General view of the Experimental Twin Ponds. School of Engineering, The American University of Beirut.

AN INVESTIGATION ON WATER EVAPORATION REDUCTION
IN SMALL RESERVOIRS
BY THE APPLICATION OF FLOATING WHITE STYROPOR BEADS

BY

HANI MUSA AZAR

SUBMITTED TO THE SCHOOL OF ENGINEERING,
AMERICAN UNIVERSITY OF BEIRUT,
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING
WITH MAJOR IN CIVIL ENGINEERING.

ADVISOR
Prof. A.N. Acra

BEIRUT, LEBANON

DATE: NOVEMBER 1, 1964

ACKNOWLEDGEMENTS

The writer of this report is indebted to the following:

Prof. A.N. Acra, School of Public Health, A.U.B. for his sincere interest in this research and his cooperation. He communicated the results of his previous research work on this subject and had the patience to answer all questions. He has also gone to the trouble of reading the manuscript and commenting on it.

Dr. E.S. Hope, Senior Professor of Civil Engineering, A.U.B., who encouraged the writer to undertake this research. His help and guidance throughout the investigation are greatly appreciated.

Prof. A. Vogt, School of Engineering, A.U.B., for reading the report and his suggestions for improvements.

Other Faculty members of the School of Engineering, A.U.B., who encouraged this work and helped in various ways.

Staff members of the Engineering Shops and Laboratories, A.U.B., for their cooperation with equipment and physical arrangements.

Hani M. Azar

The American University of Beirut
Beirut, Lebanon
November, 1964

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iii

INTRODUCTION 1

Chapter I. WATER CONSERVATION 6

- The need for water conservation in arid and semi-arid regions
- Magnitude and significance of evaporation

Chapter II. THE EVAPORATION PROCESS 11

- Factors affecting evaporation
- Measurement of evaporation
- Control of evaporation

Chapter III. EVAPORATION CONTROL BY THE APPLICATION OF MONOLAYERS 21

- Historical development
- Laboratory and field studies
- Evaluation of the use of monolayers
- Limitations of monolayer use

Chapter IV. ARAB MIDDLE EAST CONDITIONS 35

- Climatalogical condition of the area in general
- The need for water conservation by the utilization of desert run off
- The experimental program started in the Jordan desert
- The need for conservation of impounded waters
- The use of monomolecular films is subject to limitations arising from local conditions

Chapter V. EXPERIMENTAL WORK AND RESULTS 43

- Description of the test facility; ponds, equipment, water, materials
- Testing procedure
- Experiments conducted on the use of Styropor beads for water evaporation reduction and results

Page

Chapter VI. DISCUSSION OF THE RESULTS. 97

- Evaporation suppression ability
- Effect on: water temperature
  algae growth
  mosquito breeding
  quality of water
- Durability
- Wind effect on Styropor layer
- Economy considerations
- Summary and conclusions

APPENDIXES. . . . .

I. Meteorological data recorded at site during study 125

II. Meteorological data in six cities in the Middle East and ten stations in Jordan 137

III. Climatological data in map form on the Red Sea region 155

- Distribution of arid homoclimates
- Mean annual potential evapotranspiration
- Mean annual water surplus
- Mean annual water deficit

LIST OF REFERENCES. 161

INTRODUCTION

1. General:

In many parts of the world evaporation from surface waters often exceeds the amount utilized. This pauses a serious problem in areas where the limited water supplies cannot meet the demands of the users. A possible method of increasing this supply is by conserving the water that would normally be lost by evaporation.

Most arid zone problems are associated with water shortage. The fact that the underground waters, when found, are often too saline to be of use serves to aggravate the situation still further. Often a paradoxical situation occurs in many a developing country with arid climatological conditions where water scarcity and acute water needs coexist. This is unfortunately the case throughout the Middle East and other arid regions in the world. It cannot be overemphasized that the socio-economical progress in such developing countries, which include the Arab states, is largely dependent on the availability and proper utilization of the natural water resources.

It should be the policy of any country that suffers from water shortage to formulate a master plan for the development and conservation of its water resources. Water problems are now being solved by modern technology and the adoption of comprehensive water policies. The essential measures adopted may include: watershed management, river regulation practices, tapping ground water aquifers, control of evaporation from exposed water surfaces, saline water conversion and even waste water reclamation and use. Of these measures, evaporation control has gained wide acceptance as it has been shown to be practicable and economically feasible.

Water loss resulting from evaporation from exposed water surfaces is substantial and exerts a serious drain on the available water resources. This loss would be significantly greater in magnitude and consequences in the arid zones of the world in which unfavorable climatic conditions--insufficient and seasonal rainfall--are accompanied by conditions favouring high water evaporation. It is surprising that such situations are not readily appreciated even by those countries having acute water shortages. In the desert area south east of Amman in Jordan, for instance, the yearly water evaporation losses may amount to two meters, and this value is probably exceeded in other areas. In fact, the entire Middle East region, being hot and arid, is subject to substantial water losses by evaporation. Water evaporation control is of practical value in this and other regions having 200-300 cloudless, dry days per year with an average daily solar radiation of about 2000 BTU/ft^2--a condition that generally prevails in most of the Arab states.

The fact that large bodies of surface water do not generally exist in the Middle East may be utilized as a basis for waiving the suggestion. But it must be remembered by those involved in water resources management that the overall water evaporation loss from small reservoirs, farm and ranch ponds, and oasis scattered throughout a given arid country cannot be overlooked and, in fact, merit serious consideration. Moreover, water development schemes aiming at impounding waterare becoming an extremely popular practice in this region. Fairly large man-made lakes and reservoirs are no longer an uncommon sight in this area, for some are already in existence while others are projected for construction in the near future. This is the case in Lebanon, Syria, Jordan, Iraq, Iran and Egypt.

Water evaporation control is not a new concept for it has been practiced for a number of years in a variety of ways such as roofing and minimizing the exposed surface area of the stored water. A more recent development[1] involves the application of small quantities of certain long chain organic alcohols that float on water forming extremely thin layers--monomolecular in thickness; hence the term monolayer. The most effective alcohols utilized for this purpose are hexadecanol, commonly known as cetyl alcohol, and octadecanol. Mansfield of Australia[2] was the first researcher to investigate the field application of this technique. In the light of his experiences and encouraging results, researchers in the United States of America soon followed suit. However, inspite of the somewhat fruitful efforts, this technique has its own limitations which must be overcome prior to its wide acceptance. Among the more serious limitations are the lack of reliable methods for applying and maintaining a monolayer[3]. A more recent approach investigated in a preliminary fashion at the American University of Beirut by Acra <u>et al</u>[4]., from May 10, 1962 to October 20, 1963, involved the application of floating layers of white plastic particles

(Lupolen and Styropor)* on water contained in vessels. The satisfactory preliminary results yielded by this investigation prompted the initiation of two other interrelated projects: firstly, the one conducted by the writer from July 31 to October 15, 1964, and which constituted the subject of this presentation; and secondly, the one conducted by Acra et al.[5] from July 22, 1964 to date. The latter two projects followed the first one as a natural order of sequence, and were intended to evaluate the feasibility of utilizing Styropor, which had proved to be the best variety of plastic materials experimented with, on a larger and more comprehensive scale as a water evaporation suppressant.

2. Purpose and Scope:

The most important considerations that have prompted the initiation of this study on the use of Styropor beads for the control of evaporation are:

(a) The need to confirm the preliminary studies carried out previously at the American University of Beirut[4] regarding the use of this material for water evaporation control, and to provide further background data essential for the field studies conducted on several ponds in Lebanon[5] prior to the acceptance of Styropor beads as a suitable and effective water evaporation suppressant.

(b) The need for water conservation by evaporation control measures throughout the Middle East and other arid regions of the world.

---

*Manufactured and patented by Badische Anilin and Soda Fabric AG, Ludwigshafen Am Rhein, West Germany.

(c) The serious limitations imposed upon the use of monolayers of the long chain alcohols in the control of water evaporation.

The experimental work in this study was designed to permit investigation of the use of heat-expanded Styropor beads in small reservoirs under field conditions in order to provide the following information:

(a) The establishment of the optimal and most economical dosage of Styropor beads required to reduce water evaporation effectively and the assessment of the water savings yielded.

(b) The determination of the comparative effects on water evaporation suppression by the Styropor beads and hexadecanol monolayers, and the advantages of each.

(c) Cost analysis of the water savings yielded by the water evaporation retardants in question.

(d) Study and evaluation of the comparative effects of Styropor and hexadecanol monolayers on water quality, with particular emphasis on gas transfer.

(e) Observation of some side effects of Styropor layers covering exposed water surfaces, namely, algae growth and mosquito breeding.

(f) The study of the behaviour of Styropor layers floating on water surfaces under different wind velocities.

CHAPTER I

WATER CONSERVATION

In most parts of the Middle East, the source of water which is available and mostly used is the natural precipitation and the runoff water derived thereof. Since the pattern of natural precipitation and consequently of runoff is both fluctuating and variable, the need to impound water for long periods of time is apparent. Furthermore, due to the long established observation that the variability of the available water increases with aridity, the need for water conservation is most marked in the more arid parts of the region.

Even in the more fortunate parts of the Middle East, where large rivers flow through arid regions such as Egypt and Iraq, there is also need for storage reservoirs. These could be used to control floods, to conserve water for future use, and to regulate river flow. In view of the prevailing aridity, conservation storage in which water is impounded for later release as required for some beneficial use such as municipal supply, power, or irrigation, is one of the most important functions of a storage reservoir.

The demand for pure water is increasing, and is bound to become more pressing as population continues to increase and as the standard of living is improved. More water is needed to supply newly established as well as expanding industry and agriculture.

Water supply has become a critical factor in public health and economic development in most parts of the world, particularly the developing countries. Deficiencies in water supplies create conditions that endanger public health and have adverse effects on the economic progress in a country.

In many parts of the world, among which are the countries of the Arab Middle East, special schemes which are directly concerned with helping nomads to lead a sedentary life, or at least a less nomadic one, are being contemplated. Such schemes aim at providing water to satisfy the nomad needs for domestic use, animal watering and, to some extent, agriculture. This could be done in certain localities by impounding the runoff water resulting from the scant rainfall in arid areas or by tapping fresh underground aquifers if available.

Since the available water resources in any locality remain basically the same and cannot be increased, they should be properly controlled and be made available for use by man at the proper time and in the most effective manner.

The use of impounding reservoirs, whether for river regulation or for storing runoff water has become an integral part of almost any water resources programme. It is important to note that although reservoir storage can stabilize the water supply, it can be shown that complete stabilization and utilization of all the available water is not attainable. As reservoir capacity, and hence the water surface, is increased to achieve greater control and utilization, a corresponding augmentation in water evaporation losses would be the undesirable result. Actually water loss by evaporation imposes a ceiling on water resources regulation in an arid zone.

It is of special interest to note that while arid zones are characterized by the large proportion of the water that leaves the system as vapour, yet most uses by man in the arid zones have been of a kind that converts water to atmospheric vapour--mostly irrigation of crops. Thus the nature of water use in the arid zone aggravates the chronic shortage of water, in contrast to the zones of water surplus or the humid zone, where the dominant uses of water are of a nonconsumptive kind and water is often reused.[6]

Loss of water by evaporation is a consequent tax on water storage in reservoirs. This evaporation loss assumes greater importance and proportion in an arid zone. This is because net evaporation (gross evaporation minus precipitation) increases with aridity, and because the need for hold-over reservoir storage also increases with aridity.

Since water losses by evaporation set a definite limit on the effectiveness of a reservoir and contribute substantially to water shortages in areas that are in need of whatever water is available, methods of abating evaporation have a great potential economic value.

Significance of Evaporation

The process of evaporation of water is of fundamental value to life. Evaporation of water, chiefly from the ocean surfaces, replenishes the moisture in the air. Due to the circulation pattern of the earth's atmosphere, this moisture is transported over the earth's surface to fall as precipitation. However, when a decision is made to impound water on land surfaces in reservoirs and lakes, the process of evaporation becomes a problem.

Garstka[7] states that it has been observed for a long time that a major, or at times a total, depletion of the water supply in a drainage basin may result from evaporation losses. Thought could be given to closed basins such as the Great Salt Lake in the United States or the Dead Sea in Jordan, to appreciate such facts.

When water evaporates from a water surface, the dissolved solids, the salts and the hardness causing compounds remain and serve to reduce the quality of water still in storage. Hence the process of evaporation reduction takes on added importance, since the amount of water saved by evaporation reduction practices is equivalent to pouring the same volume of "distilled" water back into the drainage basin.

Evaporation loss from a large reservoir can be tremendous, particularly if such a body of water exists in an arid zone. A thorough study of evaporation loss volume was presented by Meyers[8]. His estimate of the annual evaporation loss from the fresh water areas in the 17 western states of the United States of America was 23,641,000 acre-feet (23,641,000 x 1233.49 = 3,156,073,500 m^3). The importance of this loss in the U.S.A. can be envisioned when one considers the following rule of thumb: an acre-foot of water, on the average, satisfies the municipal and industrial demands of four people for a year.[7]

It is estimated that the annual evaporation loss from Lake Tiberias in the Jordan rift valley in northern Palestine is 300 million cubic meters--an amount slightly less than the combined annual inflow from the two rivers: Hasbani and Banias.

The lake that will be formed upstream from the High Aswan Dam (Sad el-Aali) in the United Arab Republic will have a surface area of about 5,000 square kilometers. This lake is located in an arid region and it is of interest to note that the estimated evaporation loss from this lake will be about 10 billion cubic meters per annum[9]--an item of substantial importance.

CHAPTER II

THE EVAPORATION PROCESS

Evaporation is the process by which a liquid is changed to vapour or gas. Hydrologically, it is the process by which the precipitation reaching the earth's surface is returned to the atmosphere as water vapour. The combined evaporation from water, snow, and soil surfaces, including evaporation of intercepted precipitation and transpiration from vegetation is termed total evaporation or evapo-transpiration. This is an important phase in the hydrologic cycle.

A clear explanation of the evaporation process mechanism is given by Meinzer[10]. He states that the rate at which water particles may leave the water surface and enter the adjacent air depend upon the heat supply of the water and the condition of the air. Water is continuously leaving the surface of a water body in the form of water vapour. If the air above the water is still and saturated, it cannot retain additional moisture and the water particles return to the water surface. While if the air is in contact with the water is not saturated or is replaced as it approaches its vapour-holding capacity, the rate of evaporation is determined by the heat supply available to produce evaporation.

Water vapour may be removed from a water surface by diffusion, by convection or by wind action. Diffusion is continuous whenever the vapour pressure of the air over the water is below that corresponding to the temperature of the water at its surface. Convection occurs when the water is warmer than the air; the heating of the air in contact with the water causes upward wind movement. Such removal of vapour by convection would occur in still air; but as still air seldom occurs on fully exposed water surfaces, vapour removal by convection is usually combined with removal by wind action. Vapour removal by wind action is most active when wind movement is turbulent. Fully laminar wind movement over large water areas would not change the character of air in contact with the water.

Factors Affecting Evaporation

Evaporation is related to differences in vapour pressure at the water surface and the air above, air and water temperatures, wind, atmospheric pressure and quality of water.[11] Some of these factors are themselves interrelated.

A. Vapour Pressure Differences:

The rate of evaporation depends on the difference between the vapour pressure of the water "e_w" and the vapour pressure in the air "e_a" above the water surface. In other words, it depends on the difference between the saturation vapour pressures at the water temperature and at the dew point of the air. Evaporation is proportional to $(e_w - e_a)$ and continues until $e_a = e_w$.

When the air is warmer than the water, its saturation vapour pressure "e_s" is greater than that at the water surface (i.e. $e_s > e_w$) and evaporation continues until $e_a = e_w$. This will occur before the air becomes saturated.

However, if the air is colder[12] than the water, then $e_s < e_w$; evaporation results and when equilibrium conditions ($e_a = e_w$) are reached, a state of supersaturation ($e_a > e_s$) will exist, or condensation will take place in the air.

Since condensation nuclei are generally present in abundance the superfluous vapour usually condenses into fog. However since the air is heated from below by the warmer water, it tends to be unstable and hence the tendency for the fog to be dissipated by convection. This probably accounts for the fact that evaporation has been observed to be at a maximum when the water was warmer than the air[13] and suggests the possibility that winter evaporation losses may be high.[14]

B. Temperature:

The rate of emission of molecules from liquid water is a function of its temperature--the higher the temperature, the greater the energy of the molecules and the greater the rate of emission. Experiments with heated water show that evaporation does increase with the temperature of the water surface.[15] This is a direct result of the increase in vapour pressure with temperature.

C. Wind:

Since turbulence varies with wind speed, there must necessarily be a relation between evaporation and wind movement[13, 16]. Experimental data have not yet disclosed the exact nature of this relation. It is commonly believed that the effect of increasing wind speed on water evaporation decreases as some high value is approached. This effect probably depends on surface roughness and the dimensions of the water body.[11]

D. Atmospheric Pressure:

The number of air molecules per unit volume increases with pressure. Consequently, with high pressures there is more chance that vapour molecules escaping from the water surface will collide with an air molecule and rebound into the liquid. Hence evaporation would be expected to decrease with increasing pressure.[11] It is important to note here that changes in other meteological factors accompanying pressure changes at a station generally cancel the effect of pressure.

E. Quality of Water:

The rate of evaporation is less for salt water than for fresh water and decreases as the specific gravity increases.[17] The evaporation rate decreases about 1 per cent for each 1 per cent increase in specific gravity until crusting takes place, usually at a specific gravity of about 1.3.[11] Evaporation from sea water has been estimated to be about 2 to 3 per cent less than from fresh water when other conditions are the same.[11]

F. Solar Radiation:

Since direct solar radiation is a source of heat supply it is an important factor in the evaporation process. Hence, evaporation varies with latitude, season of the year, time of the day and sky condition.

Measurement of Evaporation

Direct measurement of actual evaporation from a water surface is the most simple and accurate means of its determination. The direct determination of evaporation from a watertight reservoir requires measurement of all elements of inflow and draft, with the unaccounted difference assigned to evaporation. This method has been used for the measurement of evaporation in the present study.

However, in natural and man-made lakes and reservoirs, though inflow and outflow could be measured correctly in most cases, it is difficult to measure seepage accurately. Errors resulting from the measurement of seepage and other losses, such as the consumptive use of shoreline vegetation, may greatly affect evaporation loss measurements. Hence the above mentioned direct method is rarely satisfactory. Consequently measurement of evaporation has been restricted to the use of instruments, known as atmometers, which measure the evaporative power of the air rather than the actual evaporation[11] from a specific water surface. Corrections are then applied to adjust the evaporative power to the actual evaporation from a specified surface.

Atmometers are divided into three groups:

1. Tanks and pans.
2. Porous porecelain bodies.
3. Wet paper surfaces, e.g. the Piche atmometer.

Furthermore, evaporation formulae based on theoretical considerations of energy exchange or empirical relations developed by correlation of atmometer data with weather elements, were developed to give evaporation rates. These in general are subject to certain limitations. Presentation and discussion of such methods is beyond the scope of this paper, especially since none of these methods was employed in the investigation. Linsley[18] gives a thorough discussion on the most widely used ones.

Control of Evaporation

Any steps which can be taken to reduce reservoir evaporation per unit of storage provide a corresponding increase in usable water supply. Realization of the tremendous evaporation losses from impounded waters has led to considerations of various protective measures. A number of approaches have been either applied, or considered, by engineers in their attempts to reduce reservoir evaporation losses. Some protective measures, given by Garstka[7] are the following.

1. Construction of storage reservoirs at the highest available altitudes.

It has been generally observed that evaporation loss is reduced with increase in elevation above sea level. At such localities a number of phenomena are at work. On the one hand, the reduction of surface water temperature might be accompanied by a decrease in the dew point and hence in evaporation. Wind and solar radiation may vary greatly. However, there is increasing evidence generally to the effect that higher altitude reservoirs lose less water per unit of surface than do reservoirs in lower altitudes.

Such a measure, however, can be applied only in the planning stage of a water resources development program or its extention and cannot remedy an existing situation in an operating system.

2. Shaping the reservoir.

Reservoirs impounded by a topography consisting of vertical sides and flat bottoms, with a small area exposed to the air in proportion to their capacity, would evaporate less than reservoirs in which a comparable storage volume is spread in a shallow layer over a much greater area. In river systems originating in the mountains, the choice of a reservoir site to keep the exposed surface at a minimum is often available to the engineer.

3. Improving existing or potential reservoirs by reduction of surface area.

The construction of dikes to cut off shallow areas saves evaporation losses by reducing the total exposed areas. Such a measure may also be very useful by disposing the relatively stagnant and shallow water in a reservoir. The surface water temperatures of such shallow areas tend to be much higher than those of over the remainder of the reservoir. This practice may result in a greater evaporation saving than that indicated by a comparison of the ratios of the surfaces.

4. Modification of reservoir and river regulation practices.

In a reservoir and river system consisting of both high and low altitude reservoirs, it might be possible to operate the system so as to present the least exposed water surface, for the system as a whole, during the seasons of high evaporation loss. If hydroelectric generation is a part of the system, special care will be needed to be exercised in order to maintain efficient generating heads at power plants.

5. Covering the reservoirs either with fixed or floating covers or roofs.

In certain chemical industries it is the practice in dealing with certain materials to reduce evaporation loss by the floatation of particles of various plastic materials. Evaporation losses of crude oil have been reduced by 70 per cent through the use of a 1-inch floating layer of microscopic-sized plastic spheres.

6. Protect reservoir surfaces with windbreaks.

The effectiveness of a windbreak is primarily the result of the reduction of wind turbulence and total wind travel over the protected area. An effective windbreak must present a relatively impenetrable barrier to wind from ground level upward. Tall trees with many limbs growing around the trunk all the way from ground level were the most widely used form of protection. The potential user, however, should keep in mind that the vegetation will require a certain volume of water to satisfy the evapotranspirational requirement of the site the windbreak occupies. This water requirement, or loss, must be subtracted from whatever saving that may result.

7. Store water in ground-water reservoirs.

Of all the techniques available to the engineer and water resources developer for reducing evaporation loss, this method is the best, provided that the geology of the area is such as to offer true carry over storage in ground water reservoirs. Another complication is that unless there is a clear-cut delineation of the location and storage capacities of the ground water reservoir, it might not be possible for the engineer to withdraw water when needed.

Taking into consideration the confusing legal situation prevailing with regard to ground water ownership in most parts of the world, it is but seldom that the engineer, who has stored the water in underground water reservoirs, retains ~~little~~ title to it. There is also the added consideration that infiltration works and injectors might be necessary to place the water in ground water storage and pumps may be needed to withdraw it to meet demands.

8. Use of surface films.

Of all the techniques to date, the use of surface coverings of molecular films seems to offer the greatest promise. These consist, chiefly, of monomolecular layers of fatty alcohols and their chemical relatives. However, reliable methods for applying and maintaining a monolayer on an open surface of water have not been developed.[1] Further discussion on this type of treatment will follow in Chapter III.

Other practices of reducing water loss in reservoirs include the following:

9. Discharge of warm surface water.

In deep reservoirs, summer water-surface temperature may be several degrees above that of the bottom. If a dam is designed to permit discharge of warm surface water, evaporation will be less than if the colder water is discharged.

10. Removal of phreatophytes.

Phreatophytes are non-beneficial water consuming plants and are generally regarded as a nuisance.[19] These will be found mostly in the shallows and along the shoreline. Their removal results in great saving in lost water. Before they are removed the possibility of increased erosion should be considered as well as whether costs of removal and possible hazards to aquatic life and ecological balance of the reservoir or lake are justified by the savings.[20, 21]

CHAPTER III

EVAPORATION CONTROL BY THE APPLICATION OF MONOLAYERS

Historical Development:

The idea that the rate of evaporation of water could be suppressed by the application of a film of an oily substance is a very old one. However, the cost of applying a film thick enough to be effective on a large body of water impeded serious consideration of such a treatment for a long time.

In 1765 Benjamin Franklin, from experiments on the spreading of oils on a pond at Clapham, England, made a rough estimate that the thickness of the film must be of the order of 25 Angstrom Units (25×10^{-8} cms). This was done more than a century before the development of molecular theory and before any estimates of Avogadro's Number (6.03×10^{23} molecules/mole) had been made.[1]

The discovery that certain chemicals spread spontaneously on water surfaces to produce a film only one molecule thick--a monolayer, gave a new impetus to practical considerations.

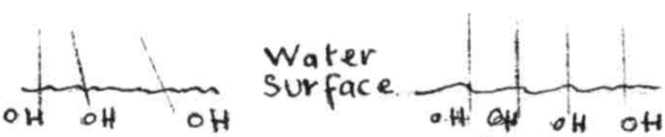
Extensive research concerning the choice, characteristics and behaviour of monolayers as well as the determination of their evaporation suppression ability was conducted in various countries during the first half of this century. This was done mainly in laboratories but the knowledge gained in this respect warranted field application. To William Mansfield[19] of Australia goes the credit of having been the first (in 1953) to demonstrate the ability of monolayers of specific compounds to reduce evaporation on open reservoirs in the field.

Laboratory and Field Studies:

The evaluation of the evaporation-reduction ability of monolayers has been studied in class A pans. Many chemicals have been screened[22] for their ability to decrease water losses due to evaporation. The most promising chemicals for field studies were cetyl alcohol and stearyl alcohol, or a mixture of the two.

Cetyl alcohol, known technically as hexadecanol, and represented by the structural formula ($C_{16}H_{33}OH$) has the characteristic of spreading spontaneously on water surfaces. Stearyl alcohol, known as octadecanol ($C_{18}H_{35}OH$), does not spread on water easily, but a mixture of the two does, since it has been demonstrated that the shorter chain carries the longer chain along over the water surface.

Monomolecular films have general properties that make their use as evaporation retardants desirable. They consist of films that are one molecule thick. The film has a low water solubility and is formed by long molecules aligning themselves, when the film is compressed, in an erect position side by side, with the hydrophyllie end of the molecule (OH^-) dipped into the water and the hydrophobic end out of the water.



(a) Uncompressed film (b) Compressed film

Straight Chain Primary Alcohols

Figure (1). Monolayer with effects of molecular structure on compressibility of films.[1]

Preliminary analysis of the evaporation-reducing ability of monolayers in class A pans revealed some important points:[23]

1. All monolayers of commercial C_{16} -C_{18} fatty alcohols exhibit a temperature effect. An increase of water surface temperature is accompanied by a decrese in savings. For example, one material produced savings of about 75% at 55° F, and about 58% at 85° F. The decrease in effectiveness with increasing water surface temperature does not follow the same relation for each material.

2. Available data indicate that the presence of octadecanol tends to decrease the influence of temperature on evaporation reduction.

3. Products with some octadecanol generally show a better ability to reduce evaporation.

Longer chain compounds, including octadecanol, could be spread on water as monolayers by applying them as a solution in a volatile solvent such as benzene. It was demonstrated, however, that benzene molecules are trapped in the monolayer and do not evaporate completely.[1] Petroleum ether, which has a lower boiling point and is more chemically inert, when mixed with octadecanol evaporates more rapidly and completely leaving only the monolayer.

As a result of laboratory investigations, the straight chain primary alkanols were found to be the most suitable for forming effective evaporation retardant films.[24] When adequate chemical is dispersed on the water surface it forms a compressed layer which is required for an effective evaporation control. Compressed films of the long chain alcohols exert an equilibrium pressure of 40 dynes/cm--a condition that affords maximum resistance to the escape of water molecules from the water surface and into the atmosphere.[23]

Theoretically, a quantity of 0.02 lbs. (9.08 grams) of monomolecular layers such as hexa or octadecanol is required to produce a compressed film on 1 acre (4047 m^2) of free water surface. Franzini,[25] working on pan tests at Stanford University, noted that an initial hexdecanol dosage of 3 lb. per acre lost its effectiveness in about six days. That indicated that the rate of bacterial attrition may have approached 0.5 lbs/acre/day. Applying a small dosage of 0.3 lbs/acre/day gave much better results than the application of one large initial dose. In practice the daily amount of a monolayer to be applied varies depending upon prevailing conditions but is generally about 0.3 lbs/acre/day.

As a means of field identification of a monolayer on a water surface a set of calibrated indicator oils was developed. Timblin,[23] states that these oils consist of a solution of a light mineral oil and dodecanol. The spreading pressure of the indicator oil is dependent upon the relative proportions of the oil and dodecanol. It was demonstrated that the spreading pressure of the indicator is proportional to the logarithm of the concentration of the dodecanol. Using a set of calibrated indicator oils in steps of 5 dynes/cm from 5 to 40, the film pressure over a water surface could be determined within ± 5 dynes/cm. Since, compressed monolayers on a water surface have a film pressure equal to, or greater than, 40 dynes/cm, the presence of a monolayer and its degree of compression can be determined.

Field studies of monolayer application and peformance were conducted by various research organizations. The most notable work was conducted by the Bureau of Reclamation, United States Department of the Interior.[23] The Texas Water Commission[24] and the universities of Arizona, Stanford and Utah have also contributed to such studies.

Field investigations show that a chemical film travels approximately 3.4 feet for each 100 feet of surface wind travel.[24] The form in which a monolayer may be applied depends upon the size of the reservoir, since application methods for pans or small reservoirs differ entirely from those for large reservoirs. Whereas a hot spray of the molten chemical could be applied to a large reservoir through a nozzle from a raft, a power boat or even an aeroplane crusing at low altitude, the equipment involved makes it uneconomical for small reservoirs. Powdered hexdecanol or a solution of the chemical to be applied may be delivered to small reservoirs and ponds by hand or by means of a number of dispensing units, with valves operated by wind action, installed around the entire shoreline.[24]

Investigations of various techniques of monolayer application were performed, by the Bureau of Reclamation, U.S. Department of the Interior, at Rattleshake Reservoir (100 acres), and Ralston Creek reservoir (150 acres).[23] The results of these investigations led to the development of a method of applying from a boat a water slurry of powdered hexdecanol. This technique was tested at Carter Lake (1000 acres) and used at Lake Hefner (2500 acres).[26]

Monolayer behaviour studies were performed at the Boulder Basin of Lake Mead (40,000 acres) and Sahuro Lake (1000 acres). The spraying of melted alcohol and the application of powdered material were used there.

