Research Project Final Technical

Completion Report

OWRR Project No. A-014 Oklahoma

Increasing Water Supplies By Suppression of Reservoir Evaporation

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by

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Project Title: Increasing Water Supplies by Suppression of Reservoir Evaporation

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Principal Investigator:

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ABSTRACT

INCREASING WATER SUPPLIES BY SUPPRESSION OF RESERVOIR EVAPORATION

Water supplies in Southwestern reservoirs are seriously affected by evaporation. Chemical evaporation suppressants are only 35 to 40% efficient and are seriously affected by the wind. As an alternative, floating covers of solid or flexible materials offer a practical method of suppressing evaporation on small reservoirs.

This study was made on paired experimental ponds to determine the extent to which evaporation losses are reduced by the use of floating solid panels. The ponds, 0.28 acres in area and 6 feet deep, were lined with Nylon reinforced butyl rubber membranes for seepage control. Energy budget and water budget instruments were installed and operated. The principal tests were with floating rafts constructed of 1 inch thick Styrofoam which were found to be highly efficient in suppressing evaporation. Unpainted Styrofoam panels covering 48% of the area reduced evaporation 35%. Long duration tests on similar panels, painted white for increased reflectance, resulted in 43% to 49% evaporation reduction when 45% of the area was covered. The insulating properties of the Styrofoam panels significantly reduced daily variation in stored thermal energy. Over long periods the Styrofoam had no significant effect on the total thermal energy content of the pond.

KEYWORDS: Evaporation/ *Evaporation Suppression/ Reservoirs/ *Ponds/ Seepage/ *Butyl Linings/ Water Budget/ Energy Budget/ *Styrofoam Panels.

INTRODUCTION

Evaporation from lakes and reservoirs is a major loss of fresh water that is needed for the expanding economy of the farms, ranches and industry of the Southwest, where the water supplies are stored in above ground reservoirs. Research over the last decade has shown that these losses can be reduced by about 35 to 40% by applying a chemical film of hexadecanol or octadecanol to the reservoir surface. However, it has also been shown that wind affects the film adversely and quickly removes the film from the surface unless the chemical film is continuously replaced. Thus there was a need for studying other methods of evaporation control which would not be affected by wind. Floating covers of insulating materials were studied in this project. For small reservoirs these materials may have a greater efficiency than chemical liquid type films of hexadecanol and octadecanol. Of particular interest was the relative efficiency of floating covers which cover only a portion of the reservoir.

PROJECT OBJECTIVES

General Objectives

The general objective of this project was to study the broad problem of evaporation suppression and methods of increasing the efficiency of evaporation suppression methods as applied to small experimental reservoirs.

The specific objectives were to:

1. Determine the evaporation retarding efficiency of floating evaporation barriers in relation to the proportion of the total water surface covered by the evaporation retardant.
2. Determine the effect on evaporation resulting from inverting or otherwise disturbing the thermal gradient of small reservoirs by pumping, bubbling, or similar techniques.

Extent of Achievement of Project Objectives

Objective No. 1 was fully achieved. Detailed experiments were planned and executed and the results were presented in this report which show a one to one correspondence between evaporation reduction and the pond area covered by a floating evaporation barrier.

Objective No. 2 was not achieved because of limitations in the available experimental facilities. Preliminary tests at the beginning of the research project showed that because of the relative shallowness of the ponds the thermal gradients essentially isothermal and therefore experimental approaches to inverting the thermal gradient would be meaningless. This objective was therefore abandoned.

FACILITIES, INSTRUMENTATION AND PROCEDURES

Ponds

The evaporation suppression investigations under this project were made on two adjoining experimental ponds located on high ground near the Oklahoma State University campus. Each pond was 120 ft. long, 100 ft. wide and 6 ft. deep. The ponds were oriented with the long axis in a North-South direction. They are referred to in this report as the East pond and the West pond.

Water for the ponds was obtained by gravity flow from a nearby standpipe in the University water system. The ponds were designed with a concrete curb around the inside edge of each dike to prevent outside runoff water from entering the ponds. Water level in the ponds was measured by a laboratory point gage operating inside a still well, and a continuous record of water level was made by a Stevens Type F water level recorder.

Seepage Control

Both ponds were lined with flexible membranes to eliminate seepage, or reduce seepage to an acceptable amount. Linings for the two ponds differed during part of the project experiments. At the outset of the investigation the East pond had an 8 mil. polyvinyl chloride sheet membrane liner which had been installed about 12 years previously for evaporation suppression investigations. The upper two feet of the liner had deteriorated due to hardening of the PVC due to exposure to sunlight. Before the tests began, this portion of the liner was covered over with a one-inch thickness of gunite concrete. As an added precaution for the first test the stage was not allowed to exceed a maximum of 4.0 ft. A new liner was installed in the East pond after this test.

The West pond had originally been similarly lined with a polyvinyl chloride membrane but this liner had deteriorated to such an extent that it was necessary to completely remove the liner and install a 30 mil. nylon reinforced butyl rubber liner before testing could begin. After the first test, from September 4 to November 9, 1969, it was concluded that in the interest of accuracy it was necessary to also remove the PVC liner from the East pond and install a new 30 mil. butyl rubber liner similar to the West pond. Figures 1 and 2 show the deteriorated condition of the existing PVC liner in the East pond. The installation was made during the summer and fall of 1970.

Laying of a leak proof butyl rubber liner proved to be an exacting undertaking, requiring a smooth subgrade to prevent puncture and utmost care in sealing overlapped joints to prevent leakage. Several of the steps in the installation procedure are shown in Figures 3 through 8.

Following the installation of the liners periodic tests were made to determine the amount of seepage. In spite of efforts to exercise extreme care to obtain high quality joints,

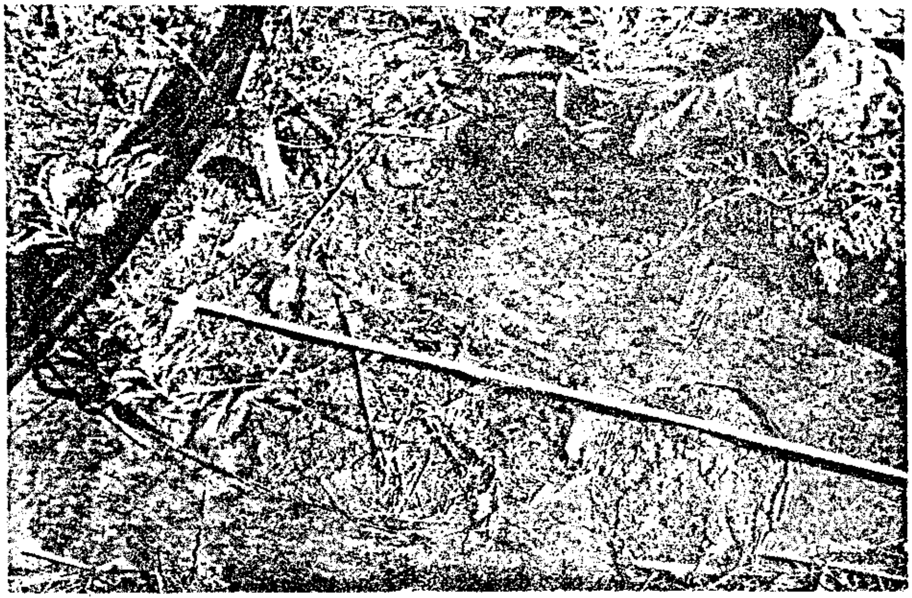

Figure 1. Existing PVC pond liner showing deteriorated condition necessitating replacement

Figure 2. Dewatering and removing existing liner from West pond

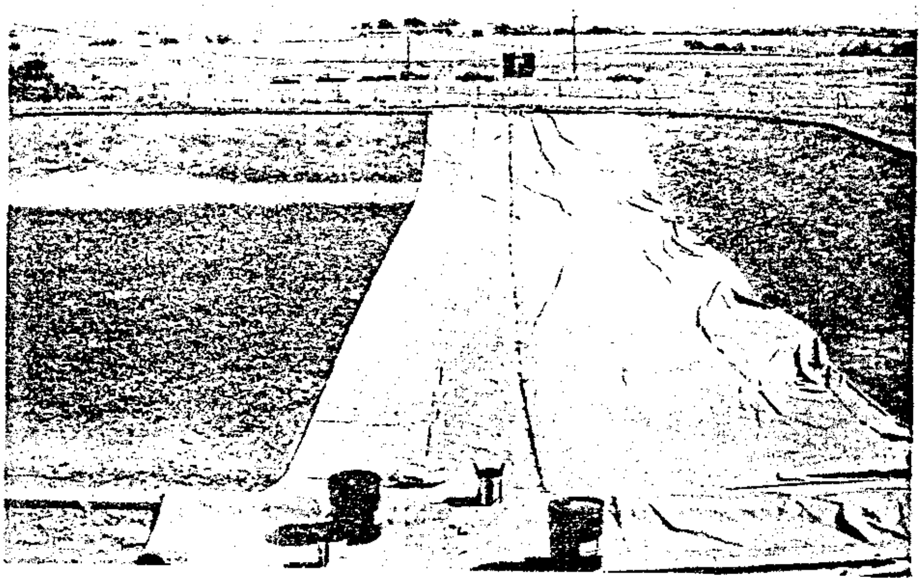

Figure 3. Butyl rubber liner installation. Sub-grade was carefully tamped and smoothed to prevent puncture of liner

