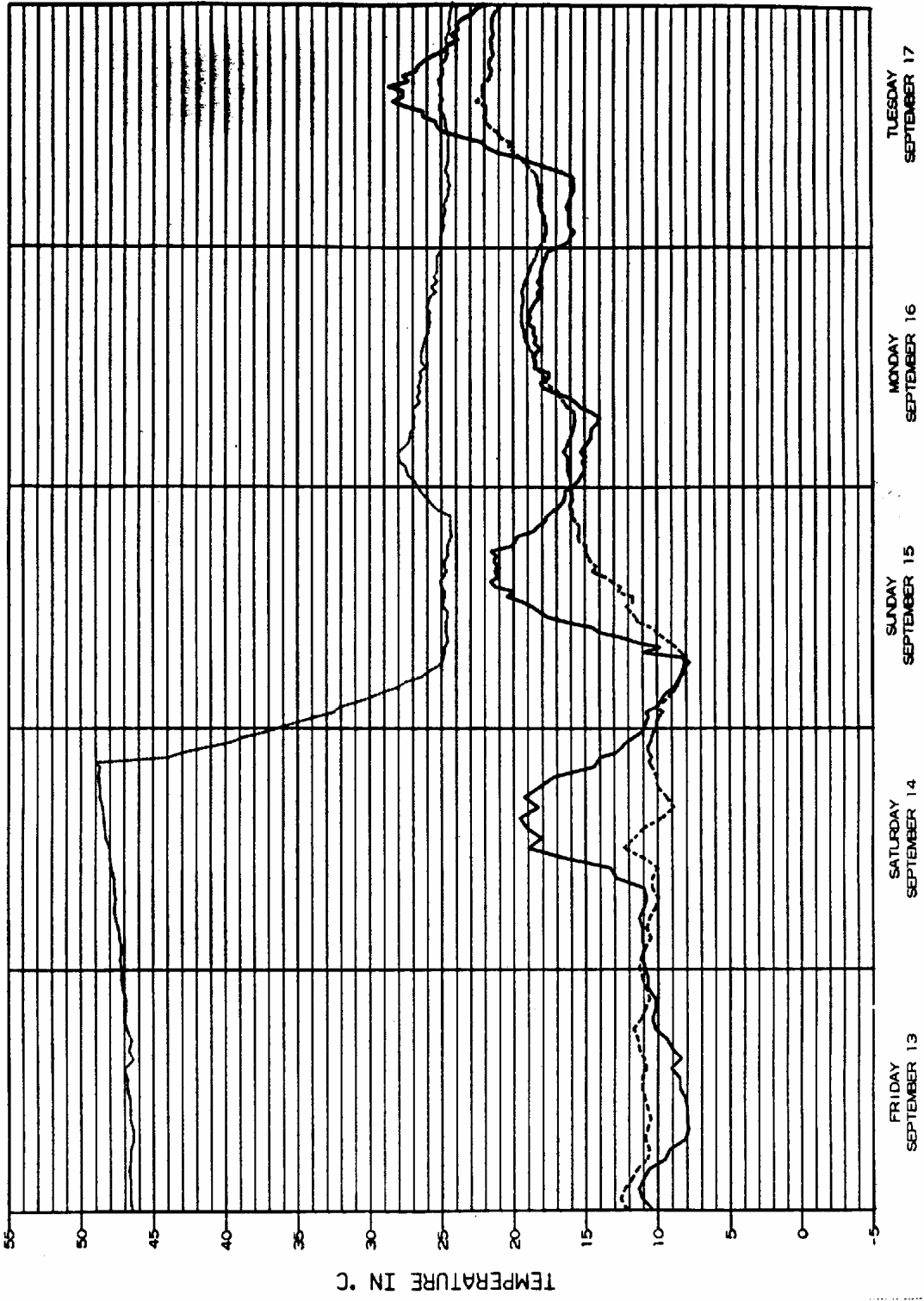


**ROOF POND  
SUMMER MODE**



# PONDING AND SPRAY

EXPERIMENT # 1 - SEPTEMBER 13, 1985 THRU SEPTEMBER 17, 1985

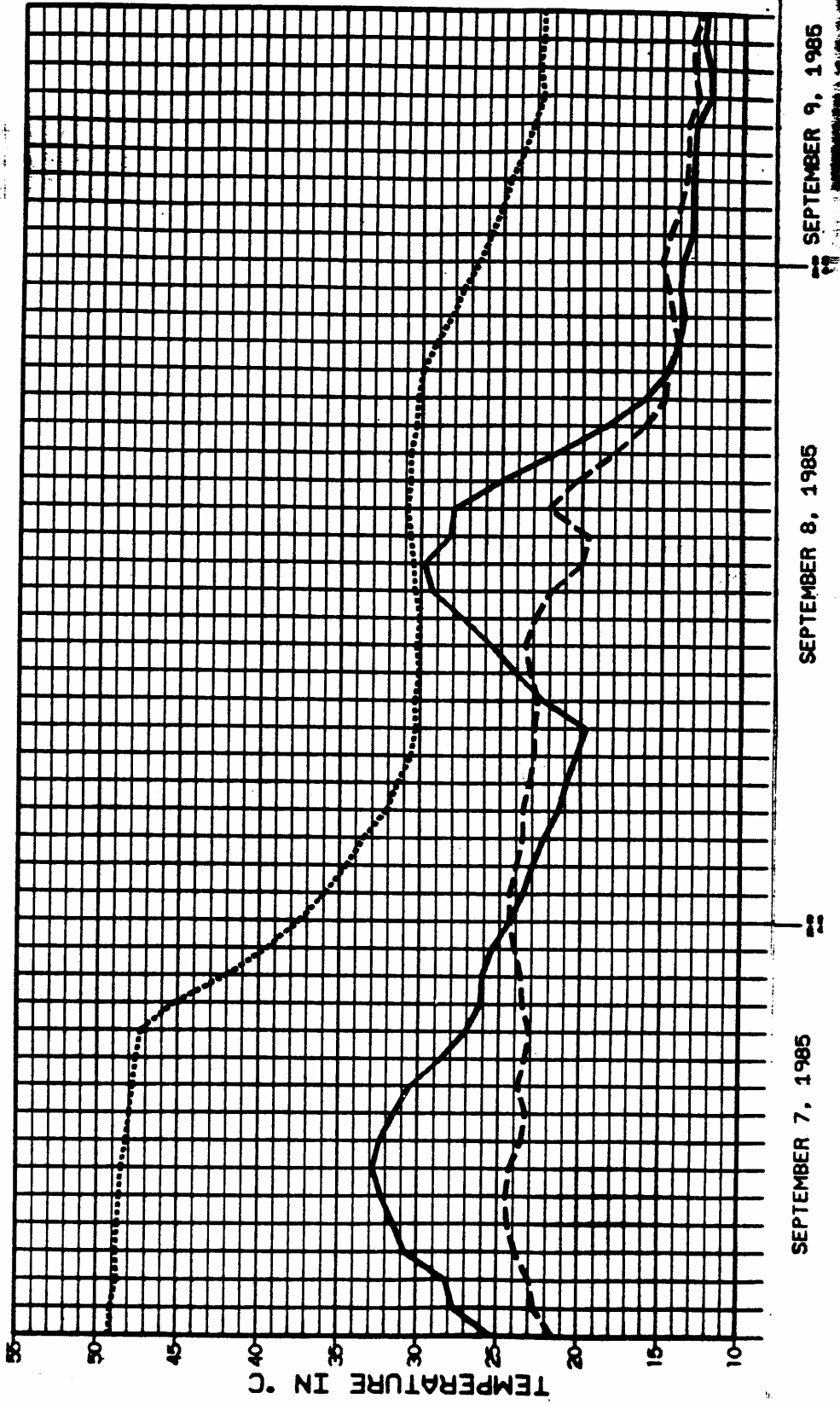


— AMBIENT TEMPERATURE  
- - - WATER TEMPERATURE  
..... DEWPOINT TEMPERATURE

TIME - DAILY

GRAPHIC PREPARED BY THE UNIVERSITY OF TEXAS AT AUSTIN

**PONDING ONLY**  
**TEMPERATURES vs TIME - EXPERIMENT #2**



**NATURAL DISCHARGING WITH PUMP OFF**  
**EXPERIMENT #3 - SEPTEMBER 27, 1985 THRU OCTOBER 3, 1985**