In 1958 beginning with the well known Lake Hefner experiment,[26] the application of monolayers as a practical field method for the evaporation suppression in large bodies of water acquired a new momentum. It was reported by the collaborators that the study demonstrated that an evaporation reducing monolayer could be applied and maintained over a free water surface, under field conditions, for an extended period of time.

Evaluation of the Use of Monolayers:

The results of laboratory and field application of monomolecular layers generally demonstrate a reduction in evaporation. This reduction varies through wide limits but field savings are much lower than those obtained in the laboratory.

The Lake Hefner experiment, conducted from July 7 - Oct. 1, 1958, is one of the most comprehensive investigations to date on the use of monolayers for evaporation reduction. An evaluation of the practical aspect of the use of such chemicals could be achieved by reporting findings of the collaborators,[26] in the evaporation reduction investigations in Lake Hefner.

1. Application:

Commercial high grade hexdecanol was used.

Composition: 90% Hexdecanol
4% Tetradecanol
2% Octadecanol

Over all average applications were 0.3 lb/acre/day. Applications, weather and other conditions permitting, were made during daylight hours 7 days a week. This was done by pumping a water slurry of finely divided powdered hexdecanol from a moving motorboat or platform, upwind, so as to take advantage of the wind in spreading the film and to maintain maximum possible coverage.

2. The techniques developed by the Bureau of Reclamation were available to cover the area of Lake Hefner (2500 acres) with a compressed layer of hexdecanol, under favourable meteorological conditions.

3. The data needed to evaluate the savings in evaporation, obtained by the U.S. Geological Survey, showed that during the period of treatment 7 July to 1 October 1958, an overall reduction in evaporation of slightly more than 9% was achieved. It was indicated that weather conditions were not favourable for maintaining the film. For individual computation periods of about 10 days, the savings in evaporations losses ranged from 7% to 14%.

4. Wind had a very pronounced effect on the monomolecular film behaviour. Poor coverage was usually obtained with winds greater than 15 miles per hour, and any coverage was usually impossible with wind velocities over 19 miles per hour.

The maximum coverage at any time was 89%. The average coverage for the entire duration of the experiment of 86 days was 10%. For the 55 days in which the film was applied the average coverage was 16%.

5. The effectiveness of the monolayer is reduced at higher temperatures. The 9% saving achieved is reported to be one quarter of the

potential reduction with the kind of material used at Lake Hefner and at the temperatures experienced.

6. The concentration of microorganisms normally present in the lake waters increased markedly. This was a result of feeding on the hexadecanol film applied. However, the purified water met Public Health Service drinking water standards.

7. No hexadecanol was detected by the Public Health Service in the water reaching the inlet of the Oklahoma water supply, of which Lake Hefner is a part.

8. The hexadecanol used was proved not to be injurious to bird, fish, animals, marine or plant life. When used in the concentrations and in the manner appropriate for evaporation control, hexadecanol does not alter the potability, mineral content, taste, odor or color of the water. It does not impair normal gas transfer into and out of the water.

9. The application of the monolayer saved water in Lake Hefner at a cost of about \$60/acre-ft. This was about the same as the value of untreated water in the lake.

Break down of cost:

Materials: 74%

Equipment: 10%

Labour: 16%

The report of the collaborators in the Lake Hefner evaporation reduction investigation[26] notes that, based on discussions with manufacturers' representatives, it was anticipated that material costs may be reduced as much as 50% of the cost already paid (51.5 cents per pound).

Furthermore, improved techniques, both in manufacture and field application of hexadecanol, could be expected to further reduce these costs.

Recent research on evaporation suppression by monolayers indicates that savings decrease with an increase in water surface area. Observations on pans and in small reservoirs[24] show reductions of 40-50 per cent, on small lakes (say from 1 to 100 acres) of 20-40 per cent, and on larger lakes or reservoirs of 10 per cent.[6]

Meinke and Waldrip[24] indicated, as a result of research conducted on evaporation reduction in small reservoirs, that a cost of $1.00 per 1000 gallons (i.e. $43.00 per acre foot) of water saved was realistic for the fractional acre pond up to $\frac{1}{2}$ acre. They indicated further, that as pond size increases to 2 or 3 acres the cost of water saved will vary from 50 cents to a minimum of 20 cents per 1000 gallons of water saved.

Limitations of Monolayer Use:

Though the application of monolayers for water evaporation reduction has gained popularity in the last decade, yet researchers in this field have pointed out certain limitations that could impair the usefulness of these monolayers under field conditions. The most relevant of these limitations are given below.

1. The effectiveness of a monolayer is reduced due to the presen~~t~~ce of molecular holes that arise from:

    a) incomplete evaporation of solvent in case it is used, and

    b) improper film application.

The resultant reduction in monolayer effectiveness is far more than the relative percentage of molecular holes would indicate.[1]

2. Monolayers will readily collect hydrophobic dust.[1] This dust reduces the effectiveness of a film because it impairs its mobility and hence coverage.

3. Wind exerts a very pronounced effect on a monolayer. Though it helps to spread the film when wind velocities are low, any coverage at all becomes impossible at high wind velocities.[24, 26] In large scale experiments such as the one conducted at Lake Hefner, the average coverage was only 16 percent for the 55 days in which the film was applied.[26] In small scale experiments,[24] it was found necessary to install a number of simple chemical dispensing units, with valves opened and closed by wind vanes, around the entire shoreline of the reservoir in order to approach complete water surface coverage by the film--a rather costly solution for small reservoirs.

4. When the monolayer becomes decompressed, it loses its ability to reduce evaporation.[26] A monolayer film on a water surface can be decompressed in three ways:

  a) When the compressing force, usually the wind, becomes very little or zero.

  b) When the surface area of a lake or reservoir increases as a result of wind action.

  c) When some of the chemical molecules leave the layer by evaporation, solution, biological attrition or suspension in the water.

A seven per cent increase in area per molecule will reduce the film pressure to less than 10 dynes/cm.[27] This would result in reducing the effectiveness of the film by 80 percent.[26]

5. The monolayer application needs great attention as far as the rate of application and the technique used are concerned. Fully automated equipment might be necessary, skilled labour and strict supervision are needed.

6. Some restraining agent is required, usually the shores of a lake or an impounding reservoir. Continuous source of replacement for film losses is needed especially in large reservoirs. Replacement of the film should be best made from the up wind side.

7. In practice it is necessary to identify the film in order to determine its presence or loss. Field identification of the monolayer film on the water surface is not direct. When indicator oils are used the process becomes expensive and laborious, and the results subject to errors in measurement of film pressure unless the undertaker is an experienced one.

8. It has been demonstrated that the monolayer is consumed rapidly as food for bacteria.[25, 26] This necessitates continuous replacement on large reservoirs and daily replacement on small ones. The result is an increase in cost of water saved.

9. At high temperatures the effect of the monolayer is reduced.[26] No definite information yet is available regarding the range of temperature within which a monolayer could be applied for water evaporation suppression for economic advantage.

In many areas in the world, especially the arid zones, high temperatures are experienced during long dry summers. This is bound to reduce the effectiveness of a monolayer and consequently the saving in water would be decreased appreciably in the season of high water evaporation losses.

10. Desert areas, where the need for water conservation is most vital, experience frequent sand storms which may impair the effectiveness of the monolayer.

11. The cost of equipment involved in monolayer application and the supervision needed make such a treatment on small isolated reservoirs and farm ponds is economically prohibitive.

12. The amount of the savings realized by the monolayer application do not appear sufficiently large to make it attractive everywhere, nor so small that it can be ignored.[6] Considerable research is still needed to improve methods of applications and to define the field conditions under which the technique is economically feasible.

CHAPTER IV

ARAB MIDDLE EAST CONDITIONS

In general the Middle East is a region of high water evaporation and low rainfall (see Maps 1-4, Appendix III).[30] The region suffers from a chronic water shortage while tremendous amounts of badly needed water are lost annually by evaporation from natural and man-made reservoirs and lakes. Water losses by evaporation range from about 1.2 meters per year in the belt bordering the Mediterranean Sea to more than 2 meters per year from inland water surfaces bordering the desert, where low humidity and high temperatures are experienced during the long dry summers (see Map 1, Appendix III; and Tables 1-16, Appendix II).[29, 30, 31]

In most parts of the area the only source of water is the natural precipitation, and the runoff water derived therefrom. A study of the remnants of the ancient agricultural systems of the Nabataeans and Byzantines who populated the desert areas in Southern Jordan and Palestine (the Naqab), at different times, can lead to a great deal of knowledge regarding the utilization of this source of water. Similar agricultural systems, based on the conservation of desert runoff water, are known to have existed from ancient civilizations in the desert areas of Southern Arabia (Yemen) and North Africa.

One of the most important problems in the utilization of desert runoff is how to deal with desert floods and to transform them from a destructive force into a productive one. The writer was acquainted with some desert floods in the southern part of the Hashemite Kingdom of Jordan, where, though rainfall is scant, the limited percolation of water into the soil results in excessive runoff causing sudden tremendous floods in the desert wadis. These great quantities of water are, in most cases, the only available source of water supply. Unless harnessed, they are lost, and all what they cause is excessive damage to property, soil erosion, and even the loss of lives. Various types of dams, terraces, and spillways were and still are the answer to this problem.

Runoff water could be conserved in desert areas in natural depressions, to be utilized where the need for it is greatest. Such water volumes could be put into beneficial use for domestic, livestock and agricultural requirements. Thus substantial economic gains could be achieved by bringing into production additional land areas uneconomically utilized at present, or not used at all.

Considerations for utilizing this source of water are being made by many arid zone countries at the present time.

Beside the economic gain, social benefits may accrue as by products of such schemes. In the Middle East desert areas the settlement of nomadic and semi-nomadic tribes is an expected result.

Various construction schemes throughout the Middle East have proved to be indirect methods of bringing about partial or even complete settlement of nomadic groups in certain instances. Most important of these are the construction of railway lines such as that extending from

Alexandria to the Libyan frontier, from Cairo across Sinai to Palestine, from Damascus to Maan to Medina, and the new railway development in Iraq. Highways also proved useful in this respect. But by far the most interesting development in this direction was that related to the production and transport of oil. Many individuals, including a large number of nomads, are employed in such construction schemes. Railway and oil pumping stations along a route become centers of contact and, with time, develop into public service centers.

Nevertheless, the temporary nature of construction work precludes complete settlement. Soon after construction is completed nomad tribal groups drift in the desert in search of pastures and water for drinking and livestock watering.

Water, therefore, is the most important single factor that determines the kind of life a nomad is forced to live; and water conservation, especially in the desert areas of the Middle East, assumes great importance for evident economic and social benefits.

The Central Water Authority in Jordan has recently started an experimental program for the development of water supplies in the wadis in the desert area south of Amman. The current plan involves the construction of some small dams. First among these are the dams located on Wadi Sultani, Wadi Qatrana, and Wadi Swaqa.[28] It is an objective that the infrequent and meager runoff in the wadis be put into beneficial use for domestic, livestock and irrigation requirements. The area under consideration is a desert where rainfall averages about 100 millimeters per year (see Fig. 2 and tables 1-10, Appendix II).[29]

These reservoirs are located in limestone which is mostly blanketed by silt, consequently reducing leakage potential.[28] The capacities of these three reservoirs are presented below.

TABLE 1

CAPACITIES OF EXPERIMENTAL RESERVOIRS IN THE JORDAN DESERT[28]

Locality	Reservoir Capacity		Drainage Area Km^2
	mcm.	acre-feet	
1. Wadi Sultani	1.2	970	1043
2. Wadi Qatrana	4.0	3240	1500
3. Wadi Swaqa	2.8	2270	458

The greatest loss of water conserved in these sites is that due to evaporation, especially since they exist in a desert region where high temperatures, low humidities and continuous wind action are experienced during long dry summers (see tables 1-10, Appendix II). Furthermore, their location in natural depressions, for economy in construction, with relatively large surface areas and shallow depths tends to increase evaporation losses. Meteorological data obtained by courtesy of the Meteorological Service of the Hashemite Kingdom of Jordan[29] are presented in tables 1 - 10, Appendix II. These include average daily evaporation during each month in 10 selected stations in Jordan. Six of these stations namely Aqaba, Azraq, H_4, H_5, Ma'an and Mafraq encircle the area under consideration.

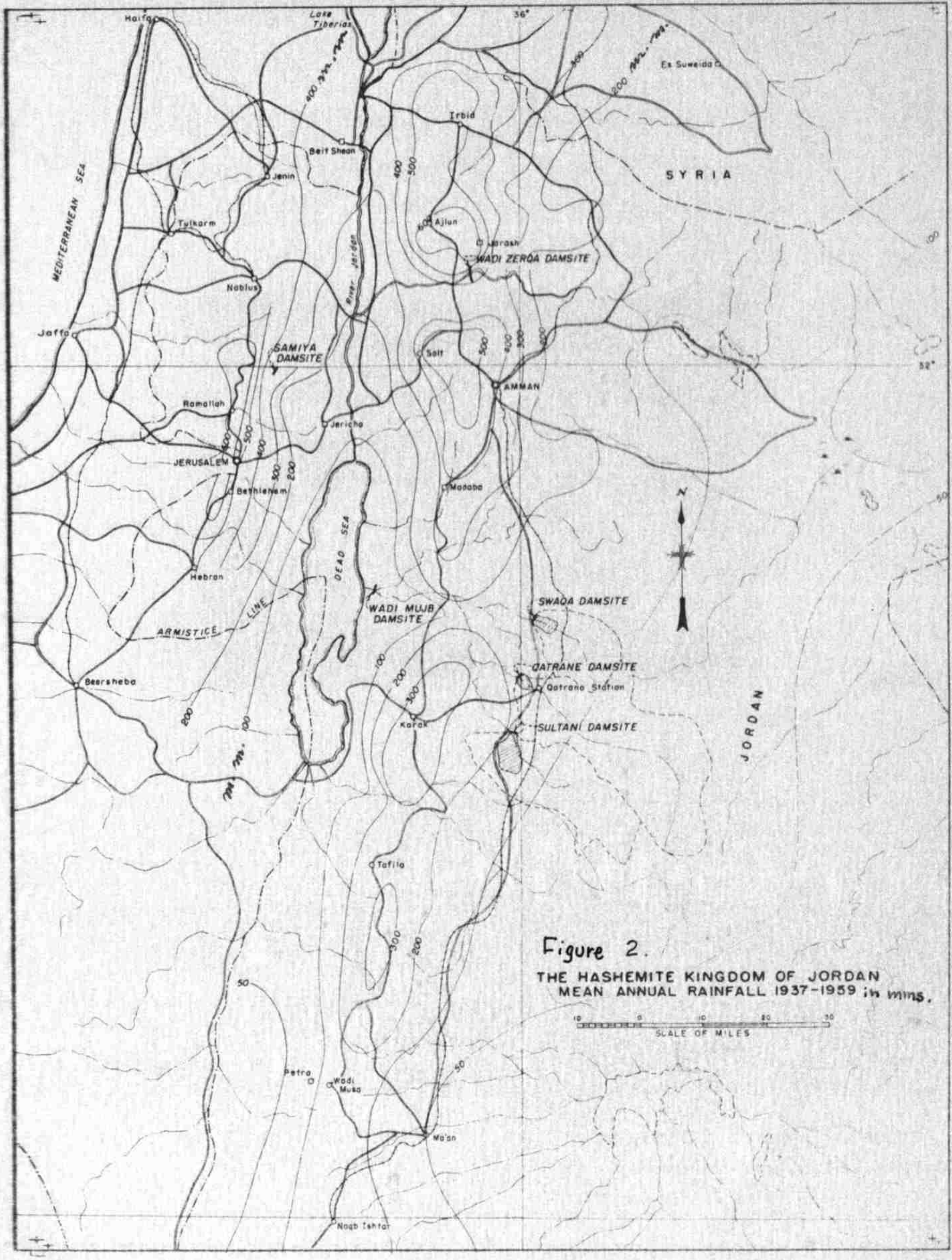


Figure 2.

THE HASHEMITE KINGDOM OF JORDAN MEAN ANNUAL RAINFALL 1937-1959 in mms.

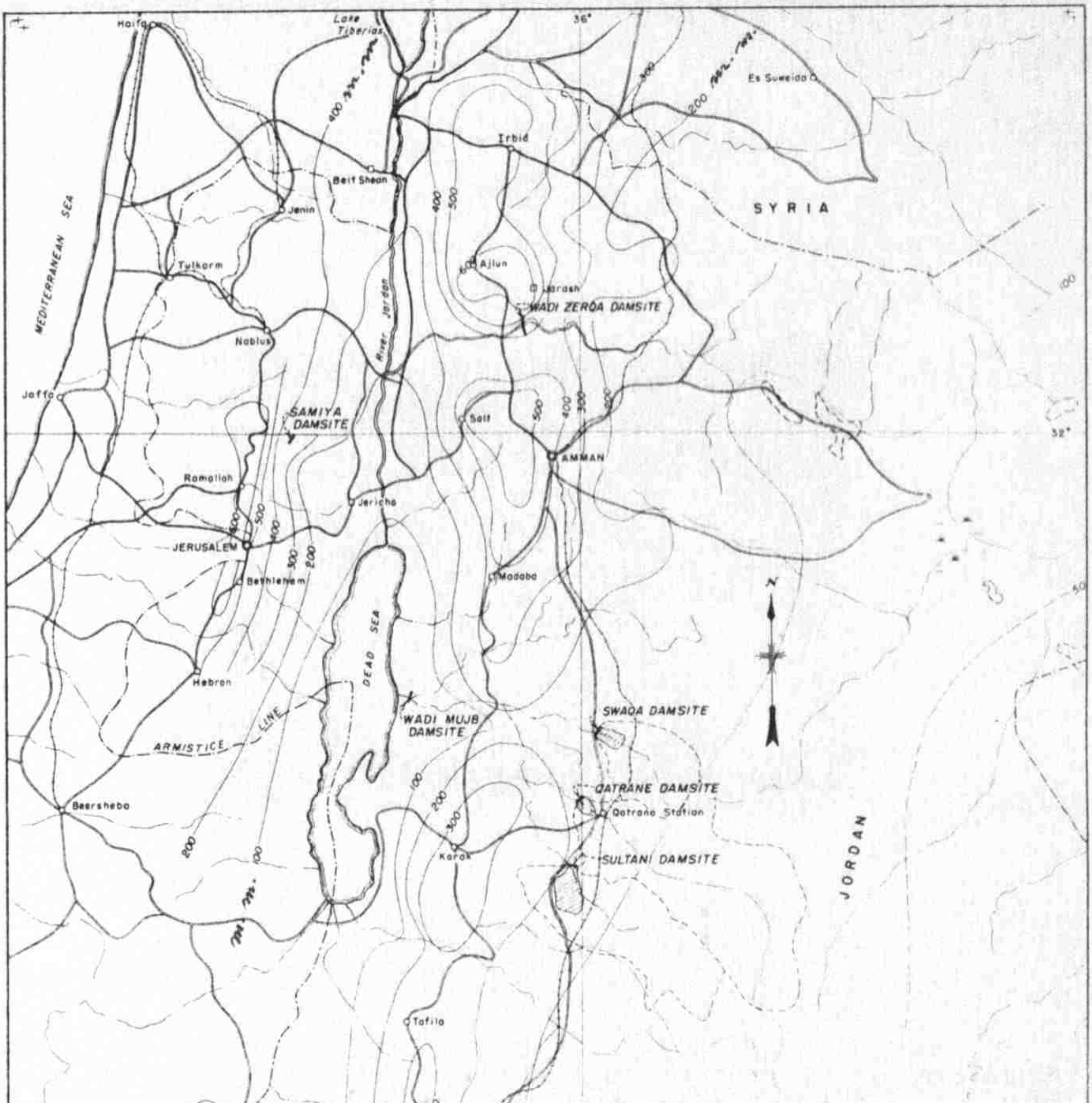


Figure 2.

THE HASHEMITE KINGDOM OF JORDAN
MEAN ANNUAL RAINFALL 1937-1959 in mms.

TABLE 2

AVERAGE MONTHLY EVAPORATION MEASURED AT SIX METEOROLOGICAL STATIONS IN THE JORDAN DESERT[29]

Station	Monthly Evaporation[1] mm./month
Aqaba	540[2]
Azraq	345[3]
H_4	285[3]
H_5	292[4]
Maan	312[2]
Mafraq	314[2]

[1] Measured by Piche atmometer.

[2] Average monthly 1962-63.

[3] Average monthly 1961-63.

[4] Average monthly 1944-46.

Since the evaporation from a Piche atmometer indicates the evaporative power of the atmosphere at these stations, the above information could be used as a yardstick to indicate that evaporation losses from water surfaces that will be formed in that locality are expected to be very high.

Because it is usually invisible evaporation is seldom regarded by the untrained eye as a serious drain on stored water. Yet it is a continuous process: in summer, from direct solar radiation, in winter, from the stored thermal energy of the water.

Water lost by evaporation has always represented an appreciable part of the available water supply. This phenomenon is especially true in arid climates such as the desert area under consideration. Langbein and Hoyt[32] state that the annual evaporation from Lake Mead in the U.S.A. averages 900,000 acre-feet per year, which represents about 16 per cent of the water made available by the reservoir. Modak[33] states that in Bombay it is found that about 25 million gallons of water per day are lost by evaporation from the Tansa Lake against the draw off of 90 million gallons per day.

Hence, an investigation on water evaporation reduction is needed in order to insure a maximum economical utilization of the impounded water in such an arid area where the need for water is great.

Recent government sponsored programmes for the development of water supplies and the individuals growing concern of agricultural expansion, in semi-arid and arid areas, based on irrigation resulted in an increase in reservoirs for domestic supplies and farm ponds. Evaporation is likely to become more critical in our water economy as more of the small reservoirs are built, because the smaller the reservoir the greater is the water loss per unit of volume. It has been reported[30] that the amount of water lost from shallow storages, such as stock tanks and farm ponds, often exceeds that utilized.

Reducing evaporation loss is equivalent to increasing the real capacity of a reservoir by conserving water for a longer period of time. In arid and semi-arid areas, suffering from a chronic water shortage, this may mean the difference between a dry reservoir and one containing water.

At Lake Hefner it was possible to suppress evaporation by monolayers and save water at a cost of $60 per acre-foot. It seems there is good reason for researchers in this field to expect that savings could be realized at a cost of $20-35 per acre-foot.[24, 25, 26]

Franzini[25] states that evaporation suppression by chemical means may become an accepted method of conserving water in certain areas. A comparison with the costs of alternate sources of water (Table 3) shows the monomolecular method to be competitive.

TABLE 3

COMPARATIVE COSTS OF WATER

FROM DIFFERENT SOURCES[25]

Source of Water	Cost of Raw Water Dollars per Acre-foot
Local Runoff	3.00 - 10.00
Ground Water	3.00 - 10.00
Recalimed Waste Water	25.00 - 40.00
Imported Water	Variable
Sea Water Conversion	
Distillation	250.00 - 600.00
Solar Stills	350.00
Freezing	700.00
Ion Exchange	8000.00*
Electrolytic Action	500.00*
Ion Permeable Membranes	3000.00*
Evaporation Suppression	20.00 - 35.00

*Considerably lower for brackis water.

Water impounded in conservation surface storages in the Middle East semi-arid and arid areas is subject to heavy evaporation losses. If savings on this item could be achieved the water saved could be used to satisfy existing requirements or to meet future demands.

The use of monomolecular films on exposed water surfaces in this area is subject to certain limitations arising from local conditions which may discourage their use.

The most important limitations are given below:

1. The high temperatures experienced in the area, in general, would reduce the effectiveness of a monolayer.[26] Hence the cost of water saved under such conditions is expected to be higher than that predicted for other more favourable localities.

2. The area under consideration experiences frequent sand storms. The fine dust particles will collect on the hydrophobic end of the aliphatic monolayer,[1] while the coarser ones will pierce the monolayer at many places. This impairs the mobility of the monolayer and results in poor coverage, and hence little savings would be achieved.

3. The existing reservoirs, as well as the planned ones, are rather small in size in most cases. Furthermore, they are scattered over a large area. The value of the relatively small portion of water saved at a given location might be offset by the cost of labour, supervision, and the cost of equipment needed for daily application of the monolayer.

4. It was demonstrated experimentally,[5] that turbidity in water increases evaporation. The effect of turbidity applies to both mono-

layers and plastic Styropor beads, but the effect on monolayers is almost double that on Styropor beads. Hence turbid waters, which exist in almost any impounding reservoir in the Middle East area, impose a limit on the savings and consequently the benefit derived from the use of monolayers as water evaporation retardants.

5. The savings realized by monolayer application, under field conditions, do not appear to be sufficiently high to encourage its use.

In view of the foregoing limitations, a research for the control of water evaporation is indicated. An evaluation of Styropor beads as a substitute for monolayers merits serious consideration and warrants research.

CHAPTER V

EXPERIMENTAL WORK AND RESULTS

Description of the Facility:

A. Test Ponds:

The twin pond test facility, selected for conducting the proposed investigation, is located on the roof of the Electric Machine Laboratory at the School of Engineering in the American University of Beirut (see Frontispiece).

Latitude: $33^{\circ}\ 54'\ 22''$

Longitude: $2^{h}\ 21^{m}\ 52.7^{5}$ E.

Altitude: 14.66 meters above M.S.L.

The roof of the building is made of ribbed slab construction with the ribs about 3.5 meters long and spanning between inverted girders. These inverted girders are about 13 meters long and rest on columns. Transverse inverted "L" beams at the sides of the roof and the longitudinal inverted girders served as the sides of the test ponds.

The whole roof comprises five rectangular bays, one of which is completely shaded by trees. In order to reduce the superimposed load on the girders, due to the weight of the added water during the study period, two alternate bays were chosen. The maximum live load to be applied was limited to 250 kgs/m^2 (25 cms. of water depth) for safety reasons.

The exposed concrete surface in the two bays selected was treated by a water proofing material in order to render it watertight throughout the investigation.

The twin ponds were identical in size, orientation, and construction. They ran in a north-south direction. The exposed surface area furnished by each pond was 12.86 m x 3.46 m = 44.5 m^2.

Since pine trees border the test facility from the north, phylon planks, with a total width of 1.6 meters and spanning between the inverted girders, were used to cover the north end of each pond. This provided even shade, over the part of the ponds bordering the trees, during the day and served to prevent the falling trash from those trees from coming into the ponds (see Figure 3).

The site was somewhat protected from wind action due to the presence of buildings all around. However, exposure to the sun was complete throughout most of the day (see Frontispiece).

The reinforced concrete forming the structure of the twin ponds seemed to be of good quality. When it was further treated for water tightness purposes no leakage at all resulted through the study period. Furthermore, the unique location of the twin ponds with their bottom forming the roof of the Electric Machines Laboratory located under them, facilitated continuous inspection for any leakage that may develop. However, this provided insulation for the bottoms of the twin ponds which would not be the case in natural ponds and reservoirs.

No visible leakage has been observed throughout the investigation.

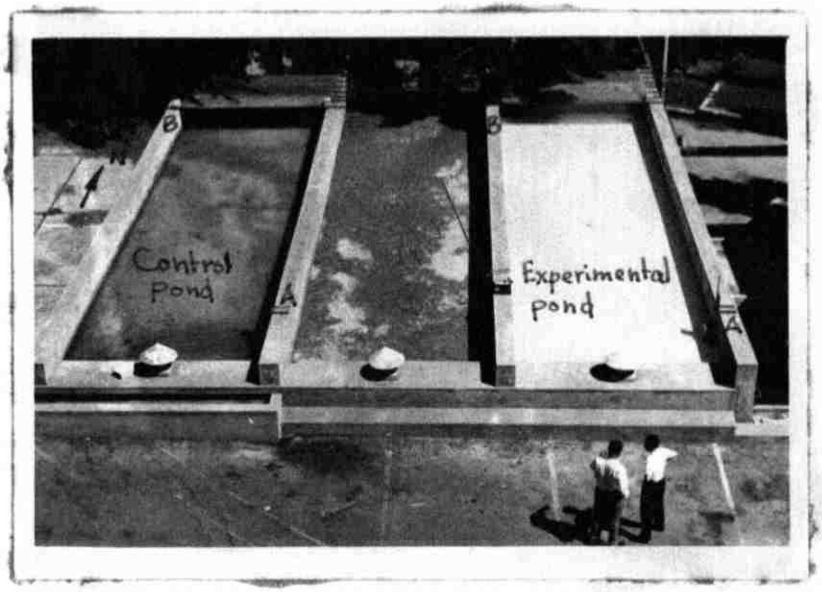


Figure 3. Layout of the experimental twin ponds. Arrow indicates North. A and B indicate the positions of hook gauges in both ponds. Styropor dosage applied is 125 gm/m^2 which provides complete compressed coverage.

B. Equipment:

The equipment used throughout the experimentation included the following:

1. Hook Gauges: Four hook gauges made by Gurley were used, each contained in a stilling well (20 cm. by 20 cm) made out of sheet metal. The gauges were calibrated to permit direct readings to 0.01 cms. They were installed diagonally opposite one another, two in each pond, in order to compensate for the effect of build up in the water surface due to wind action. Actual daily drop in water level was determined by taking the average of the two daily drops on the two gauges for each pond. All readings were taken to the nearest 0.01 cms.

2. Anemometer: A sensitive anemometer made by Casella, London, was used to record wind velocities whenever needed. Instrument No. 894.

3. Siphon Rainfall Recorder: This instrument made by Castella, England, was located in the bay between the two ponds to record the amount and/or duration of rainfall during the experimental period.

4. Thermometer: A thermometer permitting readings to 0.1° C was used to record water temperatures.

5. Barograph: Made by Casella, London. Instrument No. 750.

6. Hair Hygrograph: Made by Casella, London. Instrument No. 1459.

7. Thermograth: Made by Casella, London. Instrument No. 1491.

The above three instruments were operated in a room near the test facility. The height of these instruments was

22.30 meters above M.S.L. Continuous recording of the atmospheric pressure in mm. of mercury, the atmospheric humidity in percent, and air temperature in ^{o}C, were made on special charts each covering a period of one week of experimental work.

Supplementary meteorological data were available from the Lee Observatory at the American University of Beirut.

The meteorologic data is presented in Appendix I.