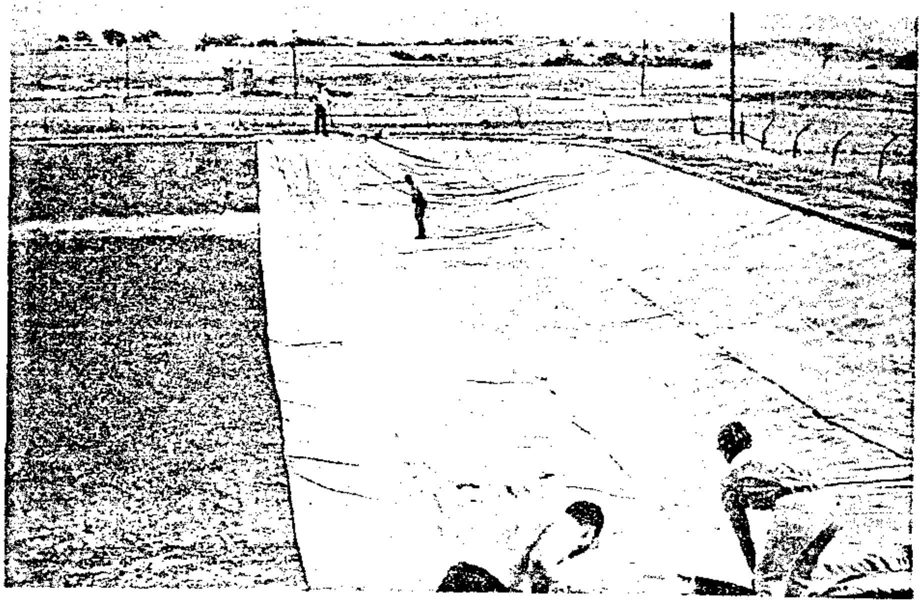

Figure 4. Butyl rubber liner installation. Liner was attached to concrete curb around perimeter

Figure 5. Butyl rubber liner installation. Watertight membrane was formed by glueing 15 ft wide strips supplied by manufacturer

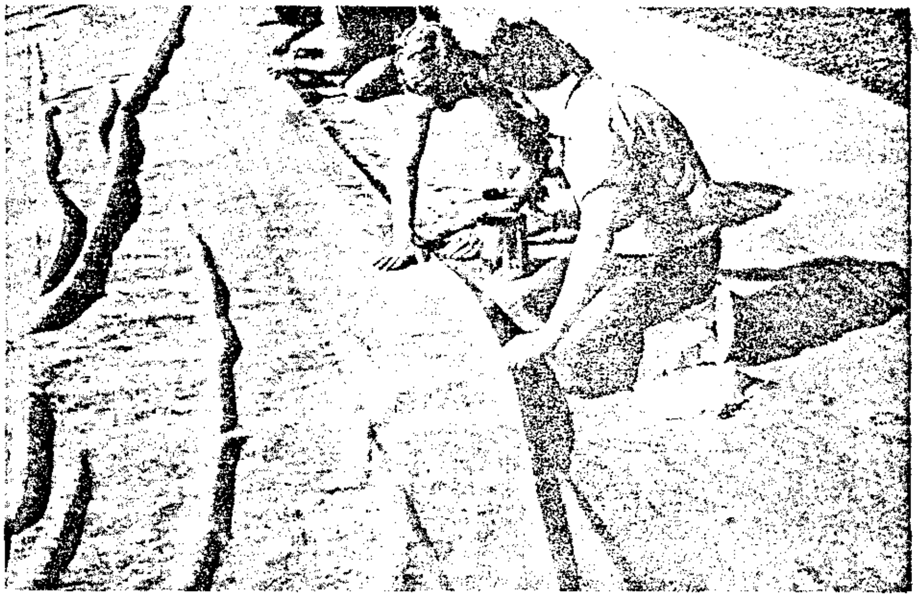

Figure 6. Butyl rubber liner installation. Failure of a lap joint similar to this caused seepage and resulted in delays in the experimental program

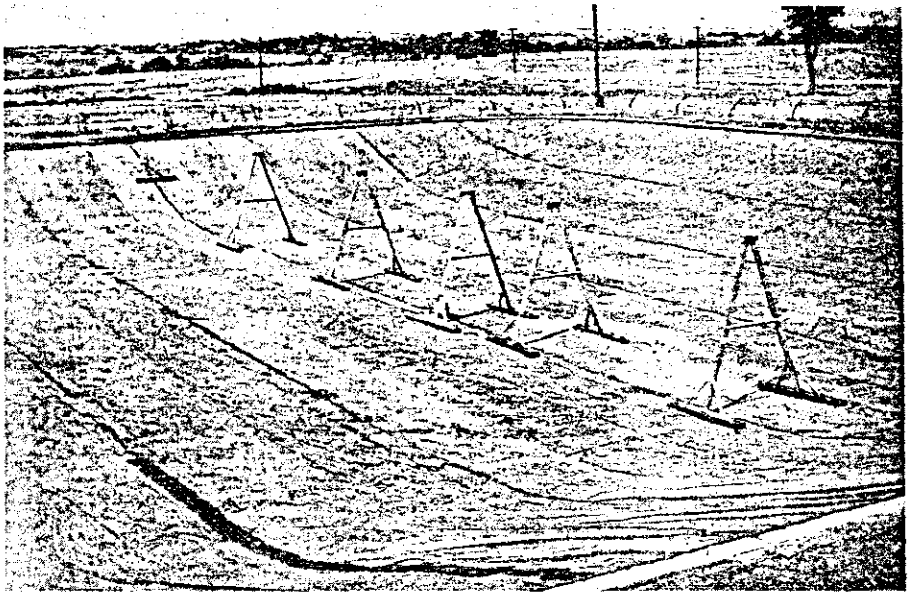

Figure 7. Complete butyl rubber liner installation. A-frame trestles are supports for cat-walk over pond

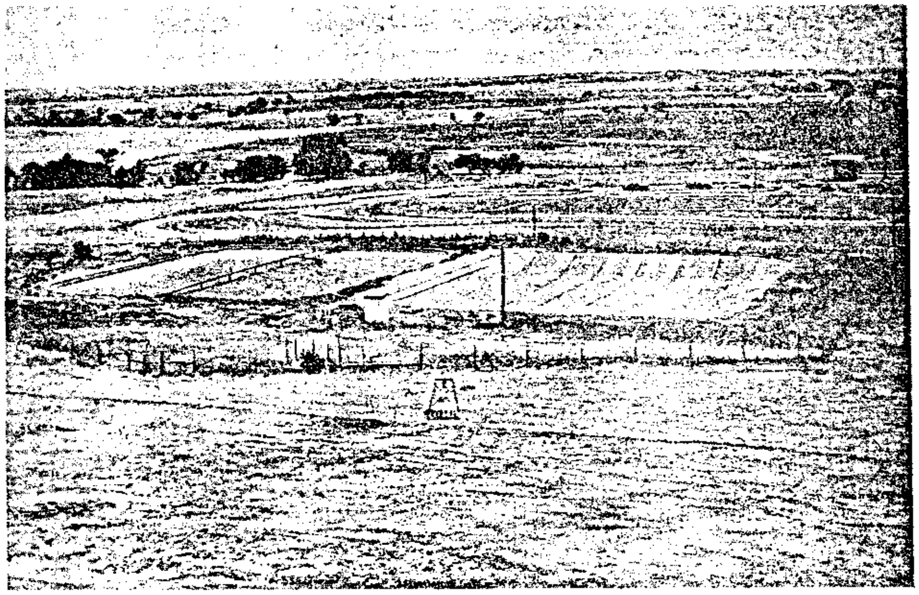

Figure 8. Areal view of completed liner installation on East pond. West pond is filled with water

seepage tests made after the installation disclosed that an unacceptable amount of seepage was taking place at one of the seams. Repair of the liner required drainage of the pond, repairing the leak, and making a new seepage calibration. The experimental program was delayed considerably because of the necessity of making liner repairs.