C. Water:

Municipal water was used throughout the investigation. The two ponds were filled, at the same time, from the same source by means of rubber hoses. This filling system was adopted in order to provide the two ponds with water of identical composition and temperature, two factors which may affect evaporation.

D. Materials:

1. Styropor: Manufactured and patented by Badische Anilin and Soda Fabric AG, Ludwigshafen Am Rhein; West Germany. The untreated material is marketed in the form of granules with a diameter range of 0.3 - 0.4 mm. These granules may be expanded up to forty times their original size by exposure to temperatures of 65 - 110^{o} C for a period extending up to 10 minutes. The extent of expansion depends upon temperature and time of exposure.

The heat expanded beads are white in color, have a globular shape, and have a very low specific gravity. Chemically the material is a Polystyrene type of plastic.

The heat-expanded Styropor beads may be prepared in small batches for trials or limited applications by merely immersing the untreated granules in hot water for a few minutes. Heat expanded beads, however, are not uniform in size. Uniformity in size may be approached under controlled conditions of temperature and exposure time. It should be evident that batches may vary in size and extent of expansion when prepared under different conditions. Hence results may vary when batches that have been prepared under uncontrolled conditions, such as immersion in hot or boiling water, are used. For purposes of duplication or comparison of results it would be imperative to state two important criteria: Sieve analysis and bulk density. Expansion by steam is done commercially and yields Styropor beads that may be closely reproduced in every batch.

The untreated Styropor granules are available in the local market and are used by a factory* in Tripoli, Lebanon, for the manufacture of insulation boards.

The expanded Styropor beads used throughout this study were purchased from the factory in Tripoli, where the material was expanded by steam. The material had the following characteristics.

a) Sieve Analysis:

U.S. Sieve No.		Percent retained on Sieve
5		67.0
7		26.4
10		4.6
pan		2.0
	Total	100.0

---

*Societe du Bois Presse pour Construction de Logements. (S.A.L.) - Tripoli, Lebanon.

b) Bulk Density = 18.5 grams/liter.

The expanded beads with their multitude of microscopical air spaces, serve as a good insulating material. The beads are globular in shape, light, soft, white in color and are chemically and biologically inert. They are insoluble in water and are not affected by its chemical or biological impurities. The beads would float on water surfaces by virtue of their low specific gravity. Moreover, they are durable and resist weather conditions for long periods of time.

Present cost of Styropor granules, which are the raw unexpanded material, as sold in Beirut is given below.

Quantity	Price L.L./kg.
Less than 1 ton	0.9825
1 ton	0.8875
4.5 tons	0.8125
9 tons	0.7750

Although the heat expanded material is not readily available in all local markets of the Middle East, yet it would be possible to prepare it locally for water evaporation control purposes.

2. **Cetyl Alcohol**: Known technically as Hexadecanol. The material used in the study was manufactured by the British Drug Houses Ltd., London, England. It was in powder form produced as a pure material for technical use in laboratories. It had been procured at the cost of 9.5 L.L. per lb. ($3.12 per lb.).

However, commercial Hexadecanol is available under different trade names such as AQUASAVE[1] and AQUALOC NX[2]. These materials are marketed at $0.35 per lb., and $0.895 per lb. respectively FAS New York. Assuming 25 per cent of the original cost is needed further to cover insurance, shipping and customs the cost of these materials in Beirut would be $0.44 per lb. (1.32 L.L. per lb.) for Aquasave and $1.15 per lb. (3.4 L.L. per lb.) for Aqualoc NX.

Procedure:

General: The proposed investigation was divided into a series of five experiments. Experiments 1 to 4 were made to investigate the effect of floating Styropor beads on water evaporation reduction. These experiments were carried out in the twin pond test facility. Experiment 5 was made to investigate the effect of wind action on the floating Styropor beads and was conducted at the School of Engineering shops.

For the first four experiments the eastern pond of the twin pond test facility was used as the experimental while the western one was used as the control pond throughout the investigation period (see Figure 3).

Experiments 1, 3, and 4 comprised one test each.

Experiment 2 comprised 4 tests.

Hence there were seven tests to be conducted at the test facility. Since the two ponds were both needed in any single test and because of time limitations it was decided that the duration of any one test should not exceed 10 days.

---

[1] Arista Industries, Inc., 122 East 42nd Street, New York 17, N.Y.

[2] M. Michel and Company, Inc., 90 Broad Street, New York 4, N.Y.

At the start of the investigation the two ponds were filled with tap water from the same source to a depth of 25 cms. At the start of every experiment or test the water lost by evaporation from each pond, during the previous testing period, was replenished and the water depth in both ponds was thus restored to the initial value of 25 cms. Replenishing of water lost by evaporation was done by supplying tap water by means of rubber hoses from the same source and during the same time interval.

Description of Procedure:

At the start of every test the readings on the two hook gauges in each pond were recorded, thus establishing the initial water level reading for that particular test.

Daily readings of water level drop, surface and mid-depth temperature of the water in each pond were recorded at 9:00 a.m. The wind velocity and direction were taken also daily at that time as well as information on algae growth, mosquito breeding in each pond, and the behaviour of the floating white Styropor beads in the experimental pond. Any other remarks which might have been of interest were recorded.

The surface and mid-depth temperature in each pond were taken at predetermined points which gave the average values of these temperatures in each pond.

The hook gauges used permitted direct readings to 0.01 cms. For the water surface area of 44.5 m^2 furnished by each pond a drop of 0.01 cms, or a saving of 0.01 cms represents a water volume of 4.45

liters. Such a change, 0.01 cms, would represent 0.1 m^3 if applied to one donum (1000 m^2) or 106.3 gallons if applied to one acre of water surface.

Throughout the investigation a barograph, a hair hygrograph and a thermograph were in operation in a room near the test facility. Thus continuous recording of atmospheric pressure, atmospheric humidity and air temperature were made.

Subsequent daily readings were taken at 9:00 a.m. and all information recorded. The savings in water obtained by the use of floating Styropor beads were reported on cumulative basis as a percentage of the volume evaporated under normal conditions (control pond). The cumulative values were used because daily values are subject to fluctuations and do not give a comprehensive picture of the results obtained.

The foregoing procedure was followed in all experiments unless otherwise stated.

Experiment No. 1.

Period: July 31 - August 10, 1964.

Objective: To check on leakage, if any, in the ponds and determine whether there is any difference in evaporation from the two ponds as a result of differences of shading, wind barriers, and location.

Procedure: Daily readings of water loss by evaporation were recorded at 9:00 a.m. The complete data is given in Table 4.

On August 7 - 8, readings of water loss by evaporation, water temperature at surface and mid-depth in each pond as well as wind velocity and direction, together with any necessary remarks were taken at

2 hrs. intervals for 24 hours. This information was gathered to give detailed and more close account of the behaviour of water in the two ponds. This data is given in Table 5. The temperature vs. time curves for the mid-point temperature in both ponds during the 24 hr. period is given in Figure 4.

Results: At the end of the 10-day experiment, the cumulative evaporation loss from the experimental pond was 4.995 cms., and that from the control pond 4.975.

The factor relating evaporation from the experimental pond to that from the control during this 10-day period was 4.995 ÷ 4.975 = 1.00402.

This factor could be considered unity for all practical purposes. Hence it was concluded that evaporation from the two ponds was almost the same indicating no leakage. This was confirmed by observation.

The temperature vs. time curves for the two ponds, taken on August 7-8, showed that the water in the two ponds reached a maximum temperature of 34.8° C at 3 p.m, and a minimum temperature of 26.2° at 5 a.m. ~~during that~~ the next day. This indicated that the two ponds were equally exposed to sunlight during that period, hence the heat energy absorbed by both during the day was the same.

TABLE 4.   EXP. NO 1   TEST No 1   PERIOD JULY 31 - AUG. 10

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF zero gms/m²									CONTROL POND									Remarks
		water depth	water temp °C		Hook gauge reading (cms)		24 hrs. difference		Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	water depth	water temp °C		Hook gauge reading (cms)		24 hrs difference (cms)		Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	
		(cms)	Top	Mid.pt	A	B	A	B			(cms)	Top	Mid pt	A	B	A	B			
July 31	W 0.7	25	26.2	26	40.70	42.26					25	27.2	27	48.82	49.18					Start of Experiment.
							0.54	0.60	0.57	0.570						0.50	0.56	0.53	0.530	
Aug. 1	W 0.6		27.0	26.8	40.16	41.66						28.4	28.2	48.32	48.62					
							0.52	0.53	0.525	1.095						0.48	0.50	0.49	1.020	Some trash from
2	SW 0.6		27.6	27.4	39.64	41.13						28.2	28.0	47.84	48.12					adjacent pine trees falls into
							0.51	0.53	0.52	1.615						0.51	0.51	0.51	1.530	ponds.
3	W 0.4		28.2	28.0	39.13	40.60						29.2	29.0	47.33	47.61					
							0.50	0.48	0.49	2.105						0.50	0.48	0.49	2.020	
4	W 0.5		28.2	28.0	38.63	40.12						29.4	29.2	46.83	47.13					
							0.50	0.50	0.50	2.605						0.50	0.50	0.50	2.520	
5	W 0.8		28.2	28.0	38.13	39.62						29.8	29.6	46.33	46.63					More tree trash falls
							0.51	0.48	0.495	3.100						0.51	0.48	0.495	3.015	into both ponds.
6	SW 0.7		28.2	28.0	37.62	39.14						29.9	29.7	45.82	46.15					
							0.50	0.47	0.485	3.585						0.49	0.49	0.49	3.505	On Aug. 7-8, 2 hourly
7	SW 0.4		28.6	28.4	37.12	38.67						29.3	29.1	45.33	45.66					readings were taken
							0.48	0.50	0.49	4.075						0.48	0.50	0.49	3.995	for 24 hours.
8	W 0.5		28.3	28.1	36.64	38.17						29.1	28.9	44.85	45.16					
							0.50	0.48	0.49	4.565						0.51	0.50	0.505	4.500	On Aug. 8, Second Stage
9	W 0.4		27.6	27.4	36.14	37.69						28.0	27.8	44.34	44.66					Larvae was observed in
							0.45	0.41	0.43	4.995						0.48	0.47	0.475	4.975	experimental pond.
10	W 0.6	20	27.2	27.0	35.69	37.28					20	27.4	27.2	43.86	44.19					

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE 4. EXP. NO 1 TEST No 1 PERIOD JULY 31 - AUG. 10

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF Zero gms/m²									CONTROL POND									Remarks
		water depth (Cms)	Water temp °C Top	Water temp °C Mid.pt	Hook gauge reading (cm) A	Hook gauge reading (cm) B	24 hrs. difference A	24 hrs. difference B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	water depth (cms)	water temp °C Top	water temp °C Midpt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms) A	24 hrs difference (cms) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	
July 31	W 0.7	25	26.2	26	40.70	42.26					25	27.2	27	48.82	49.18					
							0.54	0.60	0.57	0.570						0.50	0.56	0.53	0.530	Start of Experiment.
Aug. 1	W 0.6		27.0	26.8	40.16	41.66						28.4	28.2	48.32	48.62					
							0.52	0.53	0.525	1.095						0.48	0.50	0.49	1.020	Some trash from
2	SW 0.6		27.6	27.4	39.64	41.13						28.2	28.0	47.84	48.12					adjacent pine trees falls into
							0.51	0.53	0.52	1.615						0.51	0.51	0.51	1.530	ponds.
3	W 0.4		28.2	28.0	39.13	40.60						29.2	29.0	47.33	47.61					
							0.50	0.48	0.49	2.105						0.50	0.48	0.49	2.020	
4	W 0.5		28.2	28.0	38.63	40.12						29.4	29.2	46.83	47.13					
							0.50	0.50	0.50	2.605						0.50	0.50	0.50	2.520	
5	W 0.8		28.2	28.0	38.13	39.62						29.8	29.6	46.33	46.63					More tree trash falls
							0.51	0.48	0.495	3.100						0.51	0.48	0.495	3.015	into both ponds.
6	SW 0.7		28.2	28.0	37.62	39.14						29.9	29.7	45.82	46.15					
							0.50	0.47	0.485	3.585						0.49	0.49	0.49	3.505	On Aug. 7-8, 2 hourly
7	SW 0.4		28.6	28.4	37.12	38.67						29.3	29.1	45.33	45.66					readings were taken
							0.48	0.50	0.49	4.075						0.48	0.50	0.49	3.995	for 24 hours.
8	W 0.5		28.3	28.1	36.64	38.17						29.1	28.9	44.85	45.16					
							0.50	0.48	0.49	4.565						0.51	0.50	0.505	4.500	On Aug. 8, Second stage
9	W 0.4		27.6	27.4	36.14	37.69						28.0	27.8	44.34	44.66					Larvae was observed in
							0.45	0.41	0.43	4.995						0.48	0.47	0.475	4.975	experimental pond.
10	W 0.6	20	27.2	27.0	35.69	37.28					20	27.4	27.2	43.86	44.19					

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE **5.** EXP. Nº 1 TEST Nº 1 PERIOD: AUG.7 — AUG.8

Date & Time	Wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF ZERO gms./m².									CONTROL POND.									Remarks.
		Water depth	Water Temp. °C		Hook gauge reading (cm)		2 hrs. difference cm.		Average 2 hrs. Evap. cm.	Total Evap. to date cm.	Water depth	Water Temp. °C		Hook gauge reading (cm)		2 hrs. difference cm.		Average 2 hrs. Evap. cm	Total Evap. to date cm.	
		cm.	Top	Mid pt.	A	B	A	B			cm.	Top	Mid pt.	A	B	A	B			
Aug.7 7 AM	SW 0.6	21.5	26.3	26.7	37.17	38.72					21.5	27.1	27.5	45.38	45.72					
							0.05	0.05	0.05	0.050						0.05	0.06	0.055	0.055	
9 AM	SW 0.4		28.7	28.4	37.12	38.67						29.4	29.1	45.33	45.66					
							0.03	0.05	0.04	0.090						0.04	0.04	0.04	0.095	
11 AM	SW 0.5		31.6	31.3	37.09	38.62						32.0	31.7	45.29	45.62					
							0.04	0.04	0.04	0.130						0.04	0.04	0.04	0.135	
1 PM	W 0.4		34.3	34.0	37.05	38.58						34.6	34.3	45.25	45.58					
							0.05	0.05	0.05	0.180						0.05	0.05	0.05	0.185	
3 PM	W 0.4		34.8	34.8	37.00	38.53						34.8	34.8	45.20	45.53					
							0.06	0.06	0.06	0.240						0.06	0.06	0.06	0.245	
5 PM	W 0.4		33.6	33.9	36.94	38.47						33.6	33.9	45.14	45.47					
							0.06	0.07	0.065	0.305						0.05	0.07	0.06	0.305	
7 PM	W 0.7		31.7	32.0	36.88	38.40						31.5	31.8	45.09	45.40					
							0.05	0.05	0.05	0.355						0.05	0.05	0.05	0.355	
9 PM	W 0.6		30.5	30.8	36.83	38.35						30.4	30.7	45.04	45.35					
							0.03	0.04	0.035	0.390						0.03	0.04	0.035	0.390	
11 PM	W 0.7		29.5	29.7	36.80	38.31						29.4	29.6	45.01	45.31					
							0.03	0.03	0.03	0.420						0.03	0.03	0.03	0.420	
Aug.8 1 AM	W 0.7		28.6	28.8	36.77	38.28						28.6	28.8	44.98	45.28					
							0.02	0.02	0.02	0.440						0.02	0.02	0.02	0.440	
3 AM	W 0.6		27.0	27.3	36.75	38.26						27.0	27.3	44.96	45.26					
							0.02	0.02	0.02	0.460						0.02	0.02	0.02	0.460	
5 AM	W 0.4		26.0	26.2	36.73	38.24						26.0	26.2	44.94	45.24					
							0.04	0.03	0.035	0.495						0.04	0.03	0.035	0.495	
7 AM	W 0.6		26.2	26.5	36.69	38.21						27.0	27.2	44.90	45.21					
							0.05	0.04	0.045	0.540						0.05	0.05	0.05	0.545	
9 AM	W 0.5		28.4	28.1	36.64	38.17						29.3	28.9	44.85	45.16					

* ALL READINGS TAKEN AT 2 hr. Intervals.

TABLE 5. EXP. No 1 TEST No 1 PERIOD: AUG.7 – AUG.8

Date & Time	Wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF ZERO gms./m². Water depth cm.	Water Temp. °C Top	Water Temp. °C Mid pt.	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference cm. A	2 hrs. difference cm. B	Average 2 hrs. Evap. cm.	Total Evap. to date cm.	CONTROL POND. Water depth cm.	Water Temp. °C Top	Water Temp. °C Mid pt.	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference cm. A	2 hrs. difference cm. B	Average 2 hrs. Evap. cm	Total Evap. to date cm.	Remarks.
Aug.7 7 AM	SW 0.6	21.5	26.3	26.7	37.17	38.72					21.5	27.1	27.5	45.38	45.72					
							0.05	0.05	0.05	0.050						0.05	0.06	0.055	0.055	
9 AM	SW 0.4		28.7	28.4	37.12	38.67						29.4	29.1	45.33	45.66					
							0.03	0.05	0.04	0.090						0.04	0.04	0.04	0.095	
11 AM	SW 0.5		31.6	31.3	37.09	38.62						32.0	31.7	45.29	45.62					
							0.04	0.04	0.04	0.130						0.04	0.04	0.04	0.135	
1 PM	W 0.4		34.3	34.0	37.05	38.58						34.6	34.3	45.25	45.58					
							0.05	0.05	0.05	0.180						0.05	0.05	0.05	0.185	
3 PM	W 0.4		34.8	34.8	37.00	38.53						34.8	34.8	45.20	45.53					
							0.06	0.06	0.06	0.240						0.06	0.06	0.06	0.245	
5 PM	W 0.4		33.6	33.9	36.94	38.47						33.6	33.9	45.14	45.47					
							0.06	0.07	0.065	0.305						0.05	0.07	0.06	0.305	
7 PM	W 0.7		31.7	32.0	36.88	38.40						31.5	31.8	45.09	45.40					
							0.05	0.05	0.05	0.355						0.05	0.05	0.05	0.355	
9 PM	W 0.6		30.5	30.8	36.83	38.35						30.4	30.7	45.04	45.35					
							0.03	0.04	0.035	0.390						0.03	0.04	0.035	0.390	
11 PM	W 0.7		29.5	29.7	36.80	38.31						29.4	29.6	45.01	45.31					
							0.03	0.03	0.03	0.420						0.03	0.03	0.03	0.420	
Aug.8 1 AM	W 0.7		28.6	28.8	36.77	38.28						28.6	28.8	44.98	45.28					
							0.02	0.02	0.02	0.440						0.02	0.02	0.02	0.440	
3 AM	W 0.6		27.0	27.3	36.75	38.26						27.0	27.3	44.96	45.26					
							0.02	0.02	0.02	0.460						0.02	0.02	0.02	0.460	
5 AM	W 0.4		26.0	26.2	36.73	38.24						26.0	26.2	44.94	45.24					
							0.04	0.03	0.035	0.495						0.04	0.03	0.035	0.495	
7 AM	W 0.6		26.2	26.5	36.69	38.21						27.0	27.2	44.90	45.21					
							0.05	0.04	0.045	0.540						0.05	0.05	0.05	0.545	
9 AM	W 0.5		28.4	28.1	36.64	38.17						29.3	28.9	44.85	45.16					

* ALL READINGS TAKEN AT 2 hr. Intervals.

/

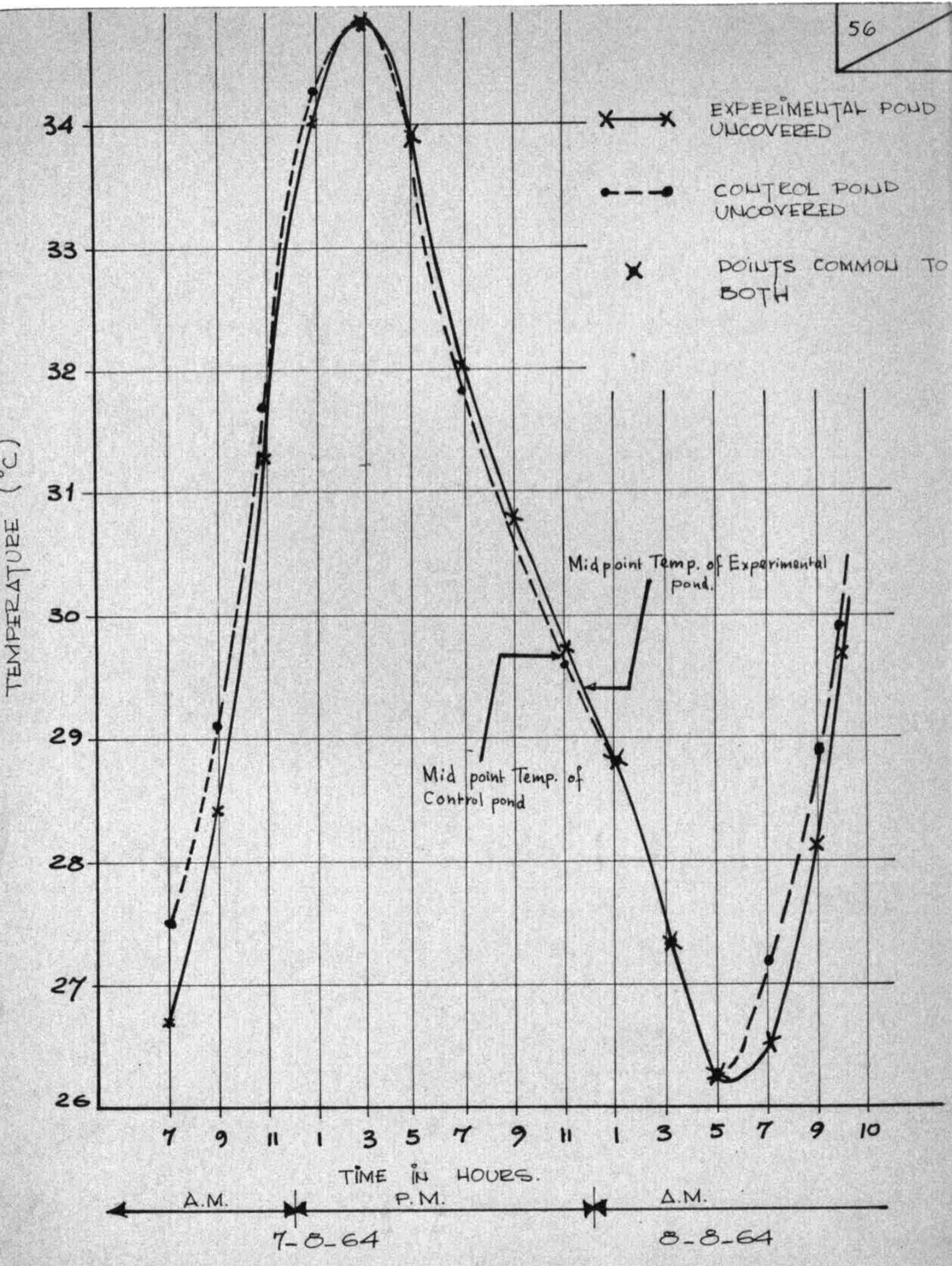


FIGURE 4. TEMPERATURE Vs. TIME

Experiment No. 2.

Period: August 10 - September 23.

Objective: To determine the percentages of water saved in the experimental pond as compared to that lost by evaporation from the control pond, for four different dosages of **white floating Styropor** beads.

The dosages selected for experimentation were 100 gm/m^2, 125 gm/m^2, 150 gm/m^2 and 75 gm/m^2. The selection was based on previous experimental observations.[5]

The percentages of water saved, over a 10-day test period for each dose were used to determine the most economical rate of application.

Procedure: The experiment was divided into four 10-day tests.

The Styropor beads were applied to the experimental pond, in the desired dosage, by immersing the bag containing the material in the pond water with the bag opening just below the water surface. The beads emerged from the bag and floated over the water surface. The beads were already wetted thus the danger of being blown away by wind, when they were dry, was eliminated. It should be noted here, however, that such a precaution was necessary at that stage due to the fact that the Styropor beads are very light and are subject to be carried away by wind action if dry.

Styropor application was done in 3 or 4 places along the edge of the pond. The beads spread out easily and quickly over the water surface aided by the hand.

Whenever a dosage was applied a slight rise in the water level would result depending upon the quantity applied. The hook gauges in the experimental pond were adjusted before the start of any test to eliminate the effect of the rise in water level.

Beads were not admitted into the stilling wells so as not to interfere with hook gauge readings.

Test No. 1.

Period: August 10 - August 20.

Dosage: 100 gm/m^2.

Procedure: All readings were taken daily at 9:00 a.m. The complete data is given in Table 6.

On August 18-19, readings of water level drop and water temperature at mid-depth and surface in each pond as well as wind velocity and direction were taken at 2 hrs. intervals for 24 hours. Any other remarks of interest were recorded. These 2 hourly readings were recorded to give detailed information regarding the effect of the floating Styropor beads on the water in the experimental pond as compared to the water in the control pond. This data is given in Table 7.

The temperature vs. time curves for surface and mid-depth temperature in both ponds for this 24 hr. period is given in Figure 5.

Results: The Styropor dose of 100 gm/m^2 applied in this test afforded a complete coverage of the surface area of the experimental pond.

At the conclusion of the 10-day test period the cumulative evaporation loss from the experimental pond was 2.645 cms., and that from the control pond was 4.995 centimeters.

The cumulative water saving for the test period was:

$$4.995 - 2.645 = 2.350 \text{ cms.}$$

This could be expressed as a cumulative saving of

$$100\ (2.350 \div 4.995) = 47.1 \text{ percent.}$$

The cumulative saving in percent vs. time in days is given in Figure 9.

TABLE 6. EXP. No 2 TEST No 1 PERIOD : AUG. 10 - AUG. 20

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms/m². water depth (cms)	water temp. °C Top	water temp. °C Mid. pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms.) A	24 hrs difference (cms.) B	Average 24 hrs Evap. (cms.)	Total Evap. To date (cms)	CONTROL POND water depth (cms)	water temp. °C Top	water temp. °C Mid. pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms) A	24 hrs difference (cms) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	Remarks
Aug. 10	W 1.0	24.5	27.2	27.0	40.15 -0.05 40.10	41.74 -0.05 41.69					24.5	27.4	27.2	48.32	48.59					Plastic material i.e Styropor beads, were applied on the experimental pond. Correction shown for hook gauges is to take care of the displaced volume due to weight of Styropor.
11	SW 1.1		27.0	26.8	39.78	41.37	0.32	0.32	0.32	0.320		27.8	27.6	47.79	48.06	0.53	0.53	0.53	0.530	
12	W 1.2		27.7	27.5	39.49	41.07	0.29	0.30	0.295	0.615		28.8	28.6	47.28	47.55	0.51	0.51	0.51	1.040	
13	W 0.9		27.1	26.8	39.23	40.81	0.26	0.26	0.26	0.875		28.2	27.9	46.77	47.04	0.51	0.51	0.51	1.550	On Aug. 13, Culex mosquito larvae were collected from the exp. pond and were sent to lab.
14	W 0.7		26.8	26.8	38.95	40.53	0.28	0.28	0.28	1.155		27.8	28.0	46.23	46.50	0.54	0.54	0.54	2.09	
15	W 0.8		27.6	27.5	38.67	40.25	0.28	0.28	0.28	1.435		29.1	29.0	45.70	45.98	0.53	0.52	0.525	2.615	On Aug. 15, Algae bloom observed in Control pond.
16	W 1.0		28.0	28.0	38.46	40.04	0.21	0.21	0.21	1.645		29.0	29.2	45.28	45.56	0.42	0.42	0.42	3.035	
17	W 1.7		28.5	28.2	38.20	39.78	0.26	0.26	0.26	1.905		29.6	29.6	44.76	45.04	0.52	0.52	0.52	3.555	
18	NW 1.1		28.5	28.1	37.94	39.52	0.26	0.26	0.26	2.165		29.8	29.7	44.24	44.52	0.52	0.52	0.52	4.075	On Aug. 18-19, 2 hourly readings were taken for 24 hours to give data on evaporation and temp. variations dring the day.
19	W 0.7		28.7	28.5	37.71	39.29	0.23	0.23	0.23	2.395		30.4	30.0	43.80	44.08	0.44	0.44	0.44	4.515	
20	N.W 1.3	22	28.1	27.8	37.46	39.04	0.25	0.25	0.25	2.645	19.5	29.8	29.6	43.32	43.68	0.48	0.48	0.48	4.995	

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE 6. EXP. No 2 TEST No 1 PERIOD: AUG. 10 - AUG. 20

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms/m². water depth (cms)	water temp. °C Top	water temp. °C Mid.pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms.) A	24 hrs difference (cms.) B	Average 24 hrs Evap. (cms.)	Total Evap. To date (cms)	CONTROL POND water depth (cms)	water temp. °C Top	water temp. °C Mid.pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms) A	24 hrs difference (cms) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	Remarks
Aug. 10	W 1.0	24.5	27.2	27.0	40.15 - 0.05 40.10	41.74 - 0.05 41.69	0.32	0.32	0.32	0.320	24.5	27.4	27.2	48.32	48.59	0.53	0.53	0.53	0.530	Plastic material i.e Styropor beads, were
11	SW 1.1		27.0	26.8	39.78	41.37	0.29	0.30	0.295	0.615		27.8	27.6	47.79	48.06	0.51	0.51	0.51	1.040	applied on the experimental pond. Correction shown
12	W 1.2		27.7	27.5	39.49	41.07	0.26	0.26	0.26	0.875		28.8	28.6	47.28	47.55	0.51	0.51	0.51	1.550	for hook gauges is to take care of the
13	W 0.9		27.1	26.8	39.23	40.81	0.28	0.28	0.28	1.155		28.2	27.9	46.77	47.04	0.54	0.54	0.54	2.09	displaced volume due to weight of Styropor.
14	W 0.7		26.8	26.8	38.95	40.53	0.28	0.28	0.28	1.435		27.8	28.0	46.23	46.50	0.53	0.52	0.525	2.615	On Aug. 13, Culex mosquito larvae were
15	W 0.8		27.6	27.5	38.67	40.25	0.21	0.21	0.21	1.645		29.1	29.0	45.70	45.98	0.42	0.42	0.42	3.035	collected from the exp. pond and were sent to lab.
16	W 1.0		28.0	28.0	38.46	40.04	0.26	0.26	0.26	1.905		29.0	29.2	45.28	45.56	0.52	0.52	0.52	3.555	On Aug. 15, Algae bloom observed in
17	W 1.7		28.5	28.2	38.20	39.78	0.26	0.26	0.26	2.165		29.6	29.6	44.76	45.04	0.52	0.52	0.52	4.075	Control pond.
18	NW 1.1		28.5	28.1	37.94	39.52	0.23	0.23	0.23	2.395		29.8	29.7	44.24	44.52	0.44	0.44	0.44	4.515	On Aug. 18–19, 2 hourly readings were taken for
19	W 0.7		28.7	28.5	37.71	39.29	0.25	0.25	0.25	2.645		30.4	30.0	43.80	44.08	0.48	0.48	0.48	4.995	24 hours to give data on evaporation and temp.
20	N.W 1.3	22	28.1	27.8	37.46	39.04					19.5	29.8	29.6	43.32	43.68					variations dring the day.