Stage-Storage-Relationships

Accurate stage-storage relationships were required for an accurate accounting of energy stored in the ponds. These relationships were developed by measuring the inflow into the pond with a Neptune water meter. The change in stage was determined by a precision point gage. The resulting stage-area-volume relationships for the experimental ponds are shown in Table I.

TABLE I

STAGE-AREA-VOLUME FOR EXPERIMENTAL PONDS

	East Pond		West Pond	
Stage ft	Area ft^2	Volume ft^3	Area ft^2	Volume ft^3
0.00	--	--	--	--
1.00	6160	5440	5243	3792
1.50	6650	8642	5825	6555
2.00	7151	12092	6479	9629
2.50	7670	15797	7151	13038
3.00	8215	19767	7788	16775
3.50	8794	24018	8335	20810
4.00	9414	28568	8739	25086
4.50	10084	33440	8946	29517

Design of Panels

Two different designs of floating panels were used in the experiments. Type A design was used in the test from September 4, 1969 to November 9, 1969. Type B was used in tests from July 14, 1971 through October 29, 1972.

The Type A panels were constructed of Styrofoam plastic foam and flat aluminum alloy stock reinforcement as shown in Figure 9. Four tongue and groove Styrofoam panels 1 inch thick, 2 feet wide, and 8 feet long were used in each raft. The material had a density of 2.2 pounds per cubic feet, thermal conductivity of 0.19 Btu/hr - ft^2 - °F/in, and a water vapor transmission coefficient of 0.6 perm-in. Tests with a flat plate radiometer indicated a solar and atmospheric radiation reflectance of approximately 43 percent after the new Styrofoam was exposed to the sun and water. Manufacturer's laboratory tests gave a 17 to 18 percent light transmission rate with a standard candle-foot meter. The panels were tied together to form a solid cover on the south half of the experimental pond.

The design of the Type B panels is shown in Figure 10. The sandwich-type plywood molding around the perimeter of the 8 ft. x 8 ft. panels significantly increased the stiffness and durability of these panels. The physical characteristics of the Styrofoam used in the two types of panels were similar. The principal difference was that the Type B panels were painted white to reflect the incoming solar radiation, while the Type A panels were unpainted. The improved evaporation suppression of the Type B panels is attributed to the painted