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE 7. EXP. N° 2 TEST N° 1 PERIOD: AUG. 18 — AUG. 19

Date & Time	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms /m²									CONTROL POND.									Remarks.
		Water depth	Water Temp. °C		Hook gauge reading (cm)		2 hrs. difference cms.		Average 2 hrs. Evap cm.	Total Evap. to date cm.	Water depth	Water Temp. °C		Hook gauge reading (cm)		2 hrs. difference cm.		Average 2 hrs Evap. cm.	Total Evap. to date cm.	
		cm.	Top.	Mid pt.	A	B	A	B			Cm.	Top	Mid pt	A	B	A	B			
Aug 18 7 AM	W 1.3	22.5	27.5	27.6	37.97	39.55					20.5	27.4	27.6	44.30	44.58					
							0.03	0.03	0.03	0.030						0.06	0.06	0.06	0.060	
9 AM	W 1.1		28.5	28.1	37.94	39.52						29.8	29.7	44.24	44.52					
							0.02	0.02	0.02	0.050						0.04	0.04	0.04	0.100	
11 AM	W 1.3		29.6	29.4	37.92	39.50						32.4	32.5	44.20	44.48					
							0.02	0.02	0.02	0.070						0.04	0.04	0.04	0.140	
1 PM	W 1.4		30.8	30.8	37.90	39.48						34.5	34.7	44.16	44.44					
							0.03	0.03	0.03	0.100						0.04	0.04	0.04	0.180	
3 PM	W 1.0		31.4	31.4	37.87	39.45						35.4	35.6	44.12	44.40					
							0.03	0.03	0.03	0.130						0.05	0.04	0.045	0.225	
5 PM	W 0.3		31.1	31.1	37.84	39.42						34.5	34.5	44.07	44.36					
							0.03	0.03	0.03	0.160						0.05	0.05	0.05	0.275	
7 PM	W 0.3		30.6	30.6	37.81	39.39						32.6	32.8	44.02	44.31					
							0.02	0.02	0.02	0.180						0.04	0.04	0.04	0.315	
9 PM	W 0.2		30.0	30.0	37.79	39.37						31.0	31.0	43.98	44.27					
							0.02	0.01	0.015	0.195						0.03	0.03	0.03	0.345	
11 PM	W 0.3		29.5	29.6	37.77	39.36						29.9	30.0	43.95	44.24					
							0.01	0.01	0.01	0.205						0.03	0.03	0.03	0.375	
Aug. 19 1 AM	W 0.4		29.0	29.2	37.76	39.35						29.2	29.3	43.92	44.21					
							0.01	0.02	0.015	0.220						0.02	0.02	0.02	0.395	
3 AM	W 0.4		28.7	28.9	37.75	39.33						28.4	28.6	43.90	44.19					
							0.01	0.01	0.01	0.230						0.02	0.02	0.02	0.415	
5 AM	W 0.4		28.2	28.5	37.74	39.32						27.8	28.0	43.88	44.17					
							0.01	0.01	0.01	0.240						0.04	0.04	0.04	0.455	
7 AM	W 0.6		28.0	28.1	37.73	39.31						27.7	27.8	43.84	44.13					
							0.02	0.02	0.02	0.260						0.04	0.05	0.045	0.500	
9 AM	W 0.7		28.7	28.5	37.71	39.29						30.4	30	43.80	44.08					

* ALL READINGS TAKEN AT 2 hrs. Intervals.

TABLE 7.　　EXP. Nº 2　TEST Nº 1　PERIOD: AUG. 18 — AUG. 19

Date & Time	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms/m² Water depth Cm.	Water Temp. °C Top.	Water Temp. °C Mid pt.	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference cms. A	2 hrs. difference cms. B	Average 2 hrs. Evap. cm.	Total Evap. to date cm.	CONTROL POND. Water depth Cm.	Water Temp. °C Top	Water Temp. °C Mid pt	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference cm. A	2 hrs. difference cm. B	Average 2 hrs. Evap. cm.	Total Evap. to date cm.	Remarks.
Aug 18 7 AM	W 1.3	22.5	27.5	27.6	37.97	39.55					20.5	27.4	27.6	44.30	44.58					
							0.03	0.03	0.03	0.030						0.06	0.06	0.06	0.060	
9 AM	W 1.1		28.5	28.1	37.94	39.52						29.8	29.7	44.24	44.52					
							0.02	0.02	0.02	0.050						0.04	0.04	0.04	0.100	
11 AM	W 1.3		29.6	29.4	37.92	39.50						32.4	32.5	44.20	44.48					
							0.02	0.02	0.02	0.070						0.04	0.04	0.04	0.140	
1 PM	W 1.4		30.8	30.8	37.90	39.48						34.5	34.7	44.16	44.44					
							0.03	0.03	0.03	0.100						0.04	0.04	0.04	0.180	
3 PM	W 1.0		31.4	31.4	37.87	39.45						35.4	35.6	44.12	44.40					
							0.03	0.03	0.03	0.130						0.05	0.04	0.045	0.225	
5 PM	W 0.3		31.1	31.1	37.84	39.42						34.5	34.5	44.07	44.36					
							0.03	0.03	0.03	0.160						0.05	0.05	0.05	0.275	
7 PM	W 0.3		30.6	30.6	37.81	39.39						32.6	32.8	44.02	44.31					
							0.02	0.02	0.02	0.180						0.04	0.04	0.04	0.315	
9 PM	W 0.2		30.0	30.0	37.79	39.37						31.0	31.0	43.98	44.27					
							0.02	0.01	0.015	0.195						0.03	0.03	0.03	0.345	
11 PM	W 0.3		29.5	29.6	37.77	39.36						29.9	30.0	43.95	44.24					
							0.01	0.01	0.01	0.205						0.03	0.03	0.03	0.375	
Aug. 19 1 AM	W 0.4		29.0	29.2	37.76	39.35						29.2	29.3	43.92	44.21					
							0.01	0.02	0.015	0.220						0.02	0.02	0.02	0.395	
3 AM	W 0.4		28.7	28.9	37.75	39.33						28.4	28.6	43.90	44.19					
							0.01	0.01	0.01	0.230						0.02	0.02	0.02	0.415	
5 AM	W 0.4		28.2	28.5	37.74	39.32						27.8	28.0	43.88	44.17					
							0.01	0.01	0.01	0.240						0.04	0.04	0.04	0.455	
7 AM	W 0.6		28.0	28.1	37.73	39.31						27.7	27.8	43.84	44.15					
							0.02	0.02	0.02	0.260						0.04	0.05	0.045	0.500	
9 AM	W 0.7		28.7	28.5	37.71	39.29						30.4	30	43.80	44.08					

* ALL READINGS TAKEN AT 2 hrs. Intervals.

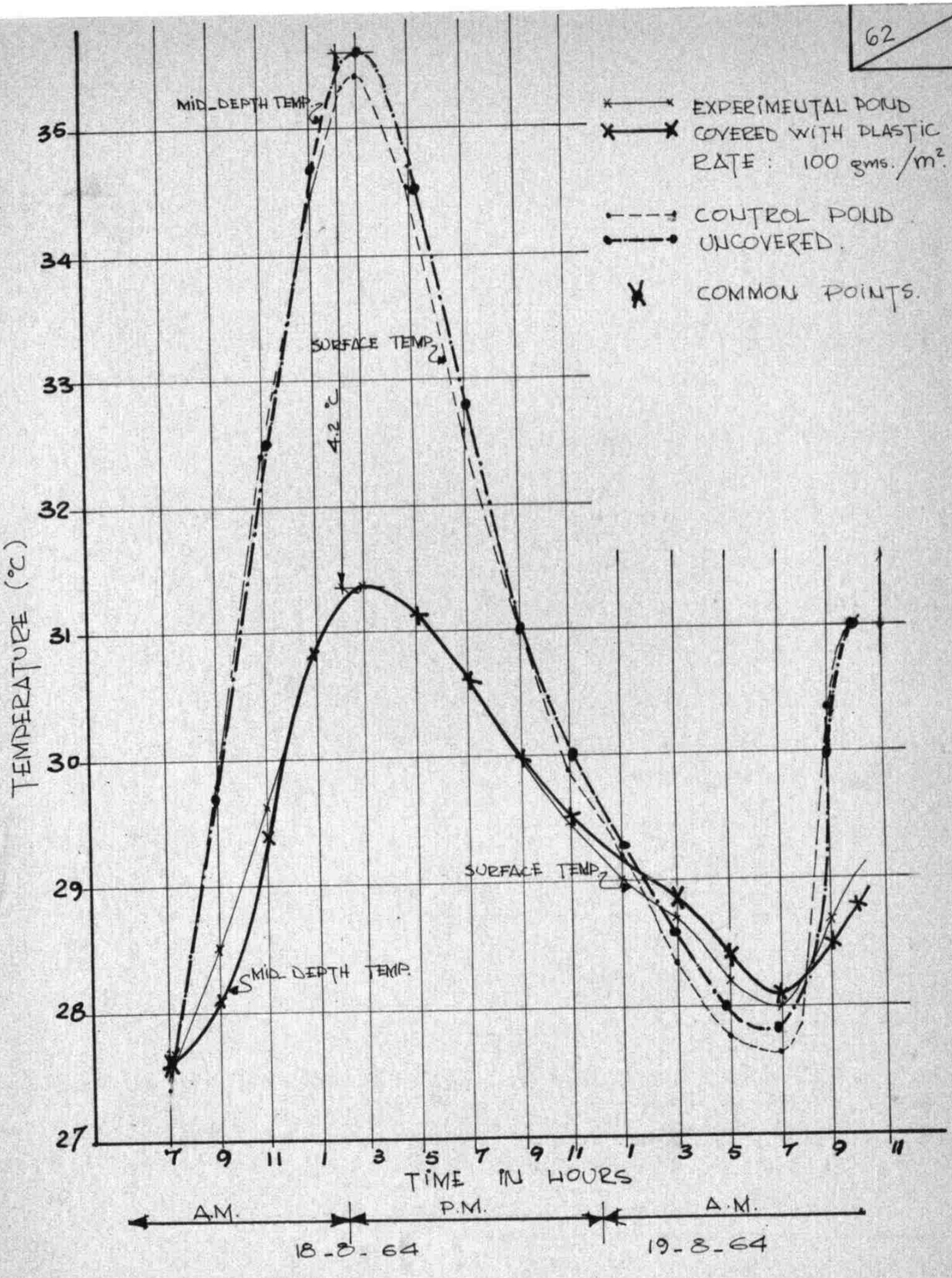


FIGURE .5. TEMPERATURE Vs. TIME

Test No. 2.

Period: August 20 - August 31.

Dosage: 125 gm/m^2.

Procedure: The Styropor dose present on the surface of the experimental pond at the end of the previous test was increased from 100 gm/m^2 to 125 gm/m^2. It was found upon close inspection that there was no need to change the Styropor beads already present since they have not undergone any change in color or any other physical characteristic.

The volume of water lost by evaporation during the previous test was replenished and the water level in both ponds was brought up to the initial depth of 25 cms. in both ponds. The volumes of tap water added to each pond were not equal due to the fact that the amount of water lost from the control pond in the previous test was more than that lost from the experimental pond. It was expected that this difference in volumes of added water will affect water temperatures and rates of evaporation from the two ponds for a certain period of time.

All readings were taken daily at 9:00 a.m. The complete data is given in Table 8.

On August 30-31, readings of water level drop and water temperature at mid-depth and surface in each pond as well as wind velocity and direction were taken at 2 hrs. intervals for 24 hours. Any other remarks of interest were recorded. This information was gathered to give a detailed account of the effect of the Styropor dose applied on the water as compared to the water in the control pond. This data is given in Table 9.

The temperature vs. time curves for surface and mid-depth temperature in both ponds is given in Figure 6.

Results: The Styropor dose of 125 gm/m^2 provided a complete and compact coverage of the surface of the experimental pond. Wind seemed to have a less pronounced effect on the layer than it had on the previous dose of 100 gm/m^2.

At the conclusion of the 10-day test period the cumulative evaporation loss from the experimental pond was 2.595 cms., while that from the control pond was 5.240 centimeters.

The cumulative water saving for the test period was:

$$5.240 - 2.595 = 2.645 \text{ cm.}$$

This could be expressed as a cumulative saving of:

$$100\ (2.645 \div 5.240) = 50.6 \text{ percent.}$$

The cumulative saving in percent vs. time in days is given in Figure 9.

TABLE 8. EXP. № 2 TEST № 2 PERIOD. AUG. 20 — AUG. 31

Date	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 125 gms/m²									CONTROL POND									Remarks
		Water depth Cms.	Water Temp °C Top.	Water Temp °C Midpt.	Hook gauge reading (Cm) A	Hook gauge reading (Cm) B	24 hrs difference cms. A	24 hrs difference cms. B	Average 24hrs Evap. Cm.	Total Evap. to date Cms.	Water depth Cms.	Water Temp °C Top	Water Temp °C Midpt.	Hook gauge reading (Cm) A	Hook gauge reading (Cm) B	24 hrs. difference cms A	24 hrs. difference cms B	Average 24hrs. Evap Cms.	Total Evap. to date cms.	
Aug 20	NW 1.3	25	28.1	27.8	37.46 +3.32 40.78	39.04 +3.24 42.28	0.22	0.20	0.21	0.210	25	29.8	29.6	43.32 +5.32 48.64	43.68 +5.24 48.92	0.42	0.41	0.415	0.415	Water added to replenish that lost by evaporation during Tes N: 1. Styropor dose increased from 100 to 125 gm/m² at start of test
21	NW 1.4		28.2	27.8	40.56	42.08	0.24	0.21	0.225	0.435		29.8	29.6	48.22	48.51	0.46	0.45	0.455	0.870	
22	NW 0.9		27.8	27.6	40.32	41.87	0.23	0.21	0.22	0.655		29.5	29.4	47.78	48.06	0.45	0.43	0.44	1.310	
23	W 0.6		28.1	27.8	40.09	41.66	0.18	0.19	0.185	0.840		30.0	29.7	47.33	47.63	0.41	0.40	0.405	1.715	
24	SW 1.4		28.5	28.2	39.91	41.47	0.22	0.22	0.22	1.060		30.5	30.3	46.92	47.23	0.45	0.45	0.45	2.165	
25	SW 1.0		28.6	28.3	39.69	41.25	0.21	0.21	0.21	1.270		30.4	30.1	46.47	46.78	0.41	0.43	0.42	2.585	
26	W 1.0		28.8	28.5	39.48	41.04	0.24	0.25	0.245	1.515		30.6	30.3	46.06	46.35	0.49	0.49	0.49	3.075	
27	SW 0.9		28.5	27.9	39.24	40.79	0.27	0.25	0.26	1.775		30.1	29.6	45.57	45.86	0.55	0.56	0.555	3.630	
28	SW 0.9		27.6	27.3	38.97	40.54	0.25	0.25	0.25	2.025		29.2	28.9	45.02	45.30	0.52	0.52	0.52	4.150	
29	SW 0.5		27.3	27.0	38.72	40.29	0.26	0.28	0.27	2.295		28.6	28.3	44.50	44.78	0.55	0.51	0.53	4.680	
30	SW 0.7		26.7	26.5	38.46	40.01	0.30	0.30	0.30	2.595		28.2	27.8	43.95	44.27	0.55	0.55	0.55	5.230	
31	SW 0.7	22.5	26.6	26.3	38.16	39.71					20	28.0	28.0	43.40	43.72					

* ALL READINGS TAKEN AT 2 hrs. Intervals.

TABLE 8.

EXP. N° 2 TEST N° 2 PERIOD. AUG. 20 — AUG. 31

Date	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 125 gms/m²									CONTROL POND									Remarks
		Water depth	Water Temp °C		Hook gauge reading (Cm)		24 hrs difference cms.		Average 24hrs Evap. Cm.	Total Evap. to date cms.	Water depth	Water Temp °C		Hook gauge reading (Cm)		24 hrs. difference cms		Average 24hrs. Evap Cms.	Total Evap. to date Cms.	
		Cms.	Top.	Midpt.	A	B	A	B			Cms.	Top	Midpt.	A	B	A	B			
Aug 20	NW 1.3	25	28.1	27.8	37.46 + 3.32 40.78	39.04 + 3.24 42.28	0.22	0.20	0.21	0.210	25	29.8	29.6	43.32 + 5.32 48.64	43.68 + 5.24 48.92	0.42	0.41	0.415	0.415	Water added to replenish that lost by evaporation during Tes N° 1. Styropor dose increased from 100 to 125 gm/m² at start of test
21	NW 1.4		28.2	27.8	40.56	42.08	0.24	0.21	0.225	0.435		29.8	29.6	48.22	48.51	0.46	0.45	0.455	0.870	
22	NW 0.9		27.8	27.6	40.32	41.87	0.23	0.21	0.22	0.655		29.5	29.4	47.78	48.06	0.45	0.43	0.44	1.310	
23	W 0.6		28.1	27.8	40.09	41.66	0.18	0.19	0.185	0.840		30.0	29.7	47.33	47.63	0.41	0.40	0.405	1.715	
24	SW 1.4		28.5	28.2	39.91	41.47	0.22	0.22	0.22	1.060		30.5	30.3	46.92	47.23	0.45	0.45	0.45	2.165	
25	SW 1.0		28.6	28.3	39.69	41.25	0.21	0.21	0.21	1.270		30.4	30.1	46.47	46.78	0.41	0.43	0.42	2.585	
26	W 1.0		28.8	28.5	39.48	41.04	0.24	0.25	0.245	1.515		30.6	30.3	46.06	46.35	0.49	0.49	0.49	3.075	
27	SW 0.9		28.5	27.9	39.24	40.79	0.27	0.25	0.26	1.775		30.1	29.6	45.57	45.86	0.55	0.56	0.555	3.630	
28	SW 0.9		27.6	27.3	38.97	40.54	0.25	0.25	0.25	2.025		29.2	28.9	45.02	45.30	0.52	0.52	0.52	4.150	
29	SW 0.5		27.3	27.0	38.72	40.29	0.26	0.28	0.27	2.295		28.6	28.3	44.50	44.78	0.55	0.51	0.53	4.680	
30	SW 0.7		26.7	26.5	38.46	40.01	0.30	0.30	0.30	2.595		28.2	27.8	43.95	44.27	0.55	0.55	0.55	5.230	
31	SW 0.7	22.5	26.6	26.3	38.16	39.71					20	28.0	28.0	43.40	43.72					

* ALL READINGS TAKEN AT 2 hrs. Intervals.

TABLE 9. EXP. № 2 TEST № 2 PERIOD: AUG. 30 - AUG. 31

Date & Time	Wind Velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 125 gms/m².									CONTROL POND									Remarks
		Water depth	Water Temp. °C		Hook gauge reading (cm.)		2 hrs. difference cm		Average 2 hrs. Evap. cm.	Total Evap. to date cm.	Water depth	Water Temp. °C		Hook gauge reading (cm.)		2 hrs. difference cm		Average 2 hrs. Evap. CM.	Total Evap. to date CM.	
		Cm.	Top	Mid pt.	A	B	A	B			CM.	Top	Midpt.	A	B	A	B			
Aug 30 7 AM	W 0.9	23	25.6	25.8	38.49	40.04					20	25.1	25.3	43.99	44.31					
9 AM	SW 0.7		26.7	26.5	38.46	40.01	0.03	0.03	0.03	0.030		28.2	27.8	43.95	44.27	0.04	0.04	0.04	0.040	
11 AM	SW 0.9		28.4	27.8	38.44	39.99	0.02	0.02	0.02	0.050		32.0	31.8	43.90	44.22	0.05	0.05	0.05	0.090	
1 PM	SW 0.9		29.1	28.8	38.42	39.96	0.02	0.03	0.025	0.075		33.9	34.3	43.85	44.17	0.05	0.05	0.05	0.140	
3 PM	W 0.5		29.4	29.7	38.39	39.93	0.03	0.03	0.03	0.105		34.4	34.8	43.78	44.10	0.07	0.07	0.07	0.210	
5 PM	W 0.5		29.0	29.4	38.35	39.89	0.04	0.04	0.04	0.145		33.0	33.2	43.72	44.04	0.06	0.06	0.06	0.270	
7 PM	W 0.4		28.6	28.8	38.31	39.85	0.04	0.04	0.04	0.185		31.2	31.5	43.67	43.98	0.05	0.06	0.055	0.325	
9 PM	W 0.4		28.2	28.4	38.27	39.82	0.04	0.03	0.035	0.220		29.6	29.8	43.63	43.93	0.04	0.05	0.045	0.370	
11 PM	W 0.4		27.6	27.8	38.24	39.79	0.03	0.03	0.03	0.250		28.5	28.6	43.58	43.88	0.05	0.05	0.05	0.420	
Aug. 31 1 AM	W 0.4		27.0	27.2	38.22	39.77	0.02	0.02	0.02	0.270		27.1	27.4	43.54	43.86	0.04	0.02	0.03	0.450	
3 AM	W 0.4		26.4	26.6	38.21	39.76	0.01	0.01	0.01	0.280		26.3	26.6	43.51	43.83	0.03	0.03	0.03	0.480	
5 AM	W 0.4		25.9	26.2	38.20	39.75	0.01	0.01	0.01	0.290		25.6	25.8	43.48	43.80	0.03	0.03	0.03	0.510	
7 AM	SW 0.6		25.6	25.8	38.19	39.74	0.01	0.01	0.01	0.300		25.0	25.2	43.45	43.77	0.03	0.03	0.03	0.540	
9 AM	SW 0.7		26.6	26.3	38.16	39.71	0.03	0.03	0.03	0.330		28.3	28.0	43.40	43.72	0.05	0.05	0.05	0.590	

* ALL READINGS TAKEN AT 2 hrs. Intervals.

TABLE 9. EXP. N: 2 TEST N: 2 PERIOD: AUG. 30 - AUG. 31

Date & Time	Wind Velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 125 gms/m^2.									CONTROL POND									Remarks
		Water depth Cm.	Water Temp. °C		Hook gauge reading (cm.)		2 hrs. difference cm		Average 2 hrs. Evap. Cm.	Total Evap. to date cm.	Water depth Cm.	Water Temp. °C		Hook gauge reading (Cm.)		2 hrs. difference cm		Average 2 hrs. Evap. Cm.	Total Evap. to date cm.	
			Top	Mid pt.	A	B	A	B				Top	Midpt.	A	B	A	B			
Aug 30 7 AM	W 0.9	23	25.6	25.8	38.49	40.04					20	25.1	25.3	43.99	44.31					
9 AM	SW 0.7		26.7	26.5	38.46	40.01	0.03	0.03	0.03	0.030		28.2	27.8	43.95	44.27	0.04	0.04	0.04	0.040	
11 AM	SW 0.9		28.4	27.8	38.44	39.99	0.02	0.02	0.02	0.050		32.0	31.8	43.90	44.22	0.05	0.05	0.05	0.090	
1 PM	SW 0.9		29.1	28.8	38.42	39.96	0.02	0.03	0.025	0.075		33.9	34.3	43.85	44.17	0.05	0.05	0.05	0.140	
3 PM	W 0.5		29.4	29.7	38.39	39.93	0.03	0.03	0.03	0.105		34.4	34.8	43.78	44.10	0.07	0.07	0.07	0.210	
5 PM	W 0.5		29.0	29.4	38.35	39.89	0.04	0.04	0.04	0.145		33.0	33.2	43.72	44.04	0.06	0.06	0.06	0.270	
7 PM	W 0.4		28.6	28.8	38.31	39.85	0.04	0.04	0.04	0.185		31.2	31.5	43.67	43.98	0.05	0.06	0.055	0.325	
9 PM	W 0.4		28.2	28.4	38.27	39.82	0.04	0.03	0.035	0.220		29.6	29.8	43.63	43.93	0.04	0.05	0.045	0.370	
11 PM	W 0.4		27.6	27.8	38.24	39.79	0.03	0.03	0.03	0.250		28.5	28.6	43.58	43.88	0.05	0.05	0.05	0.420	
Aug. 31 1 AM	W 0.4		27.0	27.2	38.22	39.77	0.02	0.02	0.02	0.270		27.1	27.4	43.54	43.86	0.04	0.02	0.03	0.450	
3 AM	W 0.4		26.4	26.6	38.21	39.76	0.01	0.01	0.01	0.280		26.3	26.6	43.51	43.83	0.03	0.03	0.03	0.480	
5 AM	W 0.4		25.9	26.2	38.20	39.75	0.01	0.01	0.01	0.290		25.6	25.8	43.48	43.80	0.03	0.03	0.03	0.510	
7 AM	SW 0.6		25.6	25.8	38.19	39.74	0.01	0.01	0.01	0.300		25.0	25.2	43.45	43.77	0.03	0.03	0.03	0.540	
9 AM	SW 0.7		26.6	26.3	38.16	39.71	0.03	0.03	0.03	0.330		28.3	28.0	43.40	43.72	0.05	0.05	0.05	0.590	

* ALL READINGS TAKEN AT 2 hrs. Intervals.

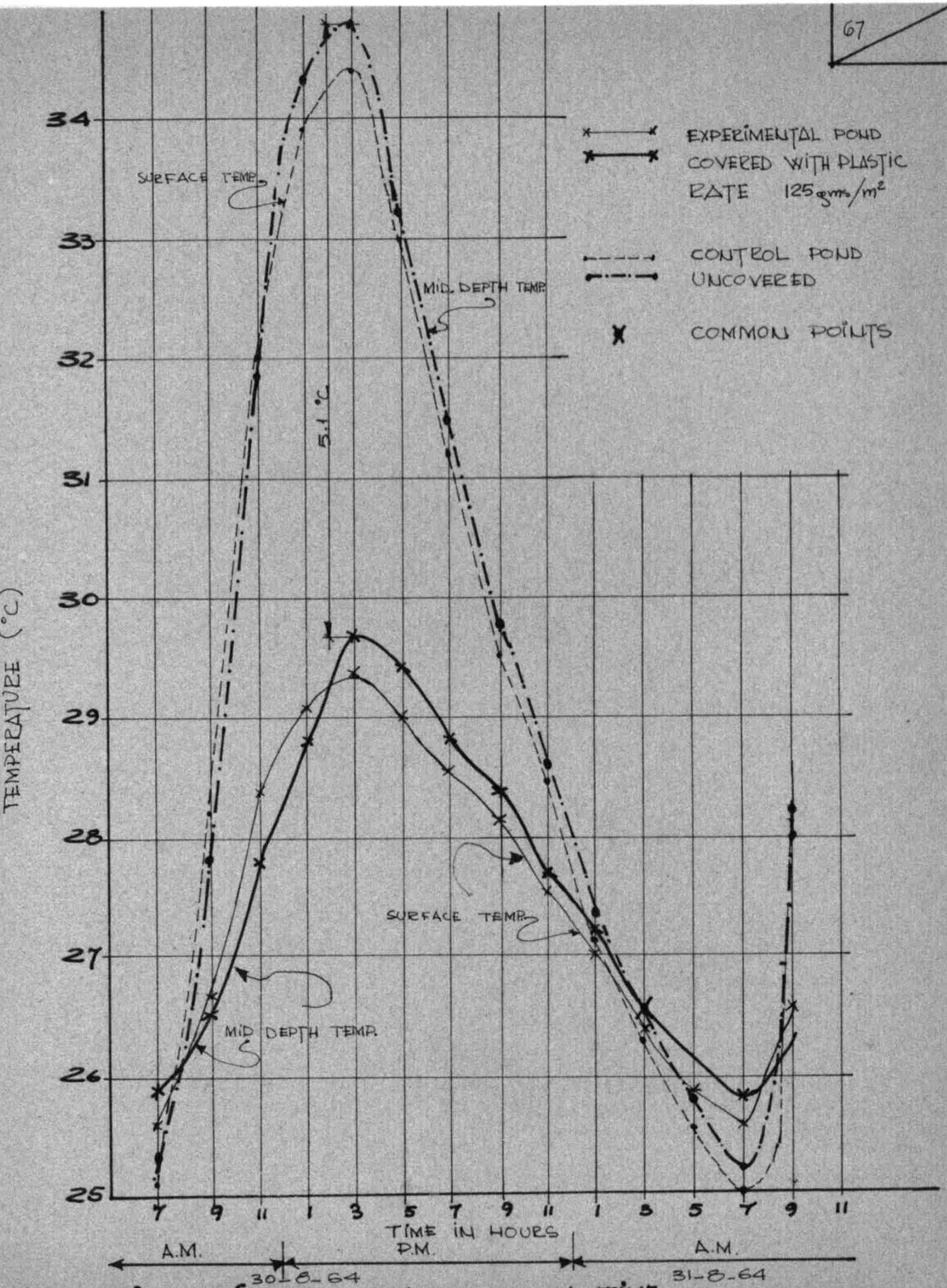


FIGURE 6. **TEMPERATURE Vs. TIME**

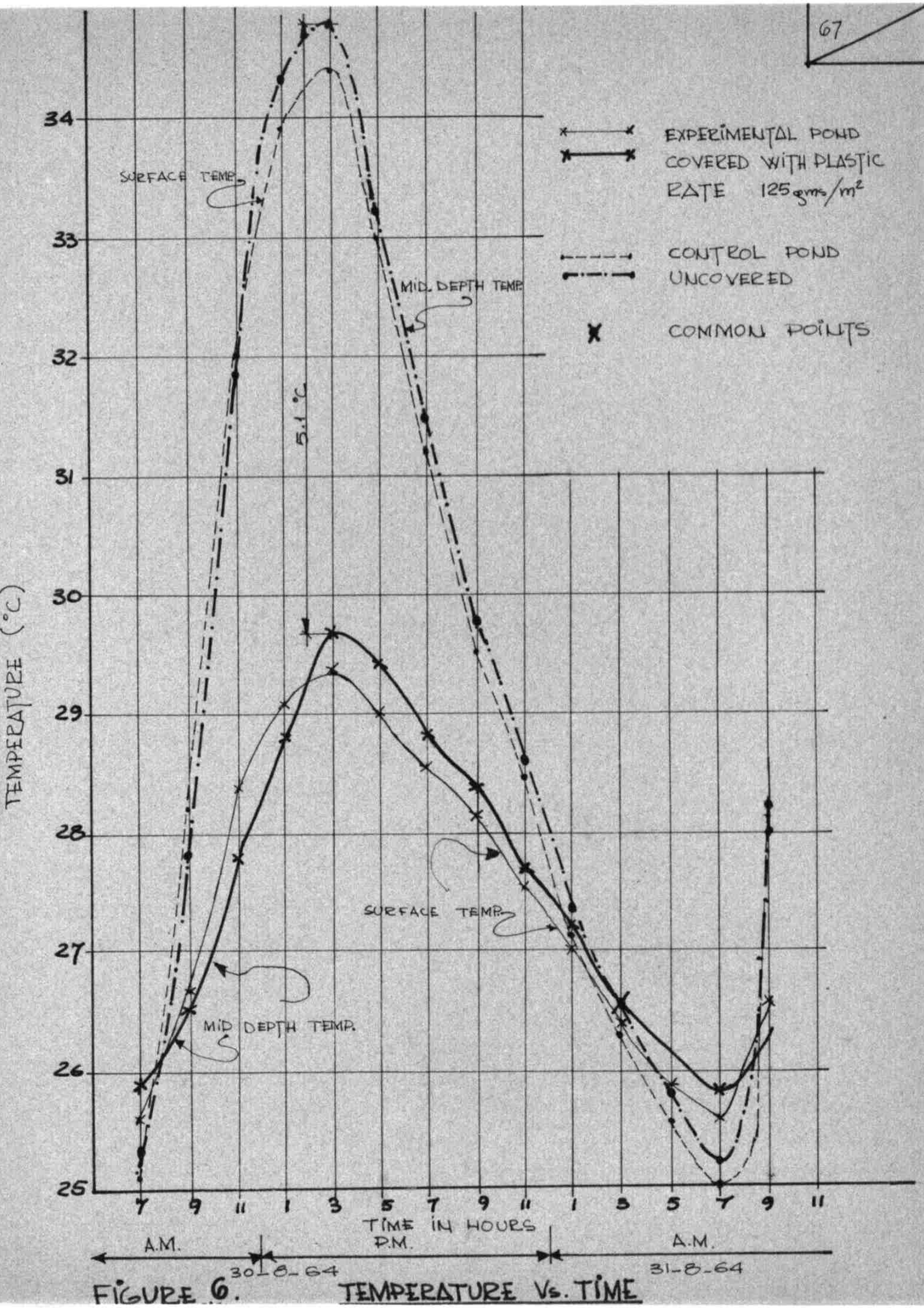


FIGURE 6. **TEMPERATURE Vs. TIME**

Test No. 3.

Period: August 31 - September 10.

Dosage: 150 gm/m^2.

Procedure: The Styropor dose present on the surface of the experimental pond at the end of the previous test was increased from 125 gm/m^2 to 150 gm/m^2. The Styropor beads already present were in good condition and there was no need to change them.

The volume of water lost by evaporation during the previous test was replenished and the water level in both ponds was brought up to the initial depth of 25 centimeters.

All readings were taken daily at 9:00 a.m. This data is given in Table 10.

On September 8-9, readings of water level drop and water temperature at mid-depth and surface in each pond as well as wind velocity and direction were taken at 2 hrs. intervals for 24 hours. Any other remarks of interest were recorded. This information is given in Table 11.

The temperature vs. time for the surface and mid-depth temperature in both ponds is given in Figure 7.

Results: It was observed during this testing period that a Styropor dose of 150 gm/m^2 provided a complete dense coverage of the experimental pond. Furthermore, the wind velocities experienced at the site did not have any effect on the coverage.

The cumulative water evaporation at the end of this test period was 1.950 cms. from the experimental pond and 4.130 cms. from the control pond.

The cumulative water saving for the test period was:

$$4.130 - 1.950 = 2.180 \text{ cms.}$$

This could be expressed as a cumulative saving of:

$$100\ (2.180 \div 4.130) = 52.8 \text{ percent.}$$

The cumulative saving in percent vs. time in days is given in Figure 9.

TABLE **10**. EXP. No 2 TEST № 3 PERIOD: AUG. 31 – SEP. 10

Date	Wind Velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 150 gms/m²									CONTROL POND									Remarks
		water depth cm.	Water temp °C Top	Water temp °C Mid. pt.	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms) A	24 hrs difference (cms) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	Water depth (cms.)	Water temp °C Top	Water temp °C Mid pt.	Hook gauge reading (cms) A	Hook gauge reading (cms) B	24 hrs difference (cms) A	24 hrs difference (cms) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cm)	
Aug 31	SW 0.7	25	26.6	26.3	38.16 2.58 40.74	39.71 2.61 42.32					25	28.3	28.0	43.40 5.25 48.65	43.72 5.25 48.97					Water was added to replenish that lost by evaporation. Styropor doe was increased on Aug. 31 from 125–150 gm/m². at start of test.
							← Reading taken at 8:30 P.M. 0.09	0.09	0.09	0.090						Reading taken at ← 8:30 P.M. 0.17	0.17	0.17	0.170	
Sept. 1	SW 0.8		26.8	26.5	40.65	42.23						28.6	28.2	48.48	48.80					
							0.20	0.21	0.205	0.295						0.39	0.40	0.395	0.565	
2	W 0.7		27.4	27.1	40.45	42.07						30.0	29.7	48.09	48.40					
							0.22	0.23	0.225	0.525						0.47	0.48	0.475	1.040	
3	W 0.6		27.0	26.6	40.23	41.79						28.5	28.1	47.62	47.92					
							0.21	0.21	0.21	0.730						0.42	0.42	0.42	1.460	
4	SW 0.7		27.3	27.1	40.02	41.58						28.6	28.3	47.20	47.50					
							0.20	0.20	0.20	0.930						0.43	0.43	0.43	1.890	
5	W 0.9		27.6	27.3	39.82	41.38						29.0	28.6	46.77	47.07					
							0.20	0.20	0.20	1.130						0.43	0.43	0.43	2.320	
6	W 1.0		27.5	27.2	39.62	41.18						28.9	28.5	46.34	46.74					
							0.20	0.20	0.20	1.330						0.46	0.46	0.46	2.780	
7	SW 0.8		27.4	27.1	39.42	40.98						30.0	29.7	45.88	46.18					
							0.23	0.21	0.22	1.550						0.45	0.45	0.45	3.230	
8	SW 0.7		27.1	26.8	39.19	40.77						28.4	28.1	45.43	45.73					
							0.21	0.21	0.21	1.760						0.45	0.47	0.46	3.690	
9	W 1.2		27.2	26.8	38.98	40.56						28.6	28.2	44.98	45.26					
							0.18	0.20	0.19	1.950						0.44	0.44	0.44	4.130	
10	SW 1.7	23	26.4	26.2	38.80	40.36					21	27.1	26.8	44.54	44.82					

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE **10**. EXP. No 2 TEST No 3 PERIOD: AUG. 31 – SEP. 10

Date	Wind Velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 150 gms/m²									CONTROL POND									Remarks
		water depth	Water temp °C		Hook gauge reading (cms)		24 hrs difference (cms)		Average 24 hrs Evap. (cms)	Total Evap to date (cms)	Water depth	Water temp °C		Hook gauge reading (cms)		24 hrs difference (cms)		Average 24 hrs. Evap. (cms)	Total Evap. to date (cm)	
		cm.	Top	Mid. pt.	A	B	A	B			(cms.)	Top	Mid pt.	A	B	A	B			
Aug 31	SW 0.7	25	26.6	26.3	38.16 2.58 40.74	39.71 2.61 42.32	← Reading taken at 8:30 P.M.				25	28.3	28.0	43.40 5.25 48.65	43.72 5.25 48.97	Reading taken at ← 8:30 P.M.				Water was added to replenish that lost by evaporation. Styropor dose was increased on Aug. 31 from 125 – 150 gm/m². at start of test.
							0.09	0.09	0.09	0.090						0.17	0.17	0.17	0.170	
Sept. 1	SW 0.8		26.8	26.5	40.65	42.23						28.6	28.2	48.48	48.80					
							0.20	0.21	0.205	0.295						0.39	0.40	0.395	0.565	
2	W 0.7		27.4	27.1	40.45	42.07						30.0	29.7	48.09	48.40					
							0.22	0.23	0.225	0.525						0.47	0.48	0.475	1.040	
3	W 0.6		27.0	26.6	40.23	41.79						28.5	28.1	47.62	47.92					
							0.21	0.21	0.21	0.730						0.42	0.42	0.42	1.460	
4	SW 0.7		27.3	27.1	40.02	41.58						28.6	28.3	47.20	47.50					
							0.20	0.20	0.20	0.930						0.43	0.43	0.43	1.890	
5	W 0.9		27.6	27.3	39.82	41.38						29.0	28.6	46.77	47.07					
							0.20	0.20	0.20	1.130						0.43	0.43	0.43	2.320	
6	W 1.0		27.5	27.2	39.62	41.18						28.9	28.5	46.34	46.74					
							0.20	0.20	0.20	1.330						0.46	0.46	0.46	2.780	
7	SW 0.8		27.4	27.1	39.42	40.98						30.0	29.7	45.88	46.18					
							0.23	0.21	0.22	1.550						0.45	0.45	0.45	3.230	
8	SW 0.7		27.1	26.8	39.19	40.77						28.4	28.1	45.43	45.73					
							0.21	0.21	0.21	1.760						0.45	0.47	0.46	3.690	
9	W 1.2		27.2	26.8	38.98	40.56						28.6	28.2	44.98	45.26					
							0.18	0.20	0.19	1.950						0.44	0.44	0.44	4.130	
10	SW 1.7	23	26.4	26.2	38.80	40.36					21	27.1	26.8	44.54	44.82					

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE **11**. EXP. No 2. TEST No 3. PERIOD: SEPT. 8 — SEPT. 9

		EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 150 gms./m²									CONTROL POND									
Date & Time	wind velocity & direction m/sec.	water depth cm.	water temp. °C Top	water temp. °C Mid pt	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference (cms.) A	2 hrs. difference (cms.) B	Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	Water depth (cm)	Water temp. °C Top	Water temp. °C Mid pt	Hook gauge readings (cm) A	Hook gauge readings (cm) B	2 hrs. difference (cms) A	2 hrs. difference (cms) B	Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	Remarks
Sept. 8 7 AM	SW 0.8	23.5	25.7	26.0	39.21	40.79					22	25.1	25.4	45.48	45.78					
							0.02	0.02	0.02	0.020						0.05	0.05	0.05	0.050	
9 AM	SW 0.7		26.9	26.8	39.19	40.77						28.3	28.1	45.43	45.73					
							0.02	0.02	0.02	0.040						0.04	0.04	0.04	0.090	
11 AM	SW 0.7		28.0	27.8	39.17	40.75						31.0	30.8	45.39	45.69					
							0.02	0.02	0.02	0.060						0.04	0.04	0.04	0.130	
1 PM	SW 0.5		29.0	28.7	39.15	40.73						33.3	33.2	45.35	45.65					
							0.03	0.03	0.03	0.090						0.06	0.06	0.06	0.190	
3 PM	W 0.4		28.9	29.0	39.12	40.70						34.0	34.4	45.29	45.59					
							0.03	0.03	0.03	0.120						0.06	0.06	0.06	0.250	
5 PM	W 0.6		28.6	28.8	39.09	40.67						32.7	33.0	45.23	45.53					
							0.02	0.02	0.02	0.140						0.05	0.05	0.05	0.300	
7 PM	W 0.8		28.1	28.4	39.07	40.65						30.8	31.0	45.18	45.48					
							0.02	0.02	0.02	0.160						0.04	0.04	0.04	0.340	
9 PM	W 0.8		27.8	28.0	39.05	40.63						29.4	29.6	45.14	45.44					
							0.01	0.01	0.01	0.170						0.03	0.03	0.03	0.370	
11 PM	W 0.8		27.4	27.6	39.04	40.62						28.2	28.4	45.11	45.41					
							0.01	0.01	0.01	0.180						0.03	0.03	0.03	0.400	
Sept. 9 1 AM	W 0.4		27.1	27.3	39.03	40.61						27.0	27.2	45.08	45.38					
							0.01	0.01	0.01	0.190						0.02	0.02	0.02	0.420	
3 AM	W 0.4		26.8	27.0	39.02	40.60						26.2	26.4	45.06	45.36					
							0.01	0.01	0.01	0.200						0.02	0.02	0.02	0.440	
5 AM	W 0.4		26.2	26.4	39.01	40.59						25.6	25.8	45.04	45.34					
							0.01	0.01	0.01	0.210						0.03	0.03	0.03	0.470	
7 AM	W 0.7		25.8	26.0	39.00	40.58						25.5	25.6	45.01	45.31					
							0.02	0.02	0.02	0.23						0.03	0.03	0.03	0.51	
9 AM	W 1.2		28.6	28.2	38.98	40.56						28.6	28.2	44.98	45.26					

* ALL READINGS TAKEN AT 2 hrs. INTERVALS.

TABLE **11**. EXP. № 2. TEST № 3. ... PERIOD: SEPT. 8 — SEPT. 9

Date & Time	wind velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF ..150.. gms./m². water depth cm.	water temp. °C Top	water temp. °C Mid pt	Hook gauge reading (cm) A	Hook gauge reading (cm) B	2 hrs. difference (cms) A	2 hrs. difference (cms) B	Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	CONTROL POND water depth (cm)	Water temp. °C Top	Water temp. °C Mid. pt	Hook gauge readings (cm) A	Hook gauge readings (cm) B	2 hrs. difference (cms) A	2 hrs. difference (cms) B	Average 2 hrs Evap (cms)	Total Evap. to date (cms)	Remarks
Sept. 8 7 AM	SW 0.8	23.5	25.7	26.0	39.21	40.79					22	25.1	25.4	45.48	45.78					
9 AM	SW 0.7		26.9	26.8	39.19	40.77	0.02	0.02	0.02	0.020		28.3	28.1	45.43	45.73	0.05	0.05	0.05	0.050	
11 AM	SW 0.7		28.0	27.8	39.17	40.75	0.02	0.02	0.02	0.040		31.0	30.8	45.39	45.69	0.04	0.04	0.04	0.090	
1 PM	SW 0.5		29.0	28.7	39.15	40.73	0.02	0.02	0.02	0.060		33.3	33.2	45.35	45.65	0.04	0.04	0.04	0.130	
3 PM	W 0.4		28.9	29.0	39.12	40.70	0.03	0.03	0.03	0.090		34.0	34.4	45.29	45.59	0.06	0.06	0.06	0.190	
5 PM	W 0.6		28.6	28.8	39.09	40.67	0.03	0.03	0.03	0.120		32.7	33.0	45.23	45.53	0.06	0.06	0.06	0.250	
7 PM	W 0.8		28.1	28.4	39.07	40.65	0.02	0.02	0.02	0.140		30.8	31.0	45.18	45.48	0.05	0.05	0.05	0.300	
9 PM	W 0.8		27.8	28.0	39.05	40.63	0.02	0.02	0.02	0.160		29.4	29.6	45.14	45.44	0.04	0.04	0.04	0.340	
11 PM	W 0.8		27.4	27.6	39.04	40.62	0.01	0.01	0.01	0.170		28.2	28.4	45.11	45.41	0.03	0.03	0.03	0.370	
Sept. 9 1 AM	W 0.4		27.1	27.3	39.03	40.61	0.01	0.01	0.01	0.180		27.0	27.2	45.08	45.38	0.03	0.03	0.03	0.400	
3 AM	W 0.4		26.8	27.0	39.02	40.60	0.01	0.01	0.01	0.190		26.2	26.4	45.06	45.36	0.02	0.02	0.02	0.420	
5 AM	W 0.4		26.2	26.4	39.01	40.59	0.01	0.01	0.01	0.200		25.6	25.8	45.04	45.34	0.02	0.02	0.02	0.440	
7 AM	W 0.7		25.8	26.0	39.00	40.58	0.01	0.01	0.01	0.210		25.5	25.6	45.01	45.31	0.03	0.03	0.03	0.470	
9 AM	W 1.2		28.6	28.2	38.98	40.56	0.02	0.02	0.02	0.23		28.6	28.2	44.98	45.26	0.03	0.03	0.03	0.51	

* ALL READINGS TAKEN AT 2 hrs. INTERVALS.

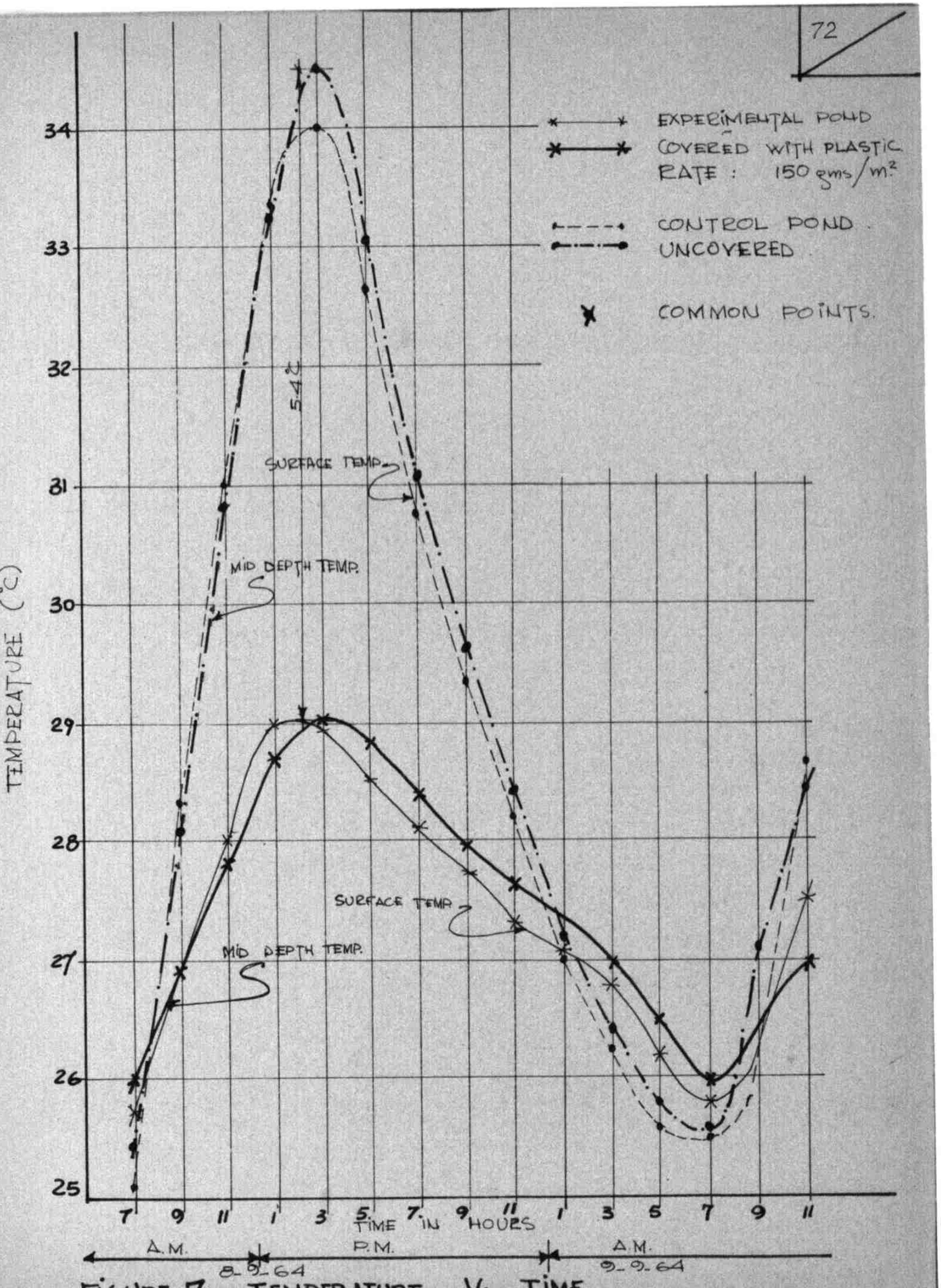


FIGURE .7. TEMPERATURE Vs. TIME

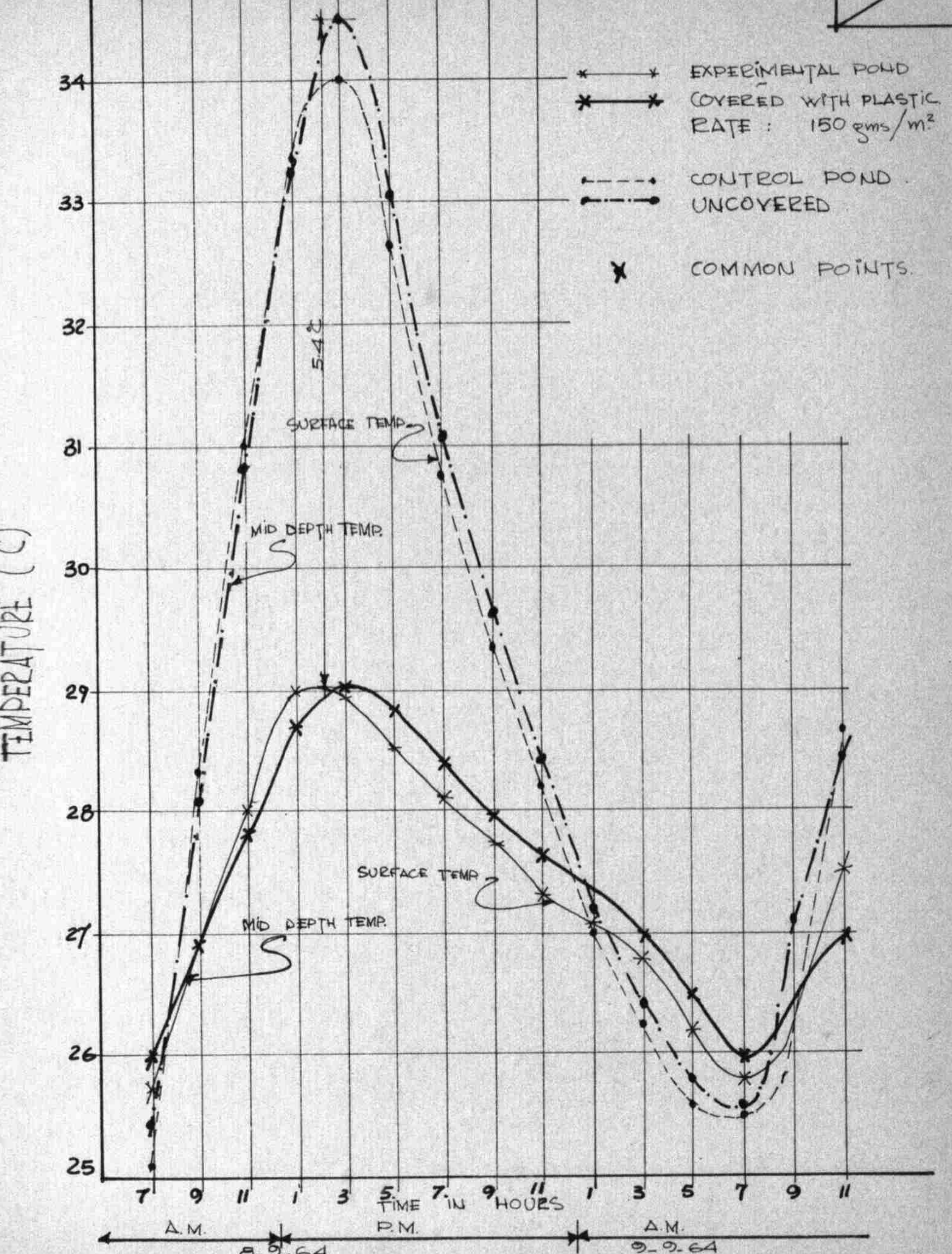


FIGURE 7. TEMPERATURE Vs. TIME

Test No. 4.

Period: September 10 - September 23.

Dosage: 75 gm/m^2.

The results of the preceeding three tests were close to one another. It was desired to investigate a wider range of doses than originally planned. The Styropor dose of 150 gm/m^2 appeared to be compact over the water surface to such an extent that a higher dosage seemed a waste of material, since the beads forming the upper part of the Styropor layer will become dry shortly after application and be blown away by wind action. An alternative was to investigate with a dose of 75 gm/m^2. This would give information regarding the performance of the Styropor in this dosage and the water saving obtained would be needed in the procedure for the selection of the most economical rate of application.

Procedure: The dosage selected for experimentation was half that existing over the water surface of the experimental pond at the end of the previous test. The beads present were evenly distributed over the water surface. A wood baffle was inserted to divide the experimental pond into two equal parts. This was done in order to facilitate the removal of half the amount of Styropor beads present. The baffle was fixed at both ends by strutting it, in the transverse direction of the pond, against the walls. The Styropor beads floating over one half of the pond were collected by means of a fine screen and removed for storage. When the baffle was later removed, the beads remaining in the experimental pond were distributed by hand over the pond surface. The beads floated in a less compact but uniform layer over the water surface with a coverage of about 90 percent.

The water levels in the two ponds were raised to 25 cms, to replenish water lost by evaporation from both and that lost by the removal of Styropor beads from the experimental.

The hook readings were adjusted and daily readings were taken as in previous tests. The data obtained are given in Table 12.

On September 21-22, readings of water loss by evaporation, water temperature at surface and mid-depth in each pond, as well as wind velocity and direction were recorded at 2 hrs. intervals for 24 hours. Other important remarks were recorded. This data is given in Table 13. The temperature vs. time curves for surface and mid-depth temperature in both ponds for this 24 hr. period is given in Figure 8.

<u>Results</u>: The results of the first six days showed a drop in the cumulative percentage saving from 45 percent in the first day to 35.2 percent in the sixth day (see Figure 9). On the tenth day, the cumulative saving was 35 percent.

Owing to the fact that a quick drop in the cumulative saving had resulted during the first six days it was decided, on the tenth day to continue the test for few more days in order to obtain more reliable data on the savings of the dose applied.

The thirteenth day results showed a cumulative percent saving of 34.1 percent.

It was noticed that the cumulative percent savings for the sixth, tenth and thirteenth days were close to one another. The drop in cumulative saving happened actually during the first six days. This result which was expected could be attributed to the following: The Styropor layer repells sunlight and thus insulates the water on which it floats up to a certain degree. As expected, when this layer was reduced from 150 gm/m^2 to 75 gm/m^2, the resulting layer was less compact and its coverage was not complete. The new dose of 75 gm/m^2 afforded less insulation and consequently a smaller difference in daily water temperatures between the experimental and control ponds. The first six days appear to be a period of adjustment. An opposite effect is expected to result when the Styropor dose is increased.

The Styropor layer in a dosage of 75 gm/m^2 did not make complete coverage. The effect of wind action on this Styropor layer was more pronounced than the effects on the higher doses applied previously. Wind velocities between 5 km/hr and 10 km/hr resulted in pressing the Styropor beads slightly against the leeward side of the pond reducing the coverage. Cracks in the layer were observed at such wind velocities.

The cumulative water evaporation for the first 10 days of the test period were 2.400 cms. from the experimental pond and 3.705 cms. from the control pond.

The cumulative water saving for this period was:

$$3.705 - 2.400 = 1.305$$

This could be expressed as a cumulative saving of

$$100\ (1.305 \div 3.705) = 35 \text{ percent.}$$

The cumulative saving in percent vs. time in days is given in Figure 9.