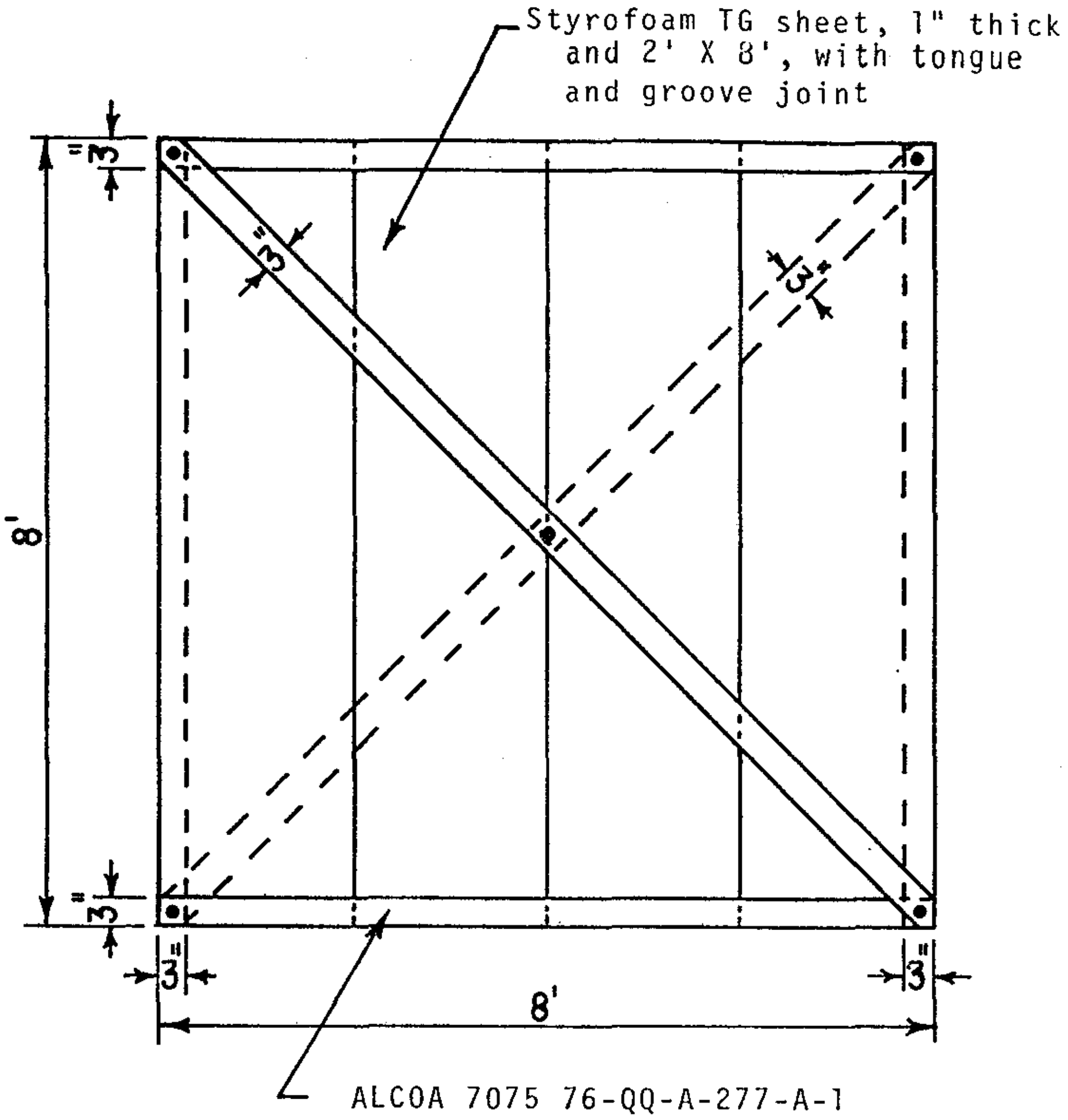

Figure 9. Type A Panel Used in Evaporation Suppression Test

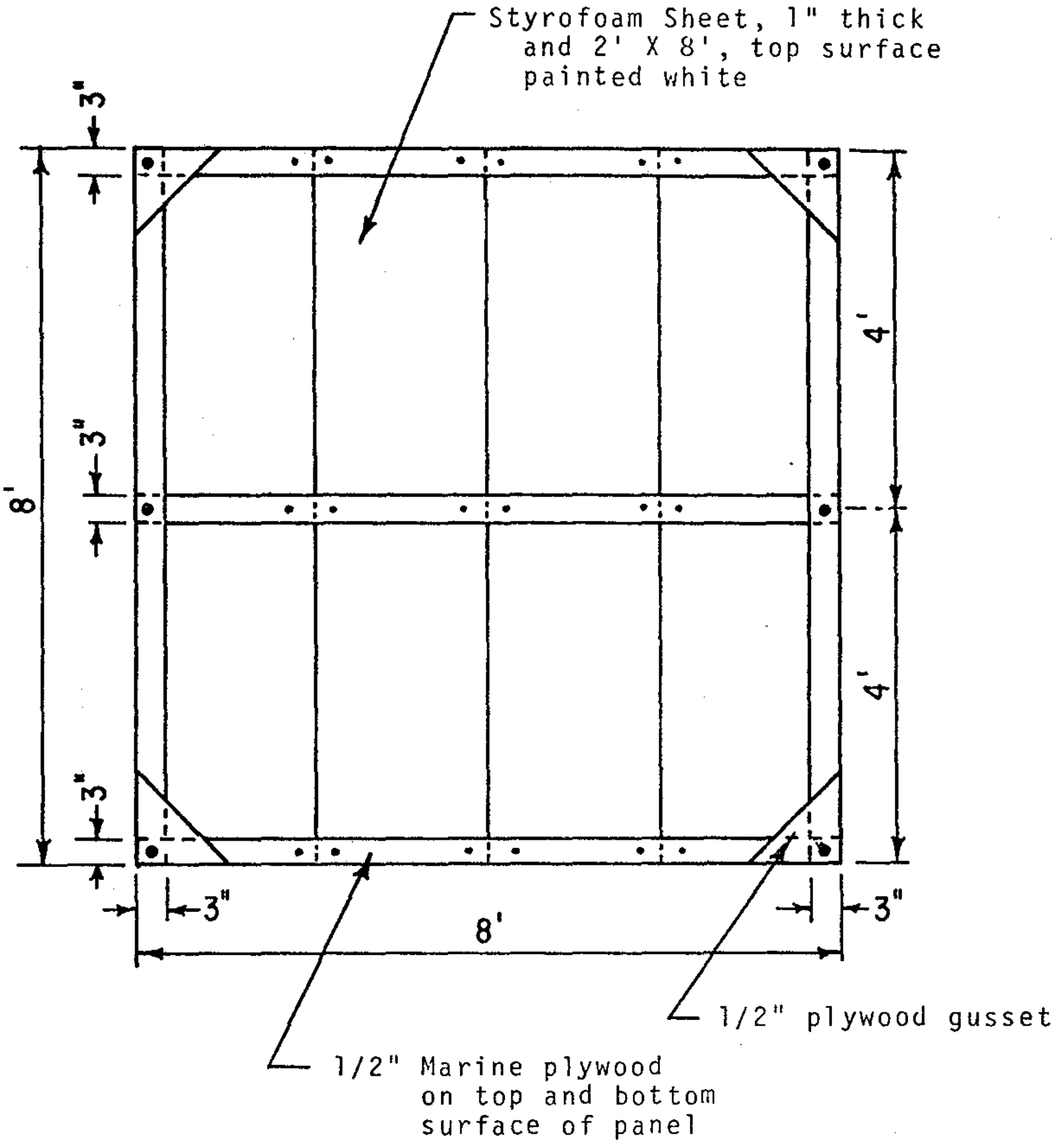

Figure 10. Type B Panel Used in Evaporation Suppression Test

surface of the Type B panels.

The experimental program using the Type B panels was conducted on the West pond. The panels were joined together to form the floating raft shown in Figures 11 and 12.

Instrumentation

Wind velocity was measured by a Bendix-Friez totalizing cup anemometer set 7 feet above mean water surface elevation. Wind travel was continuously recorded by the event recorder on a Honeywell Electronik 16 recorder.

A wet and dry bulb psychrometer measured temperatures that were used to compute the vapor pressure of the air. The psychrometer was mounted 7 feet above the mean water surface elevation. Temperatures were recorded at 7.5 minute intervals by a Honeywell Electronik 16 multipoint recorder.

Water surface temperatures were measured by thermocouples located in the center of the untreated pond, the center of the open area of the treated pond, and the center of the covered area of the treated pond. Stored energy in each pond was computed from temperatures obtained at three thermal profile stations by thermocouples located at the surface and at 1-, 2-, 3-, and 4-foot depths. Temperatures were recorded in degrees Fahrenheit with a Honeywell Electronik 16 potentiometer.

Total incoming radiation was measured by a Beckman and Whitley ventilated thermal radiometer and recorded continuously by a Honeywell Electronik 19 laboratory millivolt recorder.

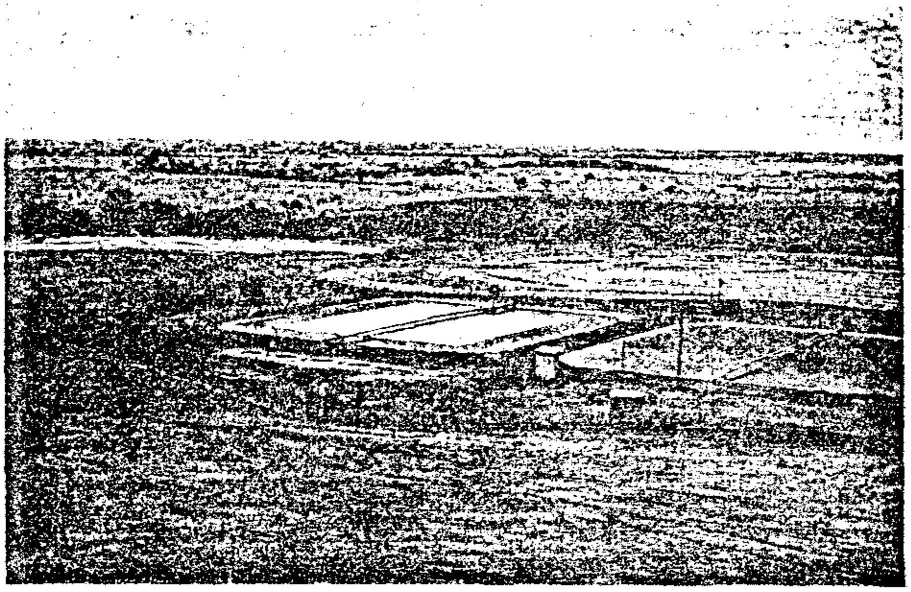

Figure 11. Areal view of experimental evaporation ponds. West pond is 45% covered by floating Styrofoam panels

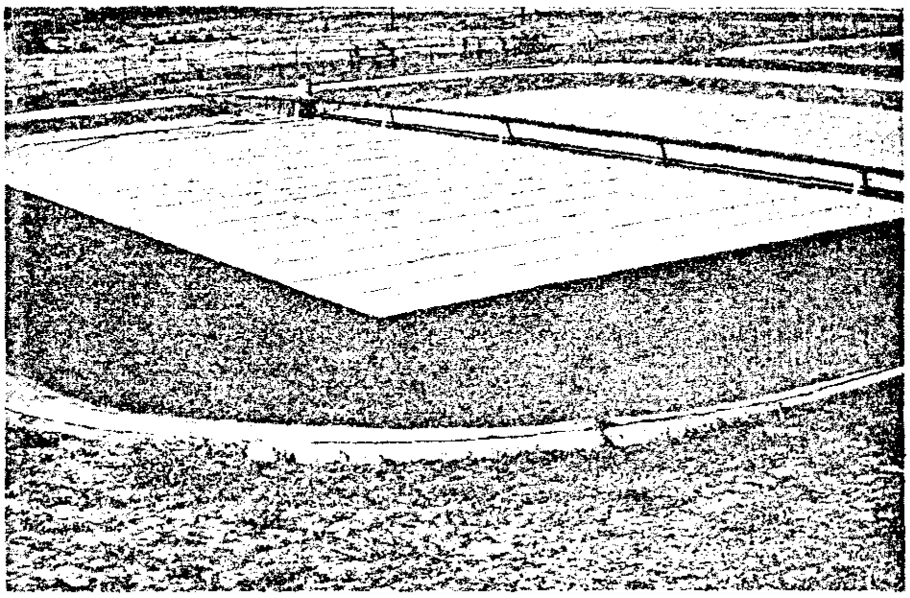

Figure 12. Floating Type B Styrofoam panel on evaporation pond

The flat plate radiometer surface temperature was recorded by a Honeywell Electronik 16 potentiometer every 7-1/2 minutes.

Two class A evaporation pans were used to estimate evaporation while the ponds were being filled. Evaporation losses were recorded during the investigation.

Procedure

The water budget was the primary method of experimental control. Due to special design of the ponds there was no runoff into the ponds from outside drainage areas. The water budget applicable to these ponds was

$$\text{Evaporation} = \text{Rainfall} - \text{Seepage} - \text{Change in Reservoir Stage}$$

The amount of seepage was kept to a minimum by the flexible membranes. Rainfall was handled in two different ways. In the 1969 tests, days having rainfall amounts of over 0.1 inch were deleted from the evaporation calculations. In the subsequent tests, days with rainfall were included, but the rise in water level due to rainfall on the pond was accounted for in the water budget equation. The data for the water budget were obtained for each 24-hour period during the tests.

The energy budget was maintained on the ponds to determine the amount of incoming energy and the effect of the floating panels on the surface temperature, the heat flow within each pond and the change in stored energy. For analysis purposes a daily thermal survey period consisted of 24 hours beginning at 0800 and ending at 0800 the following day.

The general order of proceeding with the investigation was according to the following phases.

Phase I: Preparation

- A. Pond Preparation
    1. Remove old liner
    2. Prepare subgrade
    3. Install flexible liner
    4. Conduct seepage tests
    5. Repair defects in liner if seepage tests are unsatisfactory
- B. Floating Panels
    1. Design panels
    2. Construct and paint panels
    3. Install panels when pond preparation complete
- C. Instrumentation
    1. Acquire and install instrumentation
    2. Calibrate instruments

Phase II: Experimentation

- A. Water Budget
    - 1. Acquire water budget data on a daily basis
    - 2. Analyze water budget data
- B. Energy Budget
    - 1. Acquire energy budget data on a daily basis
    - 2. Analyze energy budget data
- C. Durability Tests
    - 1. Make long duration tests to determine durability of Styrofoam panels regarding
        - a. Wind damage
        - b. Deterioration or discoloration by sunlight.

SIGNIFICANT RESULTS

Effect of Styrofoam Panels on Evaporation

The most important aspect of this investigation was to determine the degree of effectiveness of a floating vapor barrier such as Styrofoam in reducing evaporation from an open water surface and the practicability of using this material over a long period of time.

This phase of the investigation was studied in four experiments conducted in September and October of 1969 and in the period from July 1971 through October 1972. During those periods the proportion of the pond surface covered by Styrofoam panels was varied from 22.5 percent to 48 percent and the evaporation was reduced significantly.

The results of those experiments are summarized in Table II and also are shown graphically in Figures 13-16. These data show that the reduction in evaporation due to the presence of the floating Styrofoam barrier is approximately directly proportional to the percent of the pond area covered. This is significant because in actual use on a natural reservoir the surface area of the reservoir could be expected to fluctuate as the stage of the reservoir decreased or increased according to the volume of withdrawals or inflow from runoff. With the aid of stage-area-volume curves, the manager of a reservoir could predict the amount of evaporation loss that could be prevented by the floating Styrofoam panels.

TABLE II: SUMMARY OF EVAPORATION EXPERIMENTS TO DETERMINE EFFECT OF FLOATING STYROFOAM PANELS ON EVAPORATION.

Expt No.	Dates	Type and Color	Percent of Pond Covered	Percent Evaporation Reduction
1	Sept 4, 1969 to Nov 9, 1969	Type A Natural	48	35.5
2	July 14, 1971 to Jan 1, 1972	Type B White	45	43
3	Jan 1, 1972 to Aug 21, 1972	Type B White	45	49
4	Aug 23, 1972 to Oct 29, 1972	Type B White	22.5	26.6

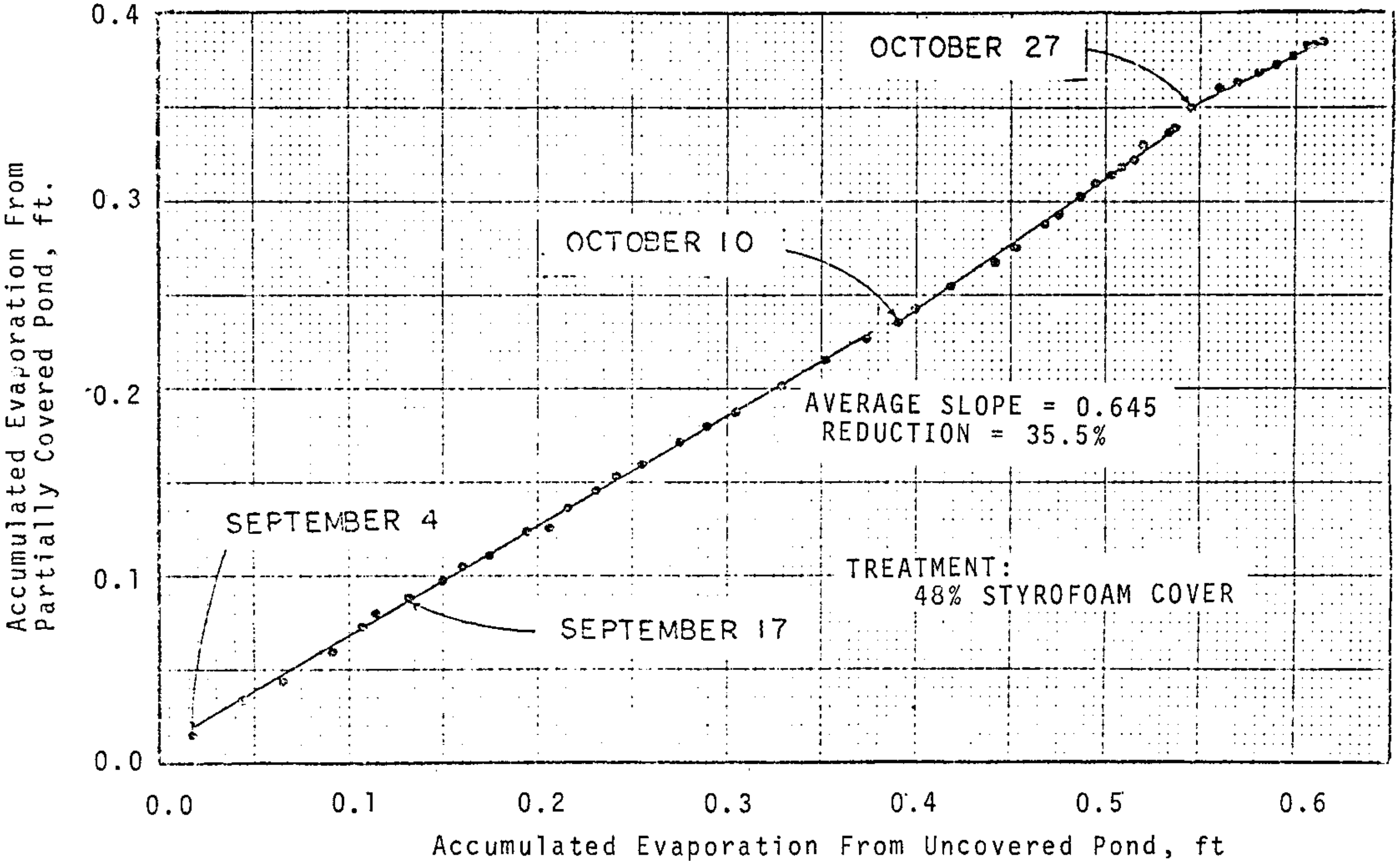

Figure 13. Double Mass Diagram of Evaporation from Partially Covered Pond Compared with Uncovered Pond, Experiment No. 1

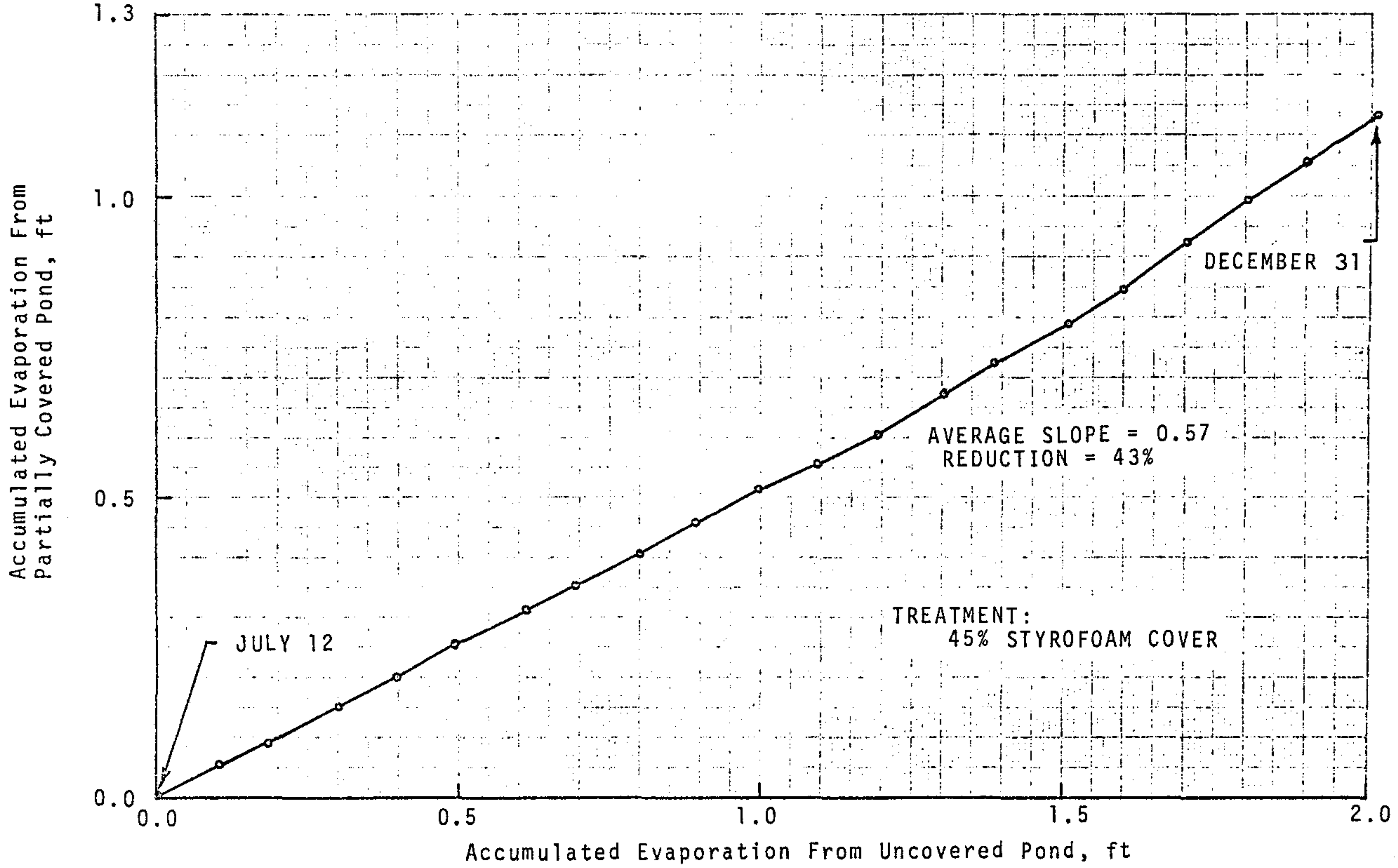

Figure 14. Double Mass Diagram of Evaporation From Partially Covered Pond Compared with Uncovered Pond, Experiment No. 2