TABLE 12

EXP 2 TEST No 4 PERIOD Sept.10 _ Sept. 23

Date	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 75 gms /m²									CONTROL POND									Remarks
		Water depth	Water Temp. °C		Hook gauge reading (cm).		24 hrs. difference cms.		Average 24 hrs. Evap. (cm.)	Total Evap. to date (cm.)	Water depth (Cm.)	Water temp. °C		Hook gauge reading (cm.)		24 hrs. difference cms.		Average 24 hrs Evap. (Cm.)	Total Evap. to date (Cm.)	
		Cm.	Top.	Mid.pt.	A	B	A	B				Top.	Mid.pt.	A	B	A	B			
Sept.10	SW 1.7	25	26.4	26.2	38.80 1.94 40.74	40.36 1.95 42.31	Reading taken at 9:00 P.M. 0.07	0.06	0.065	0.065	25	27.1	26.8	44.54 4.13 48.67	44.82 4.13 48.95	Reading taken at 9:00 P.M. 0.14	0.10	0.120	0.120	
11	W 1.7		26.0	25.8	40.67	42.25	0.24	0.26	0.250	0.315		27.6	27.4	48.53	48.85	0.43	0.45	0.440	0.560	
12	W 0.7		25.4	25.2	40.43	41.99	0.21	0.22	0.215	0.530		26.5	26.3	48.10	48.40	0.36	0.37	0.370	0.925	
13	W 0.5		25.8	25.6	40.22	41.77	0.27	0.27	0.270	0.800		26.9	26.7	47.74	48.03	0.39	0.39	0.390	1.315	
14	W 0.7		26.4	26.1	39.95	41.50	0.27	0.27	0.270	1.070		27.9	27.6	47.35	47.64	0.38	0.38	0.380	1.695	
15	W 0.8		26.3	26.0	39.68	41.23	0.27	0.27	0.270	1.340		27.7	27.4	46.97	47.26	0.37	0.37	0.370	2.065	
16	W 0.9		26.2	25.9	39.41	40.96						27.4	27.1	46.60	46.89					
17																				No readings were taken on Sept. 17, 18, and 19.
18																				
19							1.06	1.06	1.06	2.400						1.66	1.62	1.640	3.705	
20			25.9	25.6	38.35	39.90	0.28	0.25	0.265	2.665		27.1	26.8	45.94	45.27	0.46	0.43	0.445	4.150	
21	NW 0.9		25.9	25.0	38.07	39.65	0.29	0.29	0.29	2.955		27.1	26.8	44.48	44.84	0.38	0.38	0.380	4.530	
22	NW 0.85		25.9	25.6	37.78	39.36	0.38	0.38	0.38	3.335		27.8	27.6	44.10	44.46	0.48	0.48	0.48	5.010	
23	NW 1.4		24.5	24.2	37.40	38.98						25.6	25.3	43.62	43.98					

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE 12

EXP. 2 TEST No. 4 PERIOD Sept.10 – Sept. 23

Date	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 75 gms/m²									CONTROL POND									Remarks
		Water depth	Water Temp. °C		Hook gauge reading (cm).		24 hrs. difference cms.		Average 24 hrs Evap. (cm.)	Total Evap. to date (cm.)	Water depth	Water temp. °C		Hook gauge reading (cm.)		24 hrs. difference cms.		Average 24 hrs Evap. (cm.)	Total Evap. to date (cm.)	
		cm.	Top.	Mid.pt.	A	B	A	B			(cm.)	Top.	Mid.pt.	A	B	A	B			
Sept.10	SW 1.7	25	26.4	26.2	38.80 1.94 40.74	40.36 1.95 42.31	Reading taken at 9:00 P.M.				25	27.1	26.8	44.54 4.13 48.67	44.82 4.13 48.95	Reading taken at 9:00 P.M.				
11	W 1.7		26.0	25.8	40.67	42.25	0.07	0.06	0.065	0.065		27.6	27.4	48.53	48.85	0.14	0.10	0.120	0.120	
12	W 0.7		25.4	25.2	40.43	41.99	0.24	0.26	0.250	0.315		26.5	26.3	48.10	48.40	0.43	0.45	0.440	0.560	
13	W 0.5		25.8	25.6	40.22	41.77	0.21	0.22	0.215	0.530		26.9	26.7	47.74	48.03	0.36	0.37	0.370	0.925	
14	W 0.7		26.4	26.1	39.95	41.50	0.27	0.27	0.270	0.800		27.9	27.6	47.35	47.64	0.39	0.39	0.390	1.315	
15	W 0.8		26.3	26.0	39.68	41.23	0.27	0.27	0.270	1.070		27.7	27.4	46.97	47.26	0.38	0.38	0.380	1.695	
16	W 0.9		26.2	25.9	39.41	40.96	0.27	0.27	0.270	1.340		27.4	27.1	46.60	46.89	0.37	0.37	0.370	2.065	
17																				No readings were taken on Sept. 17, 18, and 19.
18																				
19																				
20			25.9	25.6	38.35	39.90	1.06	1.06	1.06	2.400		27.1	26.8	45.94	45.27	1.66	1.62	1.640	3.705	
21	NW 0.9		25.9	25.0	38.07	39.65	0.28	0.25	0.265	2.665		27.1	26.8	44.48	44.84	0.46	0.43	0.445	4.150	
22	NW 0.85		25.9	25.6	37.78	39.36	0.29	0.29	0.29	2.955		27.8	27.6	44.10	44.46	0.38	0.38	0.380	4.530	
23	NW 1.4		24.5	24.2	37.40	38.98	0.38	0.38	0.38	3.335		25.6	25.3	43.62	43.98	0.48	0.48	0.48	5.010	

* ALL READINGS TAKEN AT 9:00 A.M.

TABLE 13 EXPT. No. 2 TEST No. 4 PERIOD: SEPT. 21 – SEPT. 22

Date & Time	Wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH [illegible] AT THE RATE OF 77 [illegible]									CONTROL POND									Remarks
		Water depth cm	Water temp °C Top	Water temp °C Mid pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	2 hrs difference (cms) A	2 hrs difference (cms) B	Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	Water depth (cm.)	Water temp °C Top	Water temp °C Mid pt	Hook gauge reading (cms) A	Hook gauge reading (cms) B	2 hrs difference (cms) A	2 hrs difference (cms) B	Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	
Sept. 21 7 AM	NW 1.0	22	24.4	24.6	38.09	39.67					20.5	23.9	24.2	44.51	44.86					
							0.02	0.02	0.02	0.020						0.03	0.02	0.025	0.025	
9 AM	NW 0.9		25.9	25.6	38.07	39.65						27.0	26.8	44.48	44.84					
							0.02	0.02	0.02	0.040						0.02	0.03	0.025	0.050	
11 AM	NW 0.9		26.8	26.4	38.05	39.63						28.3	28.1	44.46	44.81					
							0.03	0.03	0.03	0.070						0.04	0.04	0.04	0.090	
1 PM	NW 0.8		27.9	27.6	38.02	39.60						30.3	30.1	44.42	44.77					
							0.04	0.04	0.04	0.110						0.05	0.05	0.05	0.140	
3 PM	NW 0.8		28.1	28.4	37.98	39.56						31.1	31.4	44.37	44.72					
							0.04	0.04	0.04	0.150						0.05	0.05	0.05	0.190	
5 PM	NW 0.8		27.3	27.7	37.94	39.52						30.3	30.6	44.32	44.67					
							0.03	0.03	0.03	0.180						0.04	0.04	0.04	0.230	
7 PM	W 0.6		26.9	27.1	37.91	39.49						29.2	29.4	44.28	44.63					
							0.02	0.02	0.02	0.200						0.03	0.03	0.03	0.260	
9 PM	W 0.6		26.4	26.6	37.89	39.47						28.0	28.2	44.25	44.60					
							0.02	0.02	0.02	0.220						0.02	0.02	0.02	0.280	
11 PM	W 0.6		25.9	26.1	37.87	39.45						27.0	27.2	44.23	44.58					
							0.01	0.02	0.015	0.235						0.02	0.02	0.02	0.300	
Sept. 22 1 AM	W 0.4		25.5	25.7	37.86	39.43						26.0	26.3	44.21	44.56					
							0.01	0.01	0.01	0.245						0.02	0.02	0.02	0.320	
3 AM	W 0.6		25.0	25.3	37.85	39.42						25.3	25.5	44.19	44.54					
							0.01	0.01	0.01	0.255						0.02	0.02	0.02	0.340	
5 AM	NW 0.5		24.8	25.0	37.84	39.41						24.5	24.7	44.17	44.52					
							0.03	0.02	0.025	0.280						0.03	0.03	0.03	0.370	
7 AM	NW 0.7		24.5	24.7	37.81	39.39						24.3	24.4	44.14	44.49					
							0.03	0.03	0.03	0.310						0.04	0.03	0.035	0.405	
9 AM	NW 0.85		25.9	25.6	37.78	39.36						27.9	27.6	44.10	44.46					

* ALL READINGS TAKEN AT 2 hrs. INTERVALS.

TABLE 13. EXP. No. 2 TEST No. 4 PERIOD: SEPT. 21 – SEPT. 22

Date & Time	wind velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 75 gms/m². water depth									CONTROL POND water depth									Remarks
		water depth	water temp °C		Hook gauge reading (cm)		2 hrs. difference (cms)		Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	water depth	water temp °C		Hook gauge readings (cm)		2 hrs difference (cms.)		Average 2 hrs Evap. (cms)	Total Evap. to date (cms)	
		cm	Top	Mid pt.	A	B	A	B			(cm.)	Top	Mid pt.	A	B	A	B			
Sept. 21 7 AM	NW 1.0	22	24.4	24.6	38.09	39.67					20.5	23.9	24.2	44.51	44.86					
							0.02	0.02	0.02	0.020						0.03	0.02	0.025	0.025	
9 AM	NW 0.9		25.9	25.6	38.07	39.65						27.0	26.8	44.48	44.84					
							0.02	0.02	0.02	0.040						0.02	0.03	0.025	0.050	
11 AM	NW 0.9		26.8	26.4	38.05	39.63						28.3	28.1	44.46	44.81					
							0.03	0.03	0.03	0.070						0.04	0.04	0.04	0.090	
1 PM	NW 0.8		27.9	27.6	38.02	39.60						30.3	30.1	44.42	44.77					
							0.04	0.04	0.04	0.110						0.05	0.05	0.05	0.140	
3 PM	NW 0.8		28.1	28.4	37.98	39.56						31.1	31.4	44.37	44.72					
							0.04	0.04	0.04	0.150						0.05	0.05	0.05	0.190	
5 PM	NW 0.8		27.3	27.7	37.94	39.52						30.3	30.6	44.32	44.67					
							0.03	0.03	0.03	0.180						0.04	0.04	0.04	0.230	
7 PM	W 0.6		26.9	27.1	37.91	39.49						29.2	29.4	44.28	44.63					
							0.02	0.02	0.02	0.200						0.03	0.03	0.03	0.260	
9 PM	W 0.6		26.4	26.6	37.89	39.47						28.0	28.2	44.25	44.60					
							0.02	0.02	0.02	0.220						0.02	0.02	0.02	0.280	
11 PM	W 0.6		25.9	26.1	37.87	39.45						27.0	27.2	44.23	44.58					
							0.01	0.02	0.015	0.235						0.02	0.02	0.02	0.300	
Sept. 22 1 AM	W 0.4		25.5	25.7	37.86	39.43						26.0	26.3	44.21	44.56					
							0.01	0.01	0.01	0.245						0.02	0.02	0.02	0.320	
3 AM	W 0.6		25.0	25.3	37.85	39.42						25.3	25.5	44.19	44.54					
							0.01	0.01	0.01	0.255						0.02	0.02	0.02	0.340	
5 AM	NW 0.5		24.8	25.0	37.84	39.41						24.5	24.7	44.17	44.52					
							0.03	0.02	0.025	0.280						0.03	0.03	0.03	0.370	
7 AM	NW 0.7		24.5	24.7	37.81	39.39						24.3	24.4	44.14	44.49					
							0.03	0.03	0.03	0.310						0.04	0.03	0.035	0.405	
9 AM	NW 0.85		25.9	25.6	37.78	39.36						27.9	27.6	44.10	44.46					

* ALL READINGS TAKEN AT 2 hrs. INTERVALS.

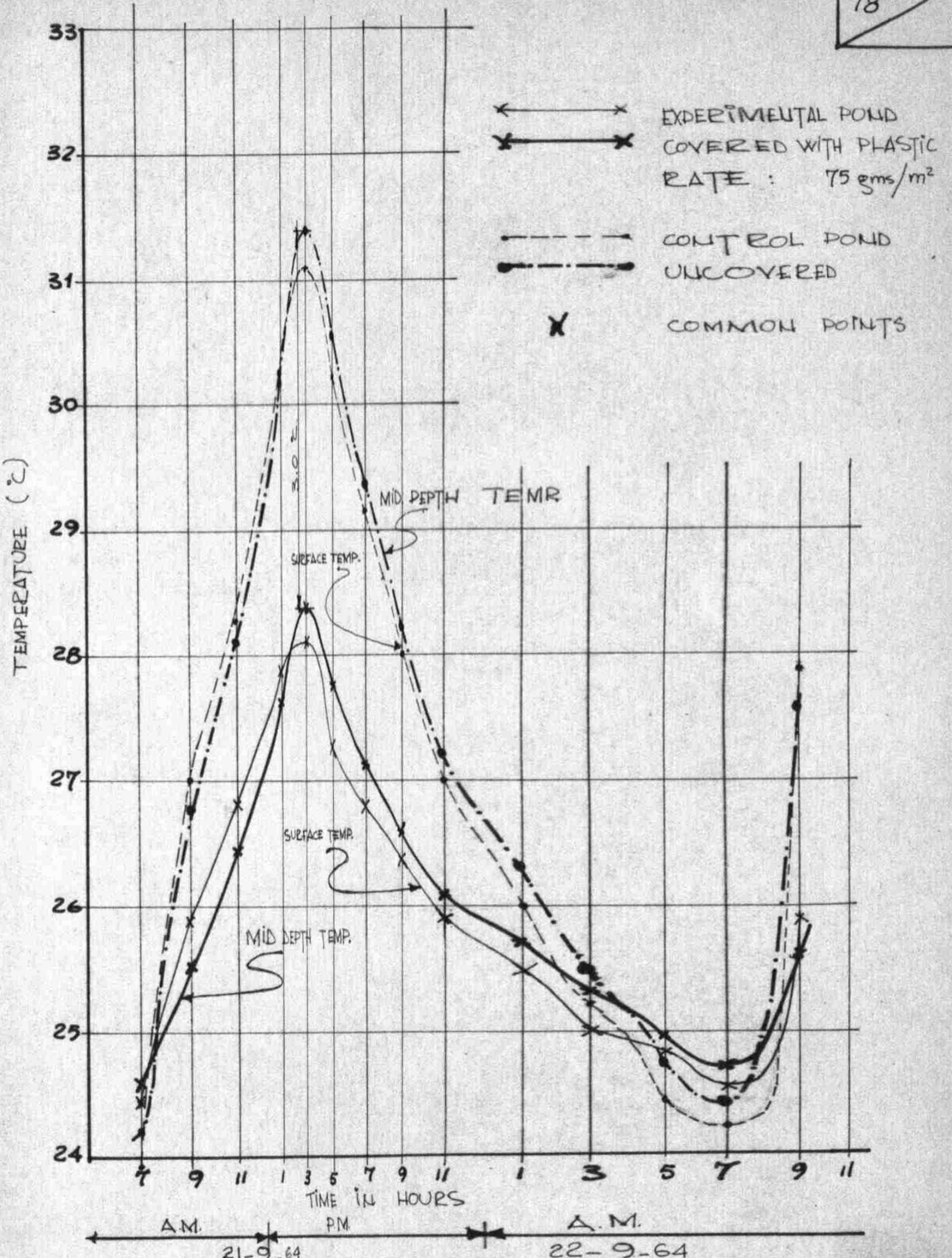


FIGURE..8. TEMPERATURE Vs TIME

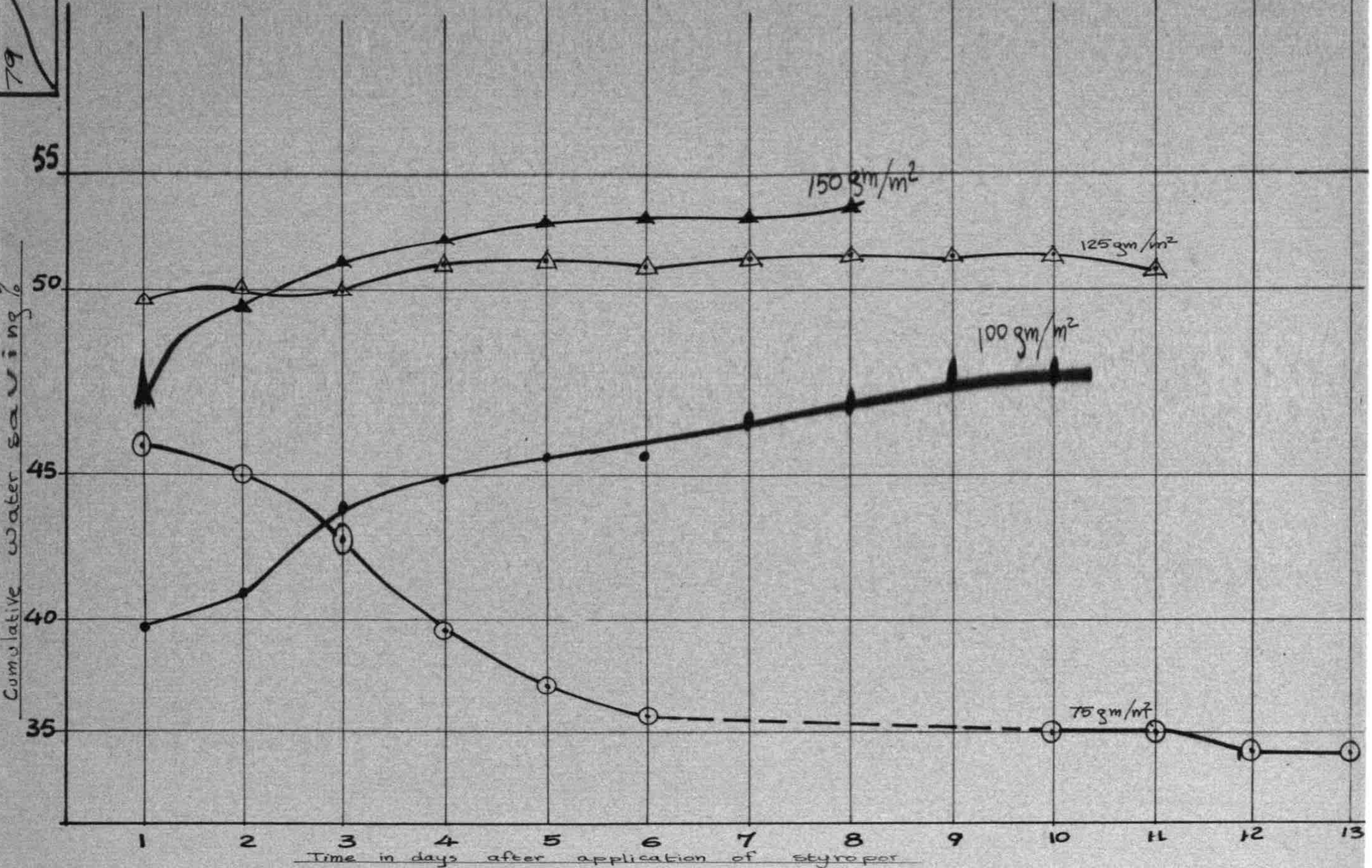


Figure (9) showing the cumulative saving in water by different styropor doses over that from an untreated surface under identical conditions in two ponds measuring 12.86 m. x 3.46 m. (Aug. 10 — Sept. 23, 1964)

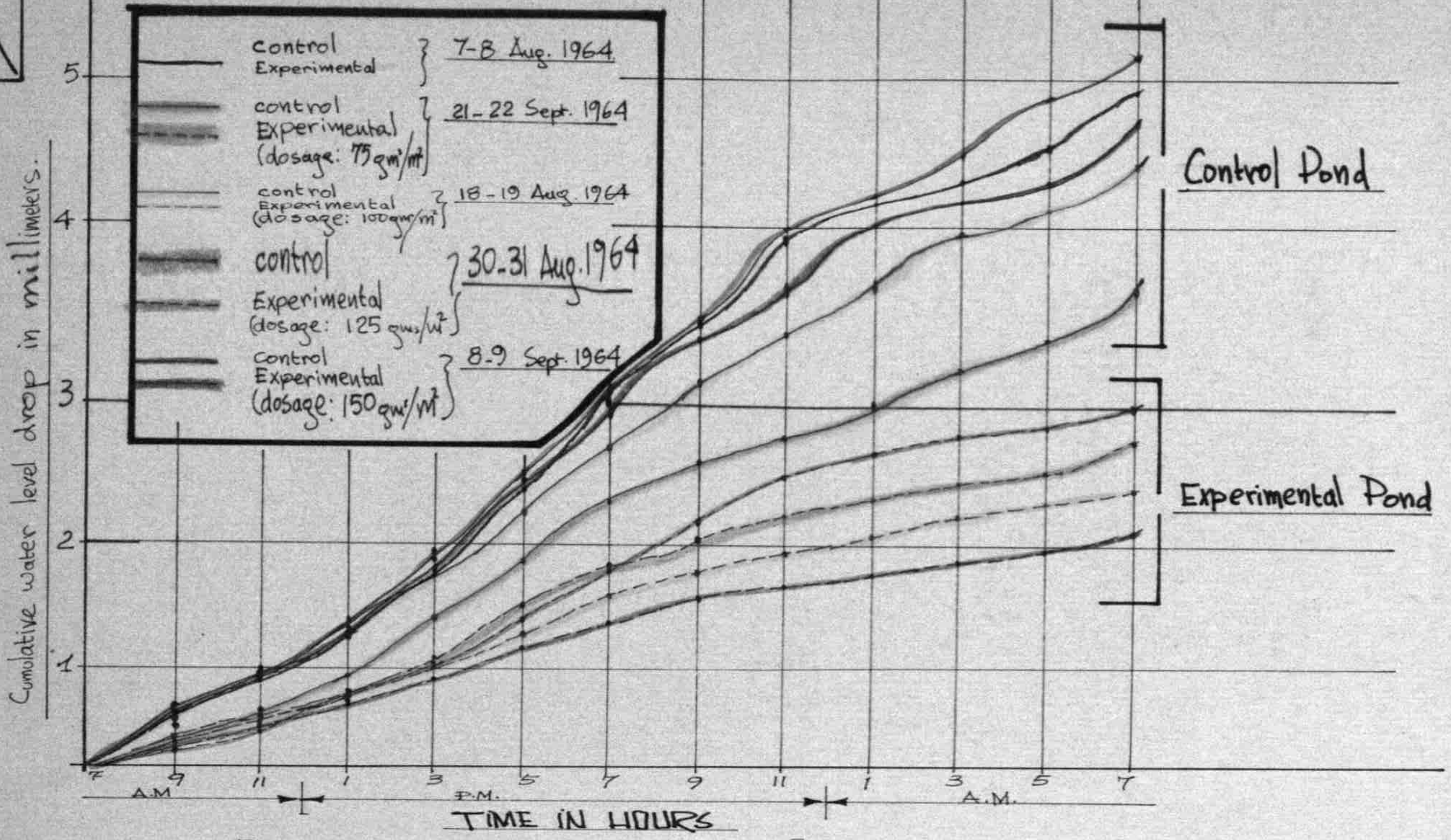


Figure 10 Typical Evaporation Curves showing the Cumulative water Level Drop vs. Time, for the control and the experimental ponds on all different days. with different Styropor application rates as indicated. Readings were taken at 2 hrs. intervals.

Experiment No. 3.

Period: September 29 - October 4.

Objective: To check whether evaporation from the control and experimental ponds was still the same or whether a factor relating the evaporation from both ponds had been introduced with time. Almost 50 days have passed since the start of the investigation and it was desired to ascertain whether factors such as leakage or unequal shading of the two ponds due to the surrounding buildings have come to exert some effects. It was necessary to establish such a fact.

Procedure: All the Styropor beads present in the experimental pond were removed by means of a fine wire screen. The two ponds were emptied by siphoning the contained water and cleaned very well.

Tap water was then admitted into the two ponds in the usual manner. The new water depth in the two ponds stood at approximately 25 centimeters. The ponds were now run as control.

Daily readings of water level drop as well as all other information gathered in previous tests were recorded daily at 9:00 a.m. This data is given in Table 14.

Results: At the end of this 5-day test the cumulative water evaporation from each of the two ponds was 1.88 cms, which indicated that the potential evaporation from both ponds was still the same.

TABLE 14. EXP. № 3 TEST № 1 PERIOD Sept 29 — Oct. 4

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF ZERO gms/m²									CONTROL POND									Remarks
		water depth (cm.)	water temp. °C Top	water temp. °C Mid pt.	Hook gauge reading (cm) A	Hook gauge reading (cm) B	24 hrs. difference (cm.) A	24 hrs. difference (cm.) B	Average 24 hrs Evap. (cms)	Total Evap. to date (cms.)	water depth (cms)	Water temp °C Top	Water temp °C Mid pt.	Hook gauge readings (cms) A	Hook gauge readings (cms) B	24 hrs. difference (cms) A	24 hrs. difference (cms) B	Average 24 hrs Evap. (cms.)	Total Evap. to date (cms.)	
Sept. 29	W 0.7	24.5	24.2	24.0	40.10	41.69					24.5	24.8	24.6	48.32	48.59					
30	W 0.7		24.4	24.2	39.74	41.33	0.36	0.36	0.360	0.360		25.1	24.9	47.96	48.23	0.36	0.36	0.36	0.360	
Oct. 1	W 0.7		24.4	24.4	39.34	40.92	0.40	0.41	0.405	0.765		25.1	25.1	47.55	47.83	0.41	0.40	0.405	0.765	
2	W 0.8		23.6	23.5	39.05	40.63	0.29	0.29	0.290	1.055		24.5	24.4	47.25	47.54	0.30	0.29	0.295	1.060	
3	W 0.4		23.5	23.3	38.67	40.26	0.38	0.37	0.376	1.430		23.9	23.6	46.87	47.16	0.38	0.38	0.380	1.440	
4	W 0.7		225	223	38.22	39.81	0.45	0.45	0.450	1.880		23.6	23.4	46.43	46.72	0.44	0.44	0.440	1.880	

* ALL READINGS TAKEN AT 9:00 AM.

Experiment No. 4.

Period: October 5 - October 15.

Objective: To determine the effect on water evaporation suppression, chemical and physical quality of water using selected doses of white floating Styropor beads and hexadecanol (Cetyl alcohol) under identical field conditions.

Procedure: Research conducted in many parts of the world on the use of hexadecanol as a water evaporation retardant had shown that the most desirable dose to be applied was 0.3 lbs/acre/day.[23,25,26]

Using the results of experiment 2, the savings realized by the use of 4 different Styropor doses, over 10-day test periods, an economy study was made. The most economical Styropor dose was found to be 100 gm/m^2 (see Figure 22).

Hence a comparison between these two materials at the most suitable dose for each seemed to be justified.

Styropor beads were applied, in the manner described earlier, to the experimental pond. The beads applied were taken from the stock which has been used earlier in the study.

The hexadecanol was applied in powder form by hand daily at 9:00 a.m. Eight feed points were selected all around the control pond in order to permit better and more quick coverage of the water surface by the chemical with the help of wind action. Daily application of the recommended dose of 0.3 lbs/acre/day was used because of the fact that applying better results than application of one large initial dose.[25]

a small daily dose gave ....

Daily readings of water level drop due to evaporation from the two ponds were recorded. Information on water temperature at surface and mid-depth, algae and mosquito breeding, if any, in the two ponds was also recorded together with the daily wind velocity and direction at 9:00 a.m. This data is given in Table 15.

Water samples were collected daily from the two ponds in the morning after recording the readings. These samples were taken to the laboratory and tested for determining the effects of the Styropor beads on the physical and chemical properties of water. The results of these tests are given in Table 16.

On October 14-15 routine readings were taken at 2 hrs. intervals, while water level drop in the two ponds was taken at 4 hrs. intervals, for 24 hours. The data collected is presented in Table 17.

Figure 11 shows the temperature vs. time curves for both ponds during the day of October 14-15.

The behaviour of the Styropor layer was observed under wind action and results were recorded. The hexadecanol film was observed frequently during the day to ascertain the degree of coverage.

Results: It was observed through the test period that the hexadecanol powder dissolved readily in the pond water and spread very quickly over the water surface. Visual inspection indicated that the resulting coverage was complete.

No mosquito breeding had been observed in either pond. Algae growth was observed in the two ponds, but the growth in the pond treated with hexadecanol was heavier.

At the conclusion of the 10-day experiment the cumulative evaporation loss from the pond covered with Styropor beads was 2.00 cms, while that from the pond treated with hexadecanol was 2.795 cms. The cumulative relative water saving for this period was:

$$2.795 - 2.00 = 0.795 \text{ cms.}$$

This could be expressed as a cumulative relative water saving of:

$$100\ (0.795 \div 2.795) = 28.5 \text{ percent.}$$

Results indicated that the savings from Styropor over those from hexadecanol increased with time.

Figure 12 shows the cumulative relative saving in percent vs. time in days.

In temperature vs. time curves for the two ponds given in Figure 11 for the day of October 14-15 showed that the maximum surface water temperature in the pond treated with Styropor beads was 4.8° C. lower than the maximum surface water temperature in the pond treated with hexadecanol. These temperatures were experienced at the same time during that day and indicate that the pond treated with Styropor has received less solar energy. This difference in temperature between the two ponds is believed to have contributed to the higher savings obtained by the use of Styropor. The laboratory tests undertaken during this experiment indicated that the Styropor layer did not affect the physical or chemical properties of the pond water on which it was applied. Further discussion of this item will be presented in Chapter VI.

TABLE **15.** EXP No 4 TEST No 1 PERIOD: Oct. 5 — Oct. 15

Date	wind velocity & direction m/sec	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms/m²									CONTROL POND. Treated with Hexadecanol at the rate of 0.3 lb/acre/day									Remarks
		water depth	water temp °C		Hook gauge reading (cm)		24 hrs difference (cms)		Average 24 hrs Evap. (cms)	Total Evap. to date (cms)	water depth	water temp °C		Hook gauge readings (cm)		24 hrs. difference (cms)		Average 24 hrs. Evap (cms)	Total Evap. to date (cms)	
		(cm)	Top	Mid pt.	A	B	A	B			(cm)	Top	Mid pt.	A	B	A	B			
Oct. 5	W 0.5	24.5	22.9	22.7	40.22	41.72					24.5	23.4	23.2	48.25	48.55					
6	W 0.8		20.9	20.5	39.67	41.29	0.45	0.43	0.44	0.44		22.7	22.6	47.75	48.06	0.50	0.49	0.495	0.495	
7	W 0.7		22.0	21.5	39.41	41.05	0.26	0.24	0.25	0.69		24.0	23.5	47.44	47.76	0.31	0.30	0.305	0.800	
8	W 0.6		22.6	22.2	39.20	40.84	0.21	0.21	0.21	0.90		25.5	25.0	47.18	47.50	0.26	0.26	0.260	1.060	
9	W 0.6		23.5	23.0	39.01	40.65	0.19	0.19	0.19	1.09		26.1	25.6	46.92	47.23	0.26	0.265	0.265	1.325	
10	W 0.3		23.6	23.2	38.85	40.49	0.16	0.16	0.16	1.25		26.5	26.0	46.66	46.97	0.26	0.26	0.260	1.585	
11	W 0.9		23.7	23.2	38.69	40.33	0.16	0.16	0.16	1.41		26.2	25.8	46.40	46.71	0.26	0.26	0.260	1.845	
12	W 0.6		23.8	23.5	38.54	40.18	0.15	0.15	0.15	1.56		27.0	26.5	46.16	46.47	0.24	0.24	0.240	2.085	
13	W 0.6		23.6	23.4	38.39	40.03	0.15	0.15	0.15	1.71		26.6	26.2	45.91	46.22	0.25	0.25	0.250	2.335	
14	W 0.6		24.0	23.7	38.26	39.89	0.13	0.14	0.135	1.845		25.8	25.5	45.69	46.00	0.22	0.22	0.220	2.555	
15	W 0.6		24.1	23.8	38.10	39.74	0.16	0.15	0.155	2.00		26.1	25.8	45.45	46.76	0.24	0.24	0.24	2.795	

* ALL READINGS TAKEN AT 9:00 A.M.