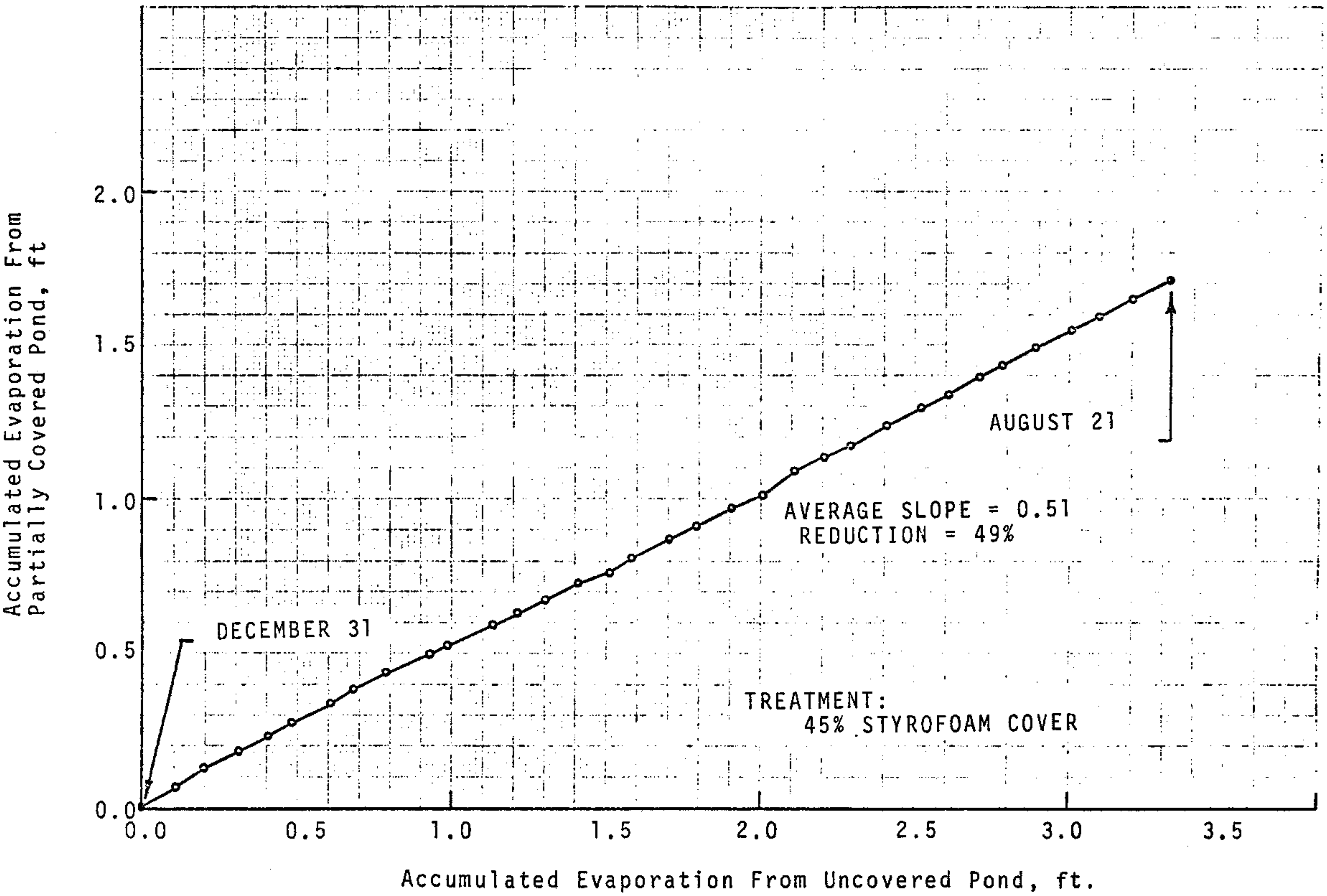

Figure 15. Double Mass Diagram of Evaporation From Partially Covered Pond Compared with Uncovered Pond, Experiment No. 3

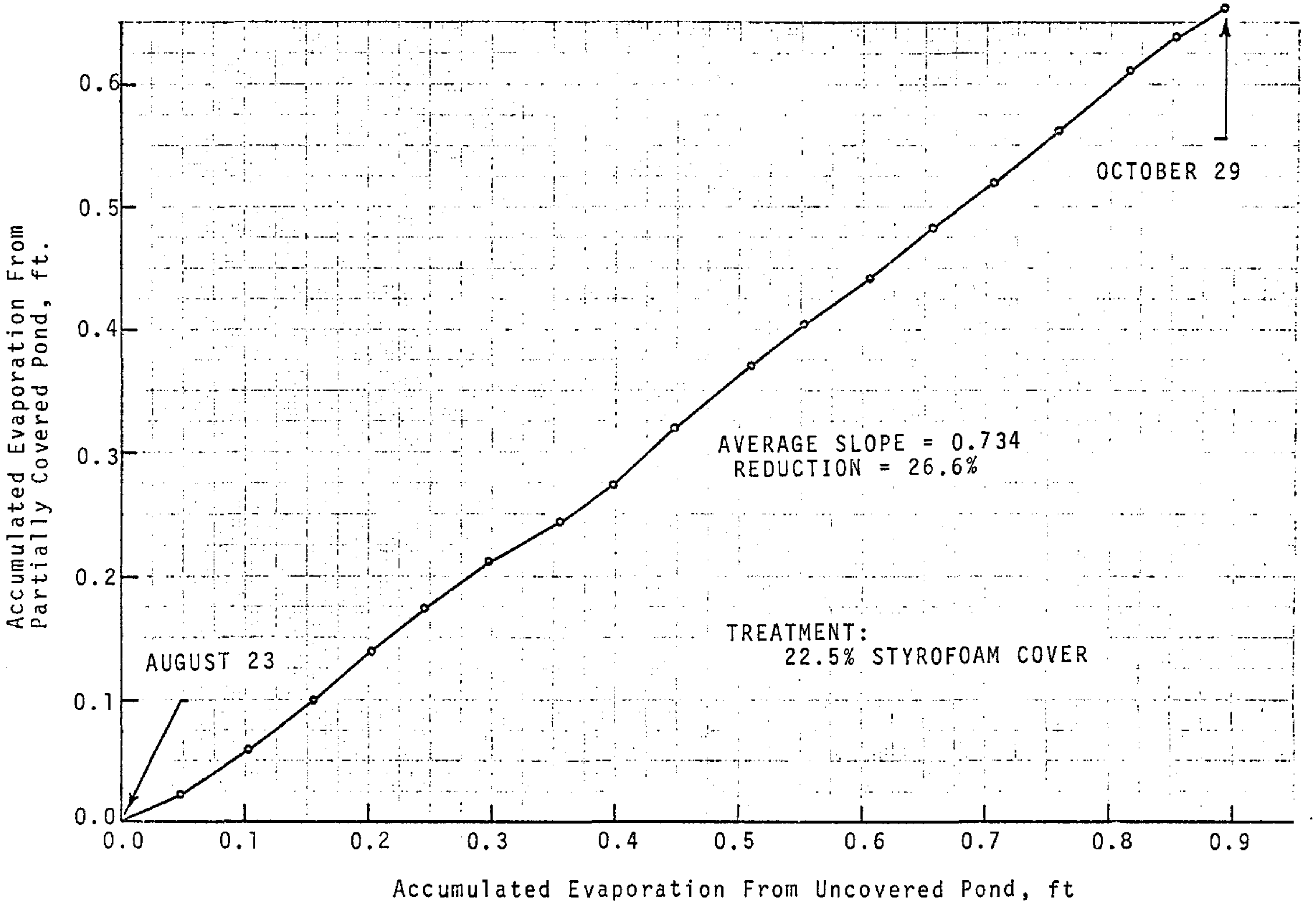

Figure 16. Double Mass Diagram of Evaporation From Partially Covered Pond Compared with Uncovered Pond, Experiment No. 4

Effect of Styrofoam Panels on Surface Temperature, Thermal Stratification, and Change in Stored Thermal Energy.