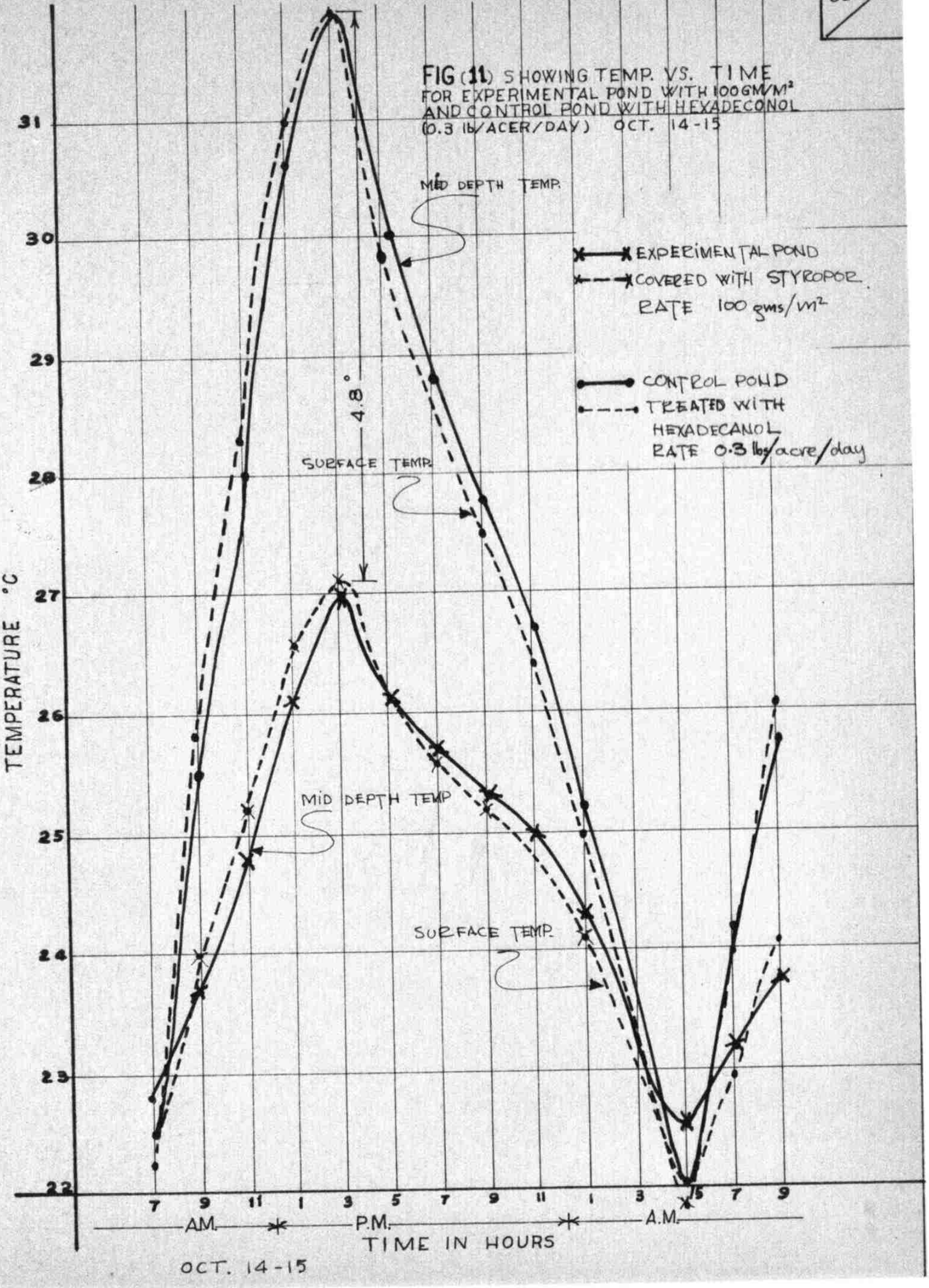


FIG (11) SHOWING TEMP. VS. TIME FOR EXPERIMENTAL POND WITH 100GM/M² AND CONTROL POND WITH HEXADECONOL (0.3 lb/ACER/DAY) OCT. 14-15

TABLE 17. EXP. No 4 TEST No 1 PERIOD: OCT. 14 — OCT. 15

Date & Time	Wind Velocity & direction m/sec.	EXPERIMENTAL POND COVERED WITH PLASTIC AT THE RATE OF 100 gms/m²									CONTROL POND. Treated with Hexadecanol at the rate of 0.3 lbs/acre/day									Remarks.
		Water depth Cm.	Water Temp. °C		Hook gauge reading (cm)		4 hrs difference cm.		Average 4 hrs Evap. Cm	Total Evap. to date Cm	Water depth Cm.	Water Temp. °C		Hook gauge reading (cm)		4 hrs. difference cms.		Average 4 hrs. Evap. Cms.	Total Evap. to date Cms.	
			Top	Mid pt.	A	B	A	B				Top	Mid pt.	A	B	A	B			
Oct.14 7 AM	SW 0.6	22.5	22.5	22.8	38.29	39.91					22	22.2	22.5	45.72	46.03					
9 AM	W 0.6		24.0	23.7	38.26	39.89	0.03	0.02	(1) 0.025	0.025		25.8	25.5	45.69	46.00	0.03	0.03	(1) 0.03	0.030	(1) Average 2 hrs. Evaporation.
11 AM	W 0.4		25.2	24.8			0.03	0.03	0.03	0.055		28.3	28.0			0.04	0.03	0.035	0.065	
1 PM	W 0.4		26.6	26.1	38.23	39.86						31.0	30.6	45.65	45.97					
3 PM	W 0.5		27.1	27.0			0.03	0.04	0.035	0.090		31.7	31.5			0.04	0.04	0.04	0.105	
5 PM	W 0.5		25.8	26.1	38.20	39.82						31.9	31.9	45.61	45.93					
7 PM	W 0.7		25.6	25.8			0.04	0.04	0.04	0.130		29.8	30.0			0.06	0.06	0.06	0.165	
9 PM	W 0.5		25.2	25.4	38.16	39.78						27.5	27.8	45.55	45.87					
11 PM	W 0.2		24.8	25.0			0.03	0.02	0.025	0.155		26.4	26.7			0.04	0.05	0.045	0.210	
Oct.15 1 AM	W 0.5		24.1	24.3	38.13	39.76						25.0	25.2	45.51	45.82					
3 AM							0.01	0.01	0.01	0.165						0.03	0.03	0.03	0.240	No Readings were taken at 3 AM.
5 AM	W 0.5		22.0	22.5	38.12	39.75						21.8	22.0	45.48	45.79					
7 AM	W 0.3		22.9	23.2			0.02	0.01	0.015	0.180		24.0	24.2			0.03	0.03	0.03	0.270	
9 AM	W 0.6		24.1	23.8	38.10	39.74						26.1	25.8	45.45	46.76					

* EVAPORATION READINGS TAKEN AT 4 hrs. INTERVALS, ALL OTHER READINGS TAKEN AT 2 hrs Intervals.

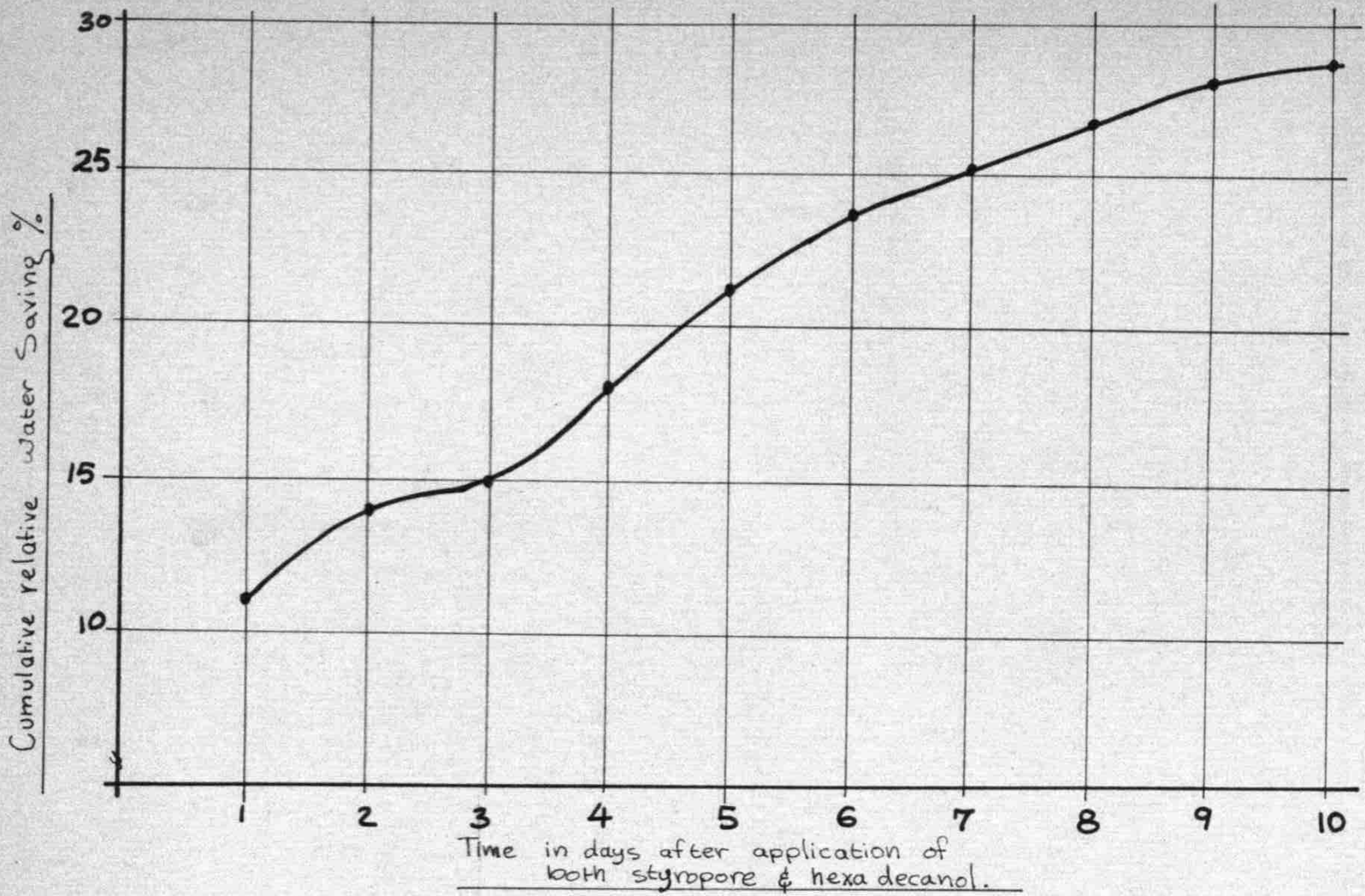


Figure (12) Showing the Cumulative relative saving in water by a styropor dose of 100 gm/m² over that due to hexadecanol applied at the rate of 0.3 lb/acre/day, under identical conditions in two ponds measuring 12.86 m. x 3.46m. at the School of Engineering, A.U.B (Oct. 5 – Oct. 15, 1964.)

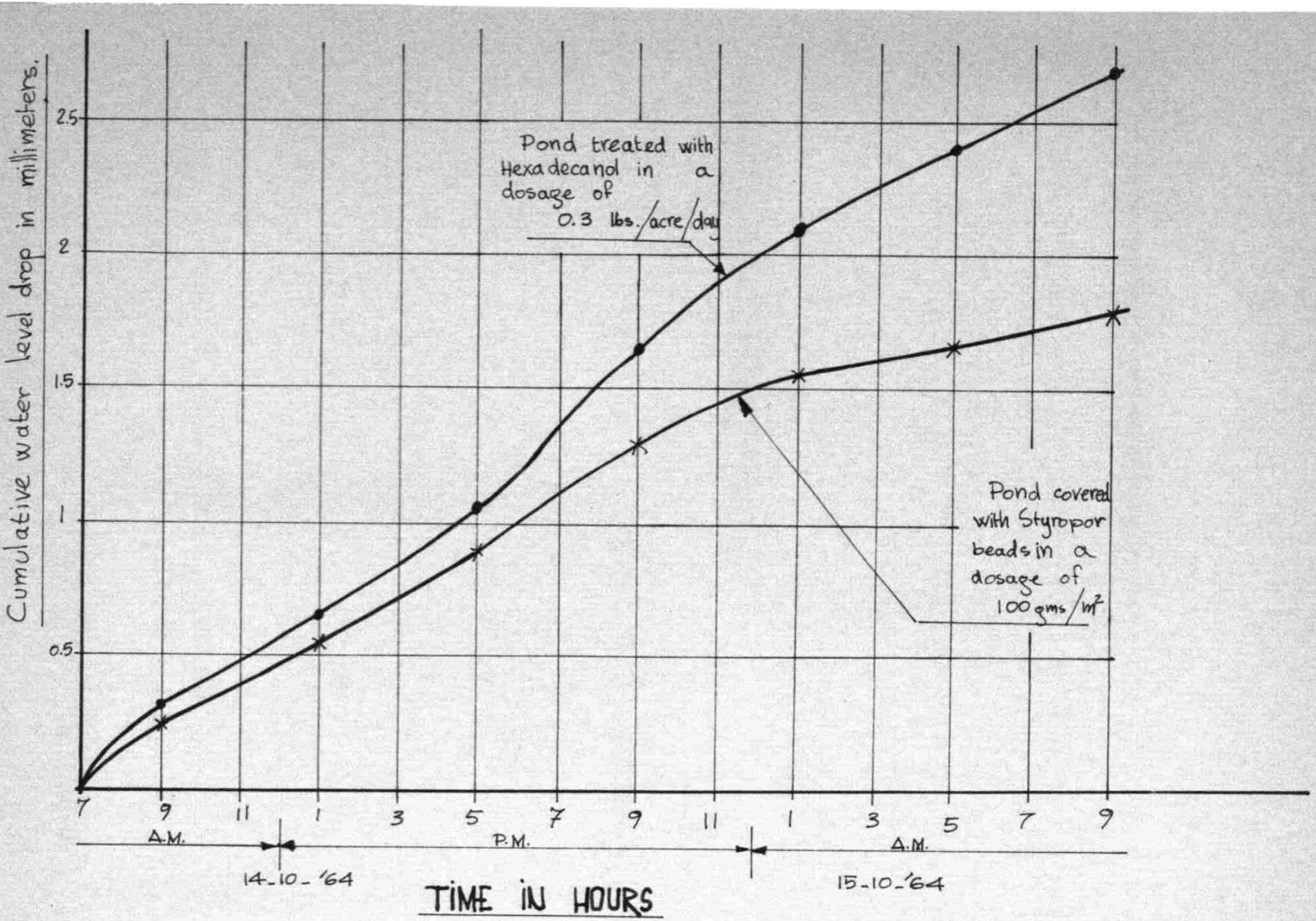


Figure 13. Showing the Cumulative water level drop vs. Time, for the two experimental ponds. Readings were taken at 4 hrs intervals on Oct. 14 – Oct. 15, 1964.

TABLE 16 . Summary Of Chemical Tests Conducted On Water . Period: Oct. 5 – 14, 1964.

Date	Sampling Time	Water Temp. * °C		pH (Tylor Analyzer)		Free CO_2 ppm.		Alkalinity ppm. $CaCO_3$		Total Hardness ppm. $CaCO_3$		Total Solids ppm.		Dissolved Oxygen				B.O.D. 5-day. ppm	
														1		2			
		1	2	1	2	1	2	1	2	1	2	1	2	ppm	% Sat.	ppm	% Sat.	1	2
5 Oct.	9 A.M.	22.7	23.2	8.2	8.2	12	12	110	110	184	184	434	430	7.7	88	7.7	89	2.3	3.0
6 Oct.	9 A.M.	20.5	22.6	8.2	8.2	12	12	108	108	184	184	428	429	6.5	72	6.8	78	3.0	3.3
7 Oct.	9 A.M.	21.5	23.5	8.2	8.2	12	12	107	108	184	184	424	443	6.9	77	7.1	82	3.3	5.3
8 Oct.	9 A.M.	22.2	25.0	8.2	8.2	12	12	95	107	184	182	455	435	7.2	83	7.5	89	3.3	6.0
9 Oct.	9 A.M.	23.0	25.6	8.2	8.2	12	12	104	106	184	180	427	413	8.2	94	8.5	105	5.0	8.0
10 Oct.	9 A.M.	23.2	26.0	8.2	8.2	12	12	105	102	180	172	419	402	10.1	116	8.9	108	8.2	12.0
12 Oct	9 A.M.	23.5	26.5	8.4	8.4	14	12	102	98	168	168	435	417	10.3	119	8	98	8.0	12.0
14 Oct.	9 A.M.	23.7	25.5	8.2	8.4	10	12	86	90	166	172	395	408	11	128	8	96	11.0	16.3

* Water Temperature at Mid Depth.

(1) Pond Covered With Styropor beads at the rate of 100 gm/m².

(2) Pond Treated With hexadecanol powder at the rate of 0.3 lbs/acre/day.

brought slowly and gradually towards the air blower. The trough was oriented to have its longer axis along the direction of the blowing wind.

Different Styropor doses, starting with the 75 gm/m^2, were applied. The trough was brought to each station and allowed to stay there in order to make possible the determination of wind effect on the Styropor beads. The starting position was at the location where the wind velocity was 5 km/hr. The wind velocity at this station was checked again during the experiment at three points 50 cms. apart along a line perpendicular to the wind direction and passing through the shorter axis of the trough. The effect of wind on the behaviour of the floating Styropor layer was observedand recorded. The trough was then moved forward to the next station where wind velocity was 10 km/hr, 20 km/hr... 30 km/hr, etc., the same procedure for checking wind velocities being repeated and observations recorded.

Before the next higher dose was applied the dose experimented with was removed completely by skimming. The same procedure was repeated for the four doses already mentioned.

Results: Observations demonstrated that the behaviour of the four Styropor doses under the effect of wind was essentially the same.

Wind velocities with a range of 10-15 km/hr affected the layer by reducing its coverage partially. The amount of reduction varied depending upon the wind velocity (see Figure 14).

Wind velocities with a range of 15-25 km/hr pushed the Styropor layer to the leeward side where it became "compressed" and more rigid by hitting against the edge of the trough. The coverage was also reduced (see Figure 15).

Under wind velocities between 25 km/hr and 30 km/hr, the floating Styropor beads were drifted by wind and were rolled over one another to form a thick layer on a small portion of the surface area of the water near the leeward side of the trough (see Figure 16). The beads forming the upper layer would dry and hence are subject to be blown away by the wind.

At wind velocities of 30 km/hr or greater the wet Styropor beads were blown off the water surface (see Figure 17).

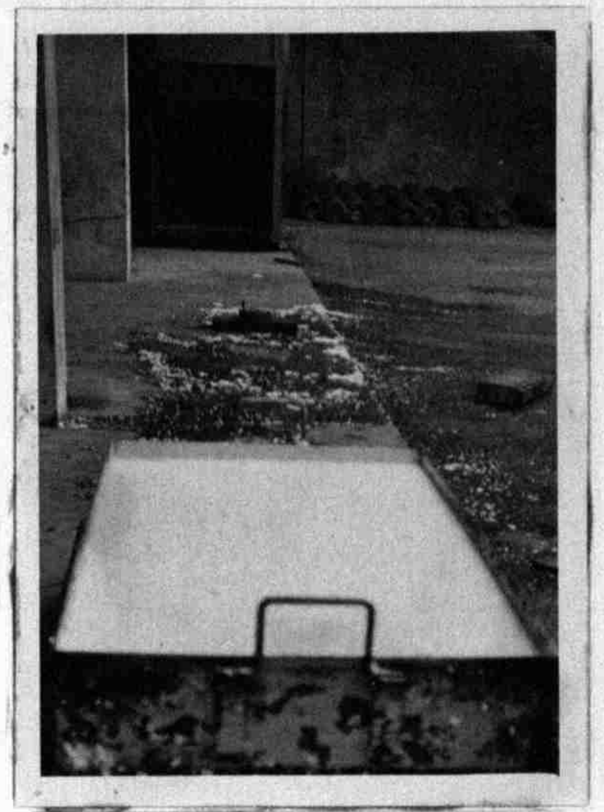


Figure 14. Styropor beads in a dosage of 125 gm/m^2 under the effect of a wind velocity of 10 Km/hr. Wind blower is shown in the back ground. Wind direction is towards the viewer.

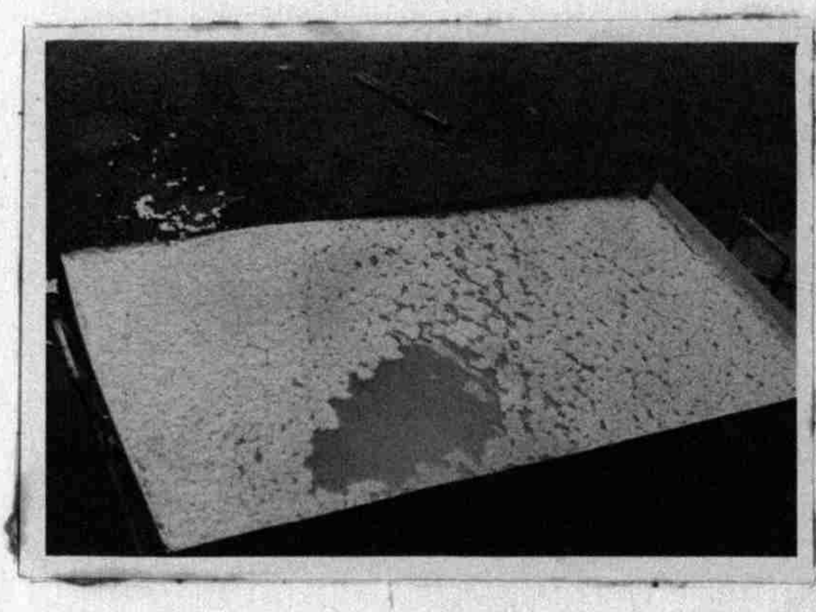


Figure 15. Styropor beads in a dosage of 100 gm/m^2 under the effect of a wind velocity of 15 Km/hr. Wind is blowing from right.

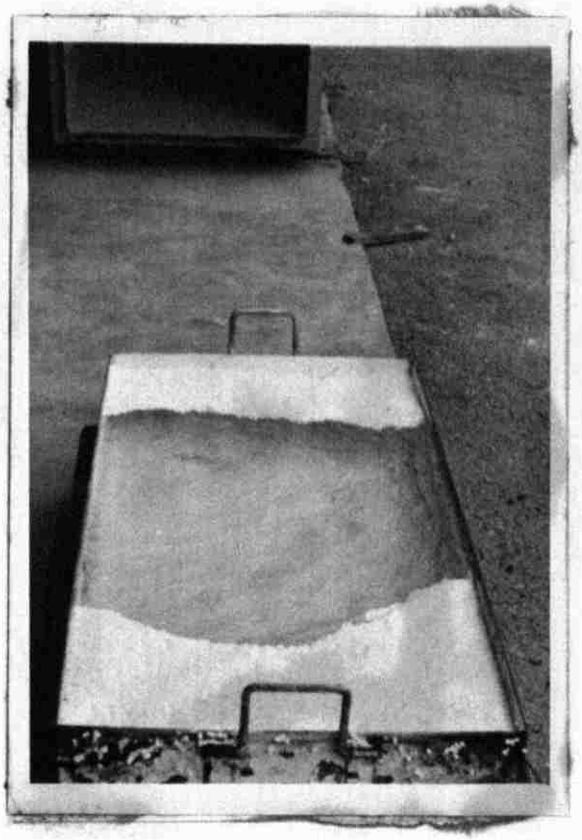


Figure 16. Styropor beads in a dosage of 100 gm/m^2 under the effect of a wind velocity of 25 Km/hr. Wind blower appears in the background. Wind direction is towards the viewer.

Figure 17. Styropor beads in a dosage of 100 gm/m^2 under the action of a wind velocity of 30 Km/hr. Wind is blowing from right. Note beads being blown off the water surface.

CHAPTER VI

DISCUSSION OF RESULTS

In general, the results obtained by the use of floating white Styropor beads for water evaporation suppression were encouraging. Discussion of the various aspects of the use of this material is presented in the following paragraphs.

1. Evaporation Suppression:

The various tests conducted throughout the investigation have shown that a layer of floating white Styropor beads is a potential water evaporation retardant. These results have confirmed previous results obtained by Acra et al.[4] for small vessels. This is evident from the summary given below.

TABLE 18

RELATIONSHIP BETWEEN STYROPOR DOSAGE AND SAVINGS

Dosage gm/m^2	Test Period days	Water Savings Cumulative%
75	10	35
100	10	47.1
125	10	50.6
150	9	52.8

It will be noted that the savings increased with the dosage but not proportionally.

Underlying Principle:

The principle underlying the ability of Styropor to suppress water evaporation is presented here on a theoretical basis. Like all white surfaces the floating layer of Styropor beads would reflect solar radiation which would otherwise provide energy for the evaporation of exposed water surfaces. The reflection of solar radiation in this case is only partial and increases with the compactness of the Styropor beads. Whatever solar energy penetrates into the water through the voids, between the beads, at daytime is partly consumed in supplying heat energy for the evaporation process, the residual energy being stored as heat in the water. The stored energy is consumed, totally or partially, during the night to continue the evaporation process. However other energy losses such as convection or radiation must be very little, or even negligible, because of the presence of the Styropor layer which not only serves as a physical barrier but also as an insulator because of its insulating properties. Evidently, the stored energy in the water covered by Styropor layer would tend to increase evaporation during the night. However the energy stored is not enough to cause appreciable evaporation losses at night. The net result of using the Styropor layer is an appreciable water saving on daily basis.

A monolayer of hexadecanol permits the transmission of solar energy into the water body, and hence the amount of energy stored during daytime would be greater than that in the case of Styropor. This phenomenon is evidenced from the temperature vs. time curves (Figure 11). Water covered by Styropor beads was significantly cooler at daytime than water covered by a monolayer, which is not surprising in the light of the foregoing discussion. Consequently a marked difference in the degree of water evaporation is observed when using the two materials (see Figure 13). However, during the early hours of the morning both materials exhibit about the same rate of evaporation suppression as evident from the close water temperatures in this period (see Figure 11; Table 17).

The degree of transmission of solar energy and its storage in water is not the sole factor involved in creating a difference in water evaporation rates. One must also account for the influence of wind action on water evaporation. The Styropor beads, being in a solid state, protrude partially from the water surface and thus form a physical barrier to the evaporative wind action at the air-water interface. The layer itself protects the water surface from wind turbulence which is an effective water vapour carrier. In contrast, the hexadecanol forming a monolayer would not conceivably prevent wind action.

Figure 9 shows the cumulative water savings in percent realized by the application of different doses of Styropor. Some explanation is needed for the fact that when Styropor doses of 100, 125, and 150 gm/m^2 were applied at the experimental pond, the cumulative savings in percent tended to increase with time. This might have been caused by the influence of the cooler tap water added to the water remaining in each pond, from the previous test, to replenish that lost by evaporation. Although the added water was from the same source, yet the volume of residual pond water was not the same in each pond. There has been more residual water in the experimental pond at the end of every test. Because replenishment water was added to bring the levels of the two ponds to the same datum, the amount of cooler tap water added to the control pond was more than that added to the experimental. Hence the resultant effect of the added water was more pronounced in the control pond. During the first few days of any one test, and until the effect of the newly added water was cancelled, evaporation from the control pond was lower than what it would have been if no colder tap water had been added.

Comparison of relative water savings realized by the Styropor at a dosage of 100 gm/m^2 and hexadecanol at a dosage of 0.3 lbs/acre/day, was done in experiment 4, with the two ponds under identical conditions. Before the start of the experiment, the amount of water added to replenish that lost by evaporation was the same for both ponds. The cumulative relative water saving in percent due to the Styropor dose increased steadily to 28.5 percent at the end of the 10-day test period, indicating superior water evaporation suppression ability over that due to hexadecanol for extended periods of time (see Figure 12).

2. Effect on Water Temperature:

Whereas hexadecanol is rendered less effective at higher temperatures,[23,26] the Styropor seemed to accomplish appreciable savings under relatively high water temperatures experienced during the summer when the investigation was being carried out.

TABLE 19

RELATIONSHIP BETWEEN STYROPOR DOSAGE, WATER TEMPERATURE AND SAVINGS

Styropor dose gm/m^2	Water surface Temp. °C.		Difference in Temp. °C.	Water Savings Percent
	Control	Experimental		
75	31.4	28.4	3.0	35
100	35.4	31.4	4.0	47.1
125	34.8	29.6	5.2	50.6
150	34.4	39.0	5.4	52.8

The above table gives the maximum water surface temperatures experienced in the two ponds on selected days when all readings were taken at 2 hrs. intervals.

The mid-depth temperature in each pond was very near to that at the surface. The difference at any time during the day did not exceed 0.4° C, the mid-depth temperature being higher than the surface temperature during most of the day except for few hours in the morning (see Figures 5, 6, 7 and 8).

The difference in surface temperature between the control and experimental ponds indicates that the Styropor layer has protected the water surface on which it floats from direct solar radiation and resulted in a lower surface and mid-depth temperatures than would have been experienced in its absence.

The preceeding table indicates that the difference in temperature between a treated and an untreated water surface is a function of the Styropor dose applied. The greater the dose the greater the water temperature lowering and hence the greater the water savings.