The surface temperature and thermal stratification of the water and changes in stored thermal energy were variables under observation to determine the extent to which these variables would be affected by a partial cover of floating Styrofoam panels.

The variation of the water surface temperatures over the partially covered pond was of special interest to determine the extent of energy migration to or from the portion of the surface covered by Styrofoam. From Figure 17 it may be seen that during the daylight hours the surface of the uncovered portion of the pond was approximately 0.4°F higher than under the Styrofoam panel. When the heat source was removed at sunset, however, the surface temperature of the uncovered portion dropped to an average 0.4°F lower than under the Styrofoam.

The untreated pond did not develop significant vertical thermal gradients and was isothermal except during the afternoons of warm days when a maximum of one degree Fahrenheit difference between the surface and bottom water temperatures would develop. In constrast the treated pond had distinct vertical thermal gradients during daylight hours and then became isothermal only later in the night. Figure 18 shows Typical average daily thermal profiles in the treated pond under the Styrofoam cover and the open area.

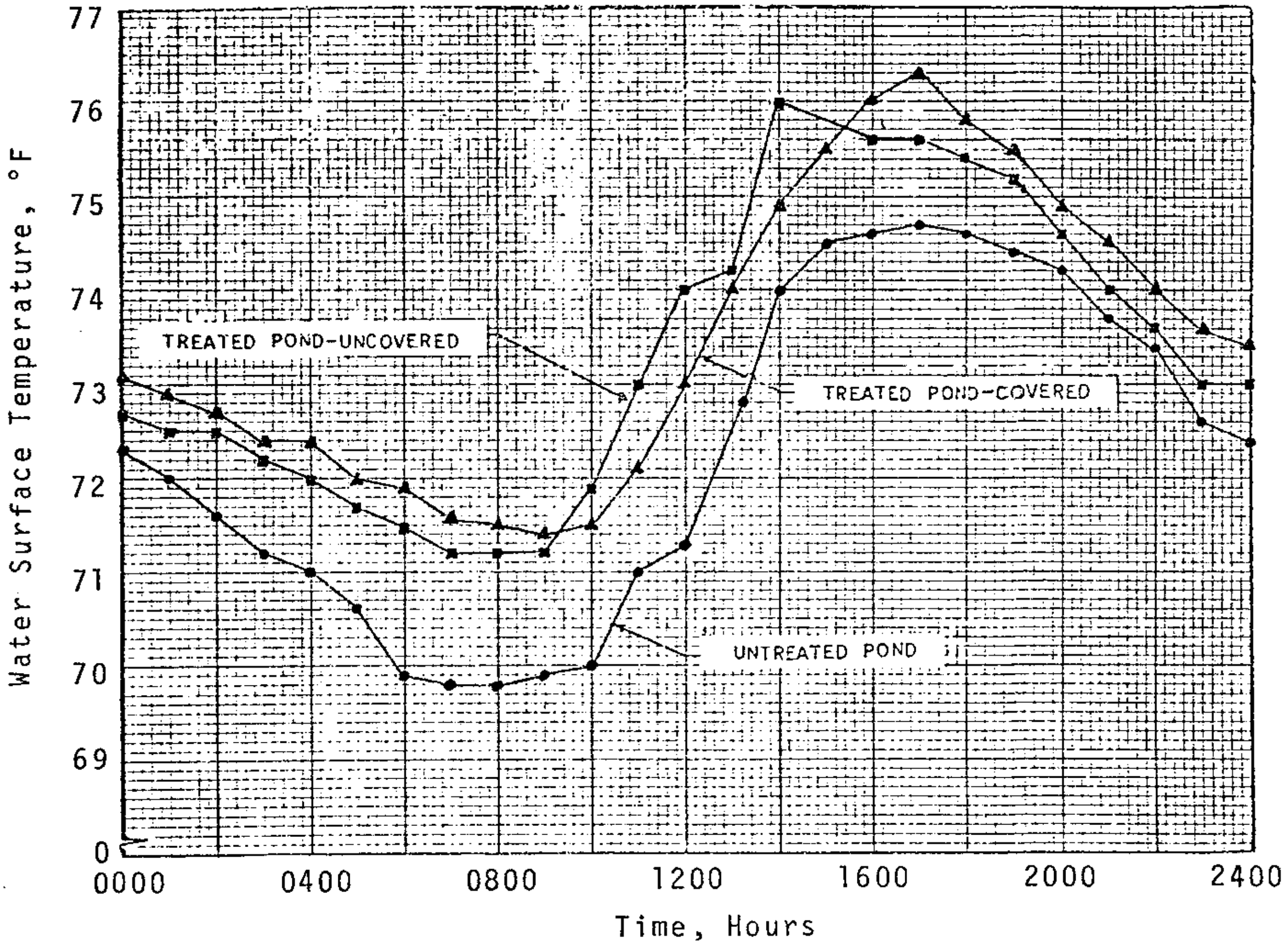

Figure 17. Diurnal Water Surface Temperature of the Ponds For a Typical Day in September

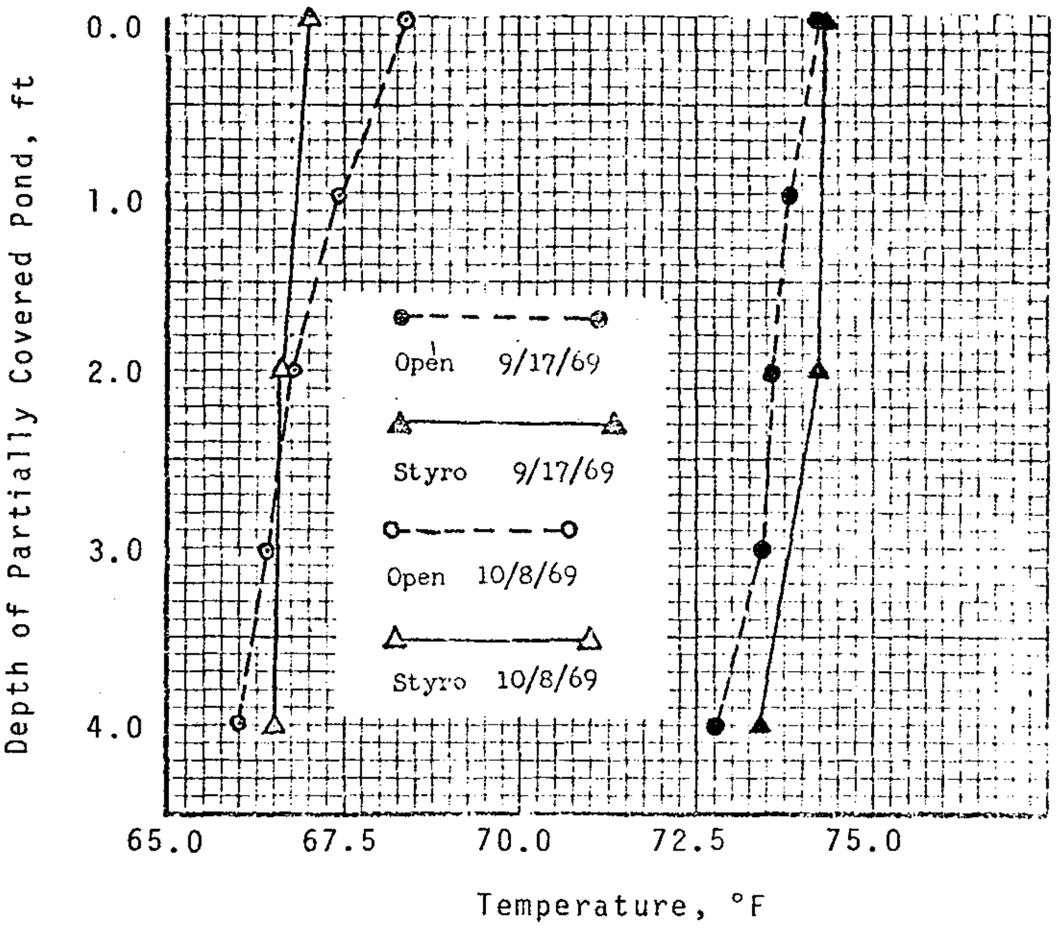

Figure 18. Typical Daily Average Temperature Profiles

Before the investigation began an assumption was made that lateral temperature gradients would develop in the water mass between the open area and covered area of the treated pond. This did not occur. Figure 19 shows typical isotherms for a cross section of the treated pond at mid-afternoon.

It may be postulated that a physical structure such as the Styrofoam panels floating on the water surface would alter the energy budget terms concerned with reflected solar and atmospheric radiation, the back radiation from the water surface and the energy transferred from the water surface as sensible heat. The total integrated effect of changes in these terms is measured by the change in thermal energy stored in the body of water.

An accounting of the stored energy in each pond was made on a daily basis for 45 days during the months of September and October. Both ponds experienced rather large fluctuations in daily change in stored energy. However, because of the insulating properties of the Styrofoam the daily change in stored energy on the partially covered pond was less pronounced than on the uncovered pond.

The change in stored energy for the two ponds is shown in Figure 20. Analysis of the stored energy showed that the day to day change was statistically significant. However, the overall change in stored energy during the period of investigation was not statistically different for either pond. This finding was similar to the results of an earlier investigation by Manges using a chemical monolayer on ponds.

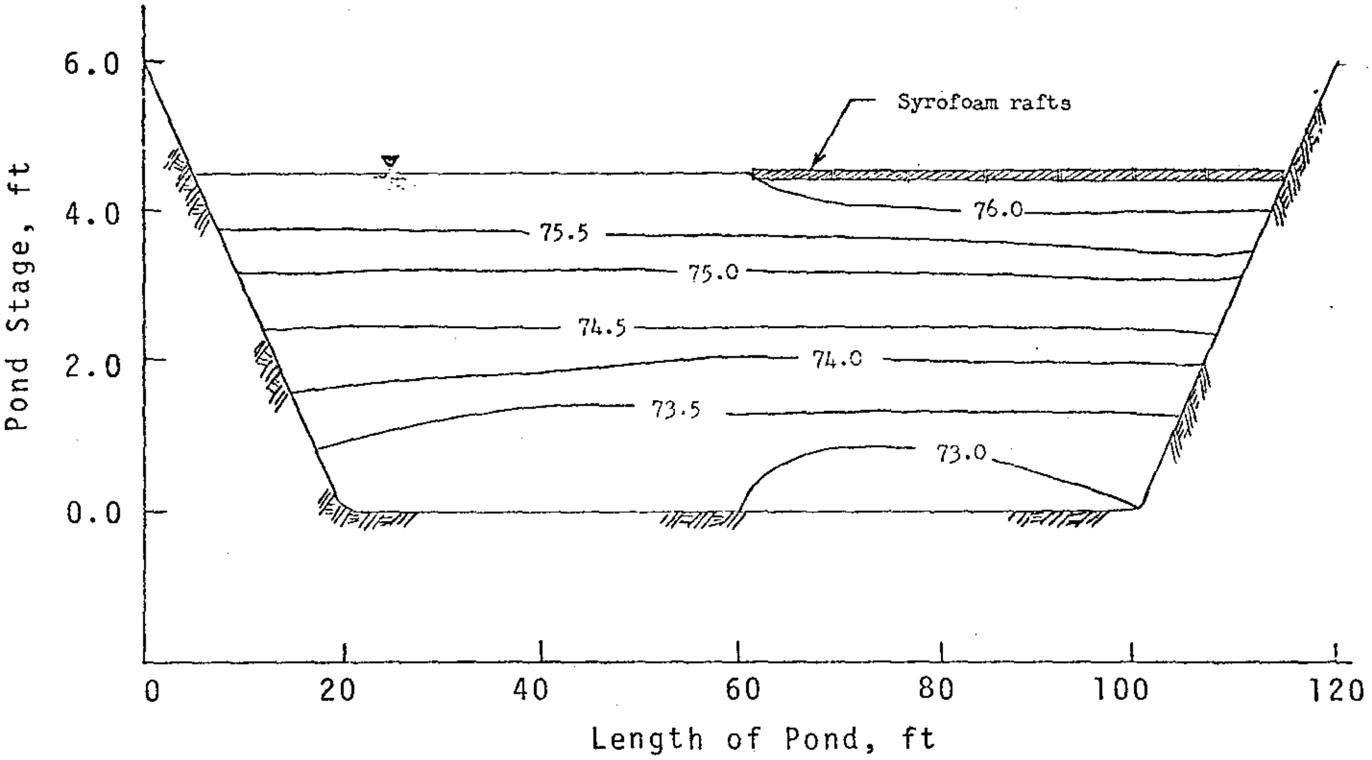

Figure 19. Typical Mid-Afternoon Temperature Isotherms For the Partially Covered Pond, Experiment No. 1

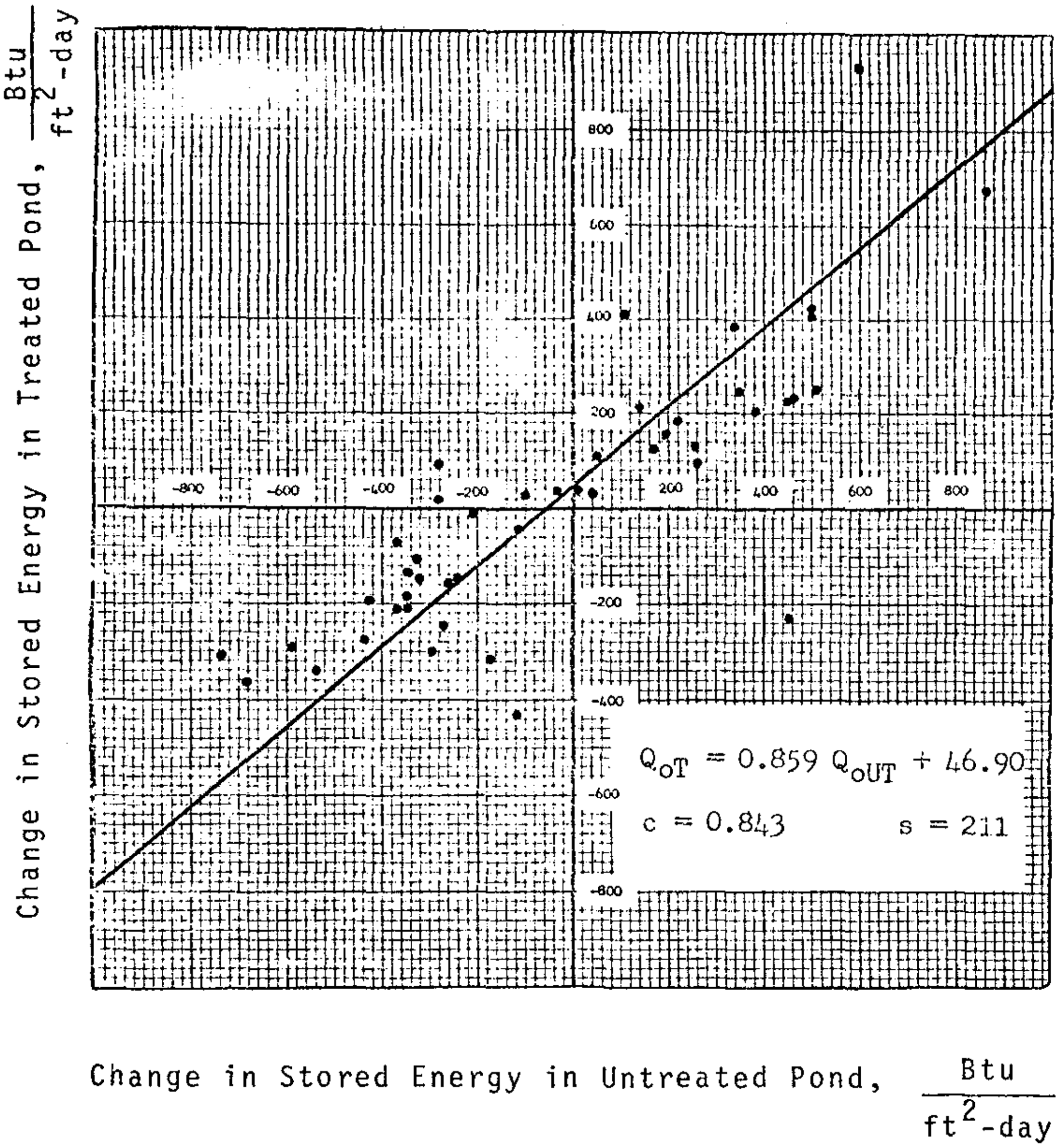

Figure 20. Change in Stored Energy for the Partially Covered Pond Compared with Uncovered Pond, Experiment No. 1

CONCLUSIONS

1. Floating rafts constructed of 1-inch thick Styrofoam panels are a highly efficient method of suppressing evaporation losses from reservoirs of a size similar to farm ponds.
2. For a pond that is partially covered with floating Styrofoam rafts there is a one to one correspondence between the percent of area covered and the percent of evaporation suppressed from the entire pond.
3. There is a statistically significant difference between the change in stored thermal energy, on a daily basis, between two ponds when one is partially covered with a floating Styrofoam raft, but there is no significant difference in stored thermal energy for long duration test periods.

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