Compared with hexadecanol, the application of floating Styropor beads results in an appreciable lowering of the water temperature at mid-depth and surface. Temperatures were recorded at 2 hrs. intervals for 24 hours on October 14-15, for both the pond covered with Styropor beads at a dosage of 100 gm/m^2 and that treated with hexadecanol at a dosage of 0.3 lbs/acre/day. The temperature vs. time curves shown in Figure 11 indicate that the maximum water surface temperature in the pond covered by the Styropor layer was 4.8° C lower than that in the pond treated with hexadecanol. Similarly a comparison of the water temperatures at mid-depth in both ponds, throughout the experiment indicated that these temperatures were near that at the surface of each. The difference at any time during the day did not exceed 0.4° C, the mid-depth temperature being higher than that at the surface except for few hours in the morning (see Figure 11).

The foregoing discussion proves that the transfer of solar radiation into the water is retarded by the floating layer of Styropor beads and that the degree of retardation and consequent water savings increaseswith the dosage. Styropor, by virtue of its insulation properties and white color, not only retards transmission of sunlight but also atmospheric heat.

Since the rate of emission of water vapour molecules from a water surface is a function of its temperature--the lower the temperature the less the evaporation. Hence the use of Styropor beads is an effective measure for water evaporation reduction. It is possible to conceive the realization of even greater savings in the field under higher atmospheric temperatures as would occur in desert or semi-desert areas.

3. Effect on Algae Growth:

Daily inspection for the presence of algae in both ponds throughout the investigation indicated that the Styropor beads discourage algae growth but do not prevent it. These observations were substantiated by similar findings derived from field applications of Styropor in ponds.[5]

Algae require sunlight for their photosynthetic activities. Cutting off sunlight prevents photosynthesis and leads to the destruction of algae. Advantage is taken of this fact to control algae growth by shading or covering water surfaces or even blacking out by means of charcoal powder in water storage tanks. Evidently Styropor functions in a similar way by blanketing the water surface thus preventing direct sunlight from entering the water. Diffused sunlight, however, may find its way through the voids between beads, permitting some algae growth.

Daily inspections for the presence of algae in the experimental and control ponds showed that the algae growth in the control pond, both when it was left untreated or when treated with hexadecanol, had been faster and more intensive than that in the experimental pond.

On the morning of August 15, fifteen days after the start of experimentation, water in the control pond was observed to be distinctly greenish in color with patches of attached (plankton) algae (see Figure 19) no microscopic tests were made, it was evident that the green color was due to the sudden blooming of algae. On the other hand, water in the experimental pond was seen upon close inspection (Figure 20) to be clean and colorless. This was taken as an indication that no algae growth had taken place in that pond, which was covered with Styropor beads at a dosage of 100 gm/m^2, as to that date. Subsequent daily inspection revealed that the growth of algae continued in the control pond. On August 25, twenty five days after the start of the investigation, few light green patches of attached algae were spotted in the experimental pond. This growth continued and increased slightly with time, but had always been less than that in the control pond. It was noticed, however, that normal algae growth occured under the two stilling wells installed in the experimental pond, as a result of more exposure to sunlight. No microscopic tests on algae were undertaken throughout the investigation.

Field observations[5] support the foregoing findings. These investigators report that in some cases Styropor has destroyed heavy algae growths within a few days after its application. They have also observed a limited growth of algae on the exposed surfaces of some of the floating Styropor beads. No algae growth was observed on the immersed portion of the beads. These occurances were more pronounced in highly polluted ponds with quiescent water, and to a much lesser degree in irrigation ponds with frequent fresh water replenishment. Turbulence caused by inflowing and outflowing water as well as wind action apparently

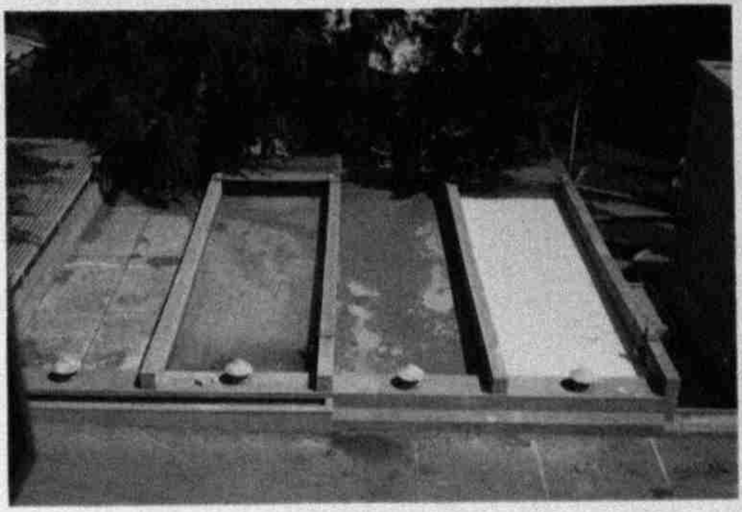
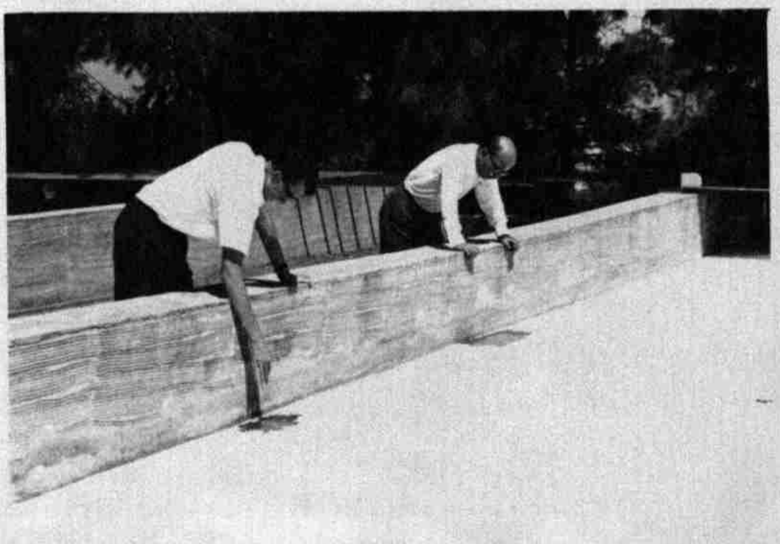


Figure 19. Algal bloom in the control pond yielding greenish color. Phylon planks in the background provide even shade over both ponds during the day and protect ponds from falling trash. Styropor dosage applied is 100 gm/m^2.

Figure 20. Openings made in Styropor layer in experimental pond for mosquito Larvae and Algae inspection. Dosage applied is 125 gm/m^2.



causes the beads that have developed some algae growth to be washed free of the thin algae coating. In quiescent waters there is less turbulence and less movement of the beads and hence less washing of the algae growth if present on the exposed surfaces of the beads. This was borne out by further observations by the same research group that have shown that under field conditions an algae-free Styropor surface resulted, in places where water turbulence was a maximum such as near inlets or outlets of water. These algae-free surfaces were distinctly whiter than the rest of the covering Styropor layer.

The washing action of water on the Styropor beads is a great advantage for, otherwise, the greenish color developed by algae growth might impair the reflectivity of the white beads and hence increase their absorptive power for solar energy. This in turn might decrease their effectiveness in retarding water evaporation.

4. Effect on Mosquito Breeding:

Mosquito breeding may be controlled by preventing either the adult female mosquito from laying its eggs on an exposed water surface, or by preventing the larvae existing in the water from feeding and breathing at the surface of the water. A compact floating layer of Styropor beads covering the exposed water surface in a pond or reservoir may accomplish both of these objectives. This possibility has been confirmed, at least in part, by the findings.

Evidence was obtained throughout this study and that in the field[5], that the floating Styropor layer presents another important advantage in its effect on mosquito control. Daily inspections for mosquito larvae were conducted in a manner shown in Figure 20.

On the morning of Aug. 8, second stage culex mosquito larvae were observed along the edges of the experimental pond. None were observed in the control pond. The two ponds were running as control to determine whether evaporation from the two was the same or not under identical conditions. No Styropor beads had been applied by that time. It was found that the pH in the control pond was about 10 and this was higher than that of the experimental pond. It is possible that this higher pH explains the absence of mosquito larvae from this pond.

On the morning of Aug. 10, Styropor beads were applied to the experimental pond at a dosage of 100 gm/m^2. On Aug. 13, no larvae were detected in the control pond. The larvae in the experimental pond were noticed along the edges even in those areas where the Styropor layer was thicker. They were then in the fourth stage and seemed to be surviving in a normal condition.

On the same day, samples of the experimental pond water and bottom sediment were taken into each of two 1 liter beckers. Five larvae, collected from the same pond, were placed in each becker. The water surface in one of the beckers was covered with Styropor beads at the rate of 150 gm/m^2. The other becker was kept as a control. The larvae in the two beckers were observed at frequent intervals. The larvae in the experimental becker showed continued reduction in activity. Two were found dead on Friday Aug. 14, and the remaining three died at noon on Aug. 15.

That death occured as a result of the Styropor covering was based on regular observation of the larvae under activity during the experimental period. The larvae in the experimental becker would attempt to rise to the water surface in order to breathe but were prevented from doing so by the presence of the floating Styropor beads. After each unfruitful attempt a larvae would return to the bottom of the becker showing signs of exhaustion. With time, the frequency of rising towards the water surface decreased leading eventually to death.

At the same time the five fourth stage larvae, already present in the control becker, continued to be living under normal conditions.

On Aug. 16, the five culex mosquito larvae present in the control becker were examined. Two were found to have developed into pupae. These together with the remaining three larvae were normal. These two pupae and one larvae were taken from the control becker and put into the experimental one for further observation.

On Monday morning Aug. 17, the two pupae and one larvae which were put into the experimental becker were found dead. Regarding mosquito breeding in the two ponds, the fourth stage culex mosquito larvae observed on Aug. 13 in the experimental pond which was covered with Styropor beads at the rate of 100 gm/m^2, were seen again on Saturday Aug. 15. None were seen in the control pond. On Aug. 20, no eggs, larvae, pupae or mosquitoes were observed in the experimental pond.

The results of the becker test performed on the mosquito larvae and pupae as well as the daily observation of the ponds indicated that the Styropor layer was an effective agent in limiting and preventing mosquito breeding.

During most of the summer days, while the study was in progress, many insects including **fly** dragons were noticed hovering over and near the water surface of the control pond but none were observed to approach the experimental pond. The strong glare resulting from sunlight reflection due to the presence of the white Styropor beads is likely to be the reason.

Field applications on ten ponds in various parts of Lebanon[5] have shown that during a period of about three months there was no evidence of the existence of mosquito larvae in the pools covered with Styropor.

It should be noted here that for efficient control of mosquito breeding in addition to evaporation control a dose of 125 gm/m^2 or better still 150 gm/m^2 is recommended. However, when only evaporation control is the major concern, then 100 gm/m^2 would be adequate.

5. Effect on Water Quality:

Daily chemical examination of water over a 10-day test period, during experiment No. 4, indicated that the Styropor beads in a dosage of 100 gm/m^2 did not impair the water quality - a finding which is in line with the observations made using hexadecanol as a water suppressant.[26]

An experiment was run in order to compare the effects of Styropor and hexadecanol on water quality. For this purpose Styropor was applied in one pond, which has been the experimental pond throughout the investigation, at a dosage of 100 gm/m^2, and hexadecanol powder was applied in the other pond at the rate of 0.3 lbs/acre/day. Sampling was done daily at 9:00 A.M. from each of the two test ponds at a predetermined point in each pond, and the desired chemical tests were performed daily.

A special sampling bottle was devised to avoid entrapping air during sampling, which would otherwise affect the dissolved oxygen and carbon dioxide values. This consisted of a 2-inch diameter glass tube, one liter in capacity, stopperedat both ends with rubber stoppers. The tube, with the stoppers removed, was dipped carefully into the water to avoid disturbing the bottom sediments. The tube was then stoppered under water and withdrawn. In this way the samples were protected from contamination by atmospheric gases. Various chemical tests were performed on the collected samples. The results of these tests are presented in Table 16.

The following deductions could be made:

a) Oxygen:

Contrary to expectations the laboratory results shown in Table 16 have indicated that Styropor layers in dosages of 100 gm/m^2 do not impair the transfer of atmospheric gases. The experimental dissolved oxygen values were similar in both ponds. The slight increase in the dissolved oxygen, obtained after the sixth day, could have been the result of oxygen production as a result of the presence of small amounts of algae in both ponds.

It is likely that more compact and thicker Styropor layers may interfere with gas transfer. Aeration of water by gas transfer is of importance in relation to the required amount of dissolved oxygen needed for the support of aquatic life. This would be of prime importance for maintenance of aerobic conditions in ponds particularly in those where fish exist. In practice, however, this would be of no consequence, since, based on economy considerations, the recommended dose for evaporation suppression was 100 gm/m^2.

The laboratory results indicated that there was no tendency for dissolved oxygen to be depleted and consequently no interference with aquatic life is expected. With regard to fish in ponds covered with Styropor beads, the potential hazard related to the presence of the beads does not seem to fully justify in view of a reported observation.[5] that fish continued to survive in a pond covered with Styropor for a period exceeding three months.

b) Biological oxygen demand:

A slight rise in the B.O.D., which is a measure of the organic load, was experienced with time in both ponds. This could have been the result of:

i) an increase in aquatic micro organisms, and

ii) falling trash from the neighbouring trees.

The slight daily increase of B.O.D. values, in the pond treated with hexadecanol over that of the pond covered with Styropor beads, can be explained by the fact that this organic chemical would contribute to the organic load of the pond. It also increases the bacterial population[26] since it is a source of bacterial food.

c) Carbon dioxide:

There was practically no difference in the amount of free carbon dioxide in the water over a 10-day test period. However, there exists the possibility that the carbon dioxide consumed by algae in their photosynthesis was replenished by an equal amount of carbon dioxide produced in the water through the metabolism of bacteria and other micro organisms.

d) Alkalinity, pH, Total Hardness, and Total Solids:

No significant change has resulted in any of these chemical characteristics in the pond water covered with Styropor.

In conclusion, there was no significant change in the overall chemical composition of the pond water covered with Styropor beads in a dosage of 100 gm/m^2 as compared to that caused by hexadecanol.

6. Durability:

Field application and small scale trials[5] extending through periods three and six months respectively have proved that the Styropor beads are resistant to the chemical action of water impurities and to environmental conditions. This is another advantage with potentialities for the durability of Styropor in field applications for periods possibly exceeding one or two years. This is of practical importance in relation to the economic aspect of the use of such material.

Furthermore, the beads are washed free of wind carried dust, that settles on their surfaces, whenever they are drifted by wind action over the water surface or whenever the water level fluctuates as a result of water inflow or outflow. This phenomenon is of practical value in areas experiencing sand and dust storms as is frequently the case in arid zones. On the other hand, the effectiveness of hexadecanol as a water evaporation retardant is highly impaired under such conditions.

7. Wind Effect:

In general the wind experienced at the test facility was not strong due to the fact that the surroundings obstructed free wind movement and afforded protection from strong wind (see Frontispiece).

Throughout the investigation period wind did not have a damaging effect on the floating Styropor layer. However, during certain days strong winds existed making it possible to observe their effect on the floating beads.

Slow winds having velocities up to 5 km/hr had practically no effect on the Styropor beads covering the pond. For Styropor doses of 75 gm/m^2 and 100 gm/m^2, winds having velocities between 5 and 10 km/hr resulted in pressing the Styropor beads slightly against the leeward end of the pond resulting in about 10-20 percent reduction in total coverage. Cracks in the Styropor layer were observed at such wind velocities (see Figure 21). Such wind effects were much less pronounced with the higher doses of Styropor.

During a stormy day, Monday October 5, 1964, the maximum wind velocity recorded at the testing cite was about 14 km/hr, this being the highest value obtained throughout the experimental period. The time was 3:00 p.m., and this high wind velocity was maintained for the rest of the afternoon. The Styropor beads, applied at a dosage of 100 gm/m^2, were drifted by the wind to the leeward side producing a 40 percent reduction in the pond coverage. The Styropor beads were pressed against the leeward end of the pond forming a compressed layer. Whenever the wind subsided momentarily, the Styropor layer would unfold and spread again more or less uniformly over the pond surface almost regaining its lost coverage.

The results obtained in Experiment 5, indicated that Styropor layers in dosages of 75 gm/m^2 to 150 gm/m^2 can effectively resist wind velocities up to 25 km/hr in the presence of the slightest edge restraint.

It is very likely that in doses exceeding 150 gm/m,^{2} the beads forming the upper part of the thick Styropor layer may become dry by exposure to wind and hence light enough to be blown away by wind action. The same effect may occur at wind velocities exceeding 25 km/hr on any dose applied.

It is recommended, therefore, that in practice some form of restraining edges be installed in ponds and reservoirs to be treated with Styropor beads as a precautionary measure.

Wind velocities in this part of the world very rarely exceed the limit indicated above. Hence the use of Styropor beads as a water evaporation suppressant by floating it over exposed water surfaces in the Middle East area is a practical possibility.

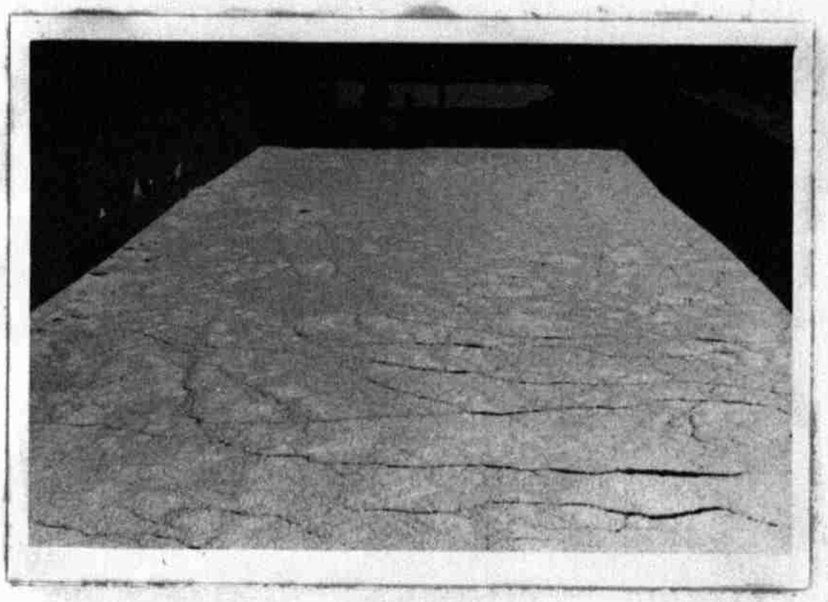


Figure 21. Cracks developed in Styropor layer as a result of wind action. Dosage applied is 100 gm/m^2. Range of wind velocity is 5-10 Km/hr.

8. Economy Considerations:

A sound economic enterprise aims at providing a maximum rate of return on the investment.

In water evaporation suppression operations the expected return is water, or what it is worth, while the investment is the cost of material applied plus the cost of labour involved in its application.

In order to determine the most economical dose of Styropor for practical application the following analysis is presented.

The cumulative savings in water, obtained during 10-day test periods, by the use of different doses of Styropor beads were as follows:

Dose gm/m^2	Water saved percent
75	35.0
100	47.1
125	50.6
150	52.8

The savings in water listed above and obtained experimentally could be considered as benefit or return realized through different investments in Styropor cost.

Since this economic analysis is a comparative one it is not necessary, at this stage, to ascertain the costs of Styropor and water saved.

Assuming cost of Styropor = C LL / gm

Value of water saved = B LL / m^3

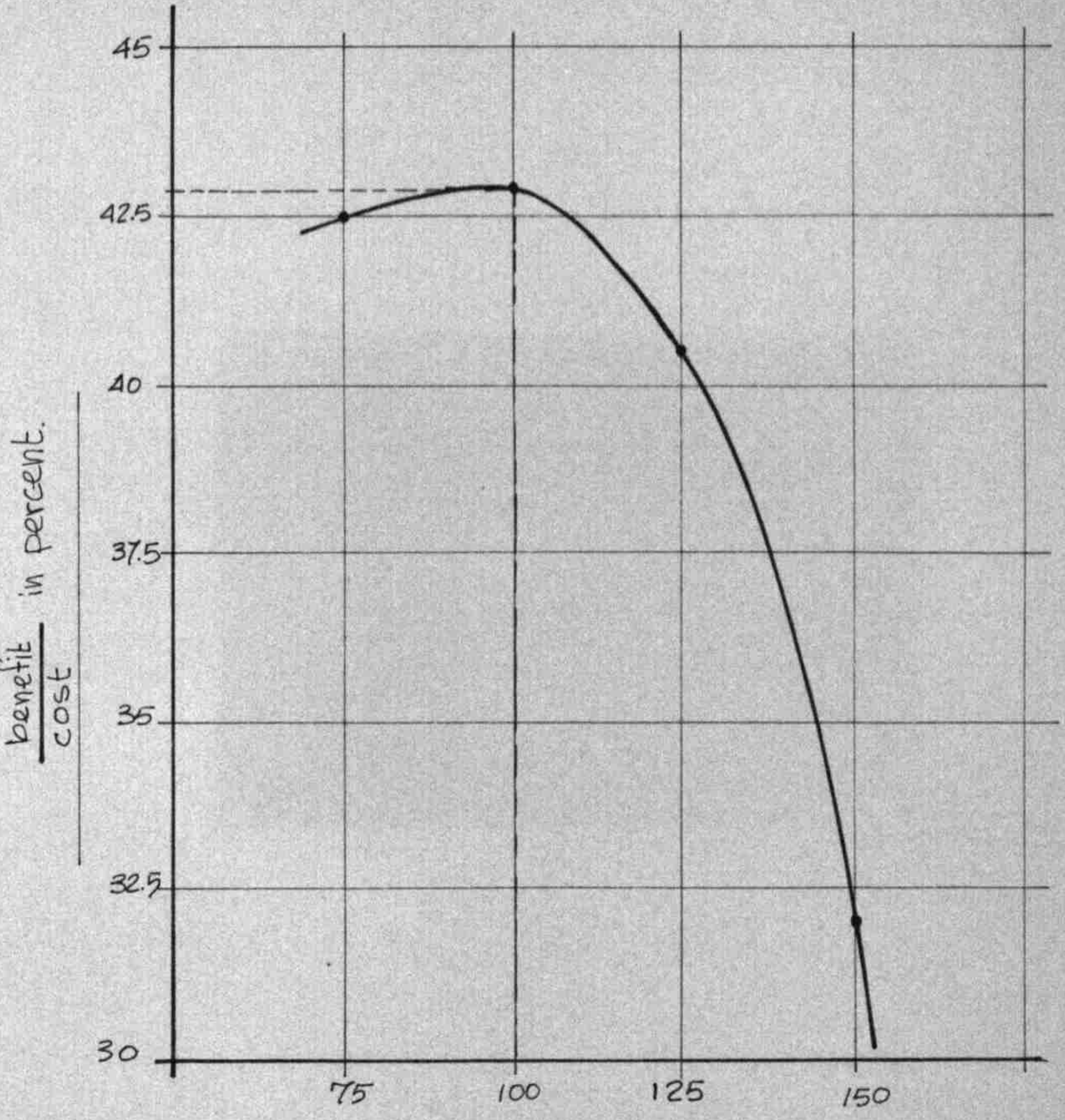
Since the cost of labour involved in the application of Styropor is proportional to the weight of the quantity applied, as far as small scale applications are concerned, it will be assumed that this labour cost is 10% of the cost of the material. Taking any locality where evaporation is E meters for a certain period of time.

Dose gm/m^2	Investment in units of C LL	Benefit in units of B LL	$\frac{\text{Benefit}}{\text{Cost}}$ in units of $\frac{B}{C}$
(1)	(2)	(3)	(4)
75	(75 + 7.5)	35.0E	$\frac{35.0}{82.5}$ = 0.425E
100	(100 + 10)	47.1E	$\frac{47.1}{110}$ = 0.428E
125	(125 + 12.5)	50.6E	$\frac{50.6}{137.5}$ = 0.402E
150	(150 + 15)	52.8E	$\frac{52.8}{165}$ = 0.320E

The factor E.$\frac{B}{C}$ is common to all values under column 4. Plotting the Benefit/cost ratios against the doses used, the maximum ordinate for the resulting curve gives the most economical dose to be applied.

From Figure 22 it is seen that the most economical dose is 100 gm/m^2.

Styropor in this dose has been compared with hexadecanol, at the rate of 0.3 lbs/acre/day, over a 10-day period.



Styropor dose in gm/m^2

Figure 22 . Relation between Costs and benefits for four doses of Styropor.

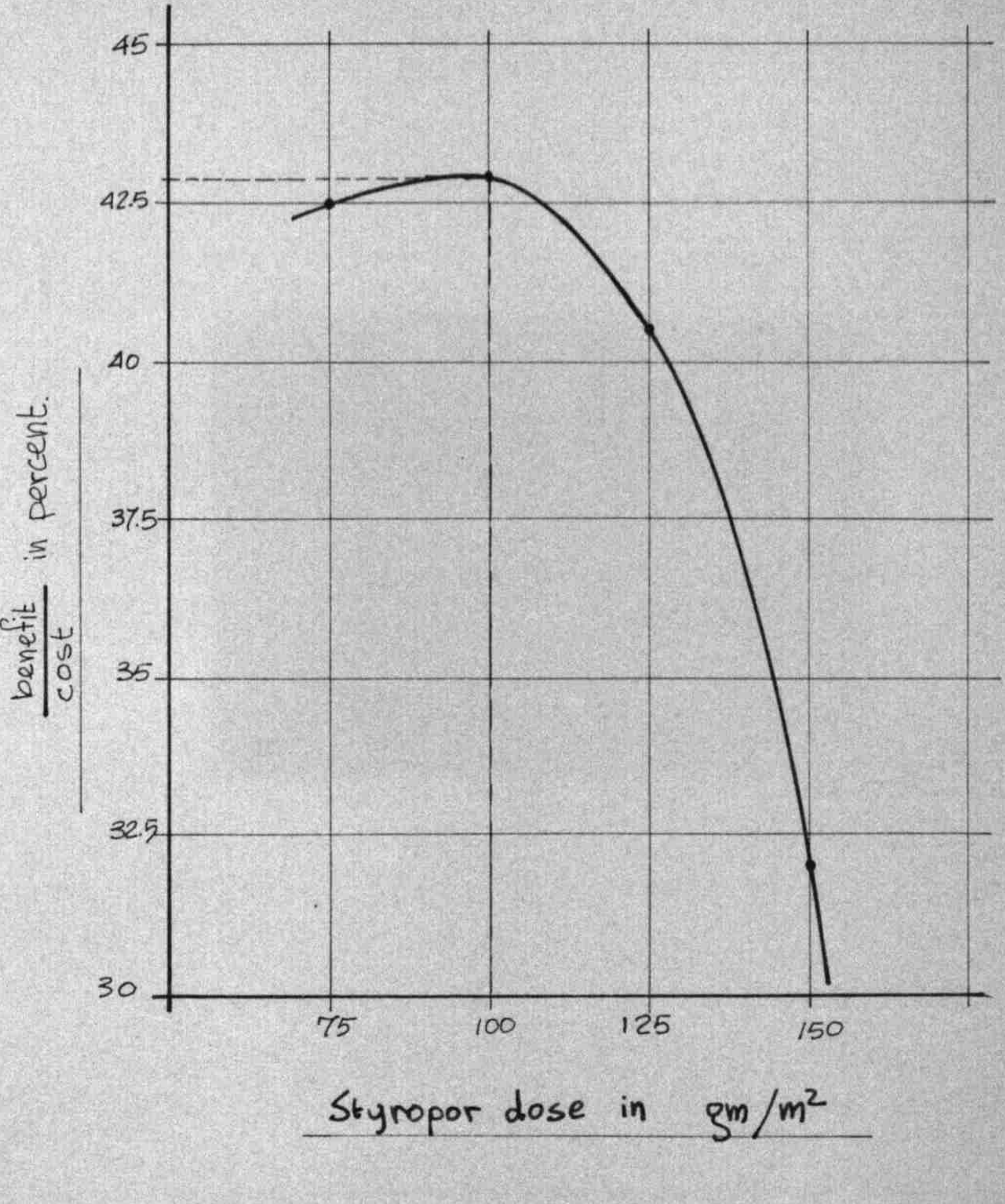


Figure 22 . Relation between Costs and benefits for four doses of Styropor.

Comparison of Costs of Water Saved:

A comparison of the cost of water saved by the application of the optimal dose of 100 gm/m^2 of Styropor beads to one pond, and that of the water saved in the other pond which was treated with hexadecanol powder at the rate of 0.3 lbs/acre/day, will be presented.

In Experiment 4, each of the twin experimental ponds was treated with one material for a 10-day test period. It was not possible to run a control pond during that period. However, the amount of cumulative water saving in percent which was realized by the use of Styropor beads in a dosage of 100 gm/m^2, over a 10-day test period, had already been established in experiment 2 test No. 1. It is possible to ascertain the cumulative water level drop, over a 10-day period, in a hypothetical control pond of identical size by projecting the savings already established.

In Experiment 2 test No. 1, the 10-day cumulative savings were 47.1 percent (see Table 6 and Figure 9).

In Experiment 4, October 5 - October 15, the cumulative water level drop was 2.00 cms in the pond covered with Styropor beads in a dosage of 100 gm/m^2, and 2.795 cms in the pond treated with hexadecanol.

Assuming that the same cumulative percentage saving of Styropor beads in the same dosage of 100 gm/m^2 and over the two 10-day test periods holds, then the following relationship is valid.

$$1 - \frac{2.00}{x} = 0.471 \qquad (1)$$

Where x equals the cumulative water level drop in a hypothetical control pond during the 10-day test period October 5 - October 15, 1964.

From equation (1)

$x = 3.8$ cms.

$\therefore$ Depth of water saved by Styropor = $3.8 - 2.00 = 1.8$ cms.

and Depth of water saved by hexadecanol = $3.8 - 1.795 = 1.005$ cms.

This saving in water depth was accomplished for a surface area of 44.5 m^2 in each pond.

Hence,

Volume of water saved by Styropor = $\frac{1.8}{100} \times 44.5 = 0.80\ m^3$,

Volume of water saved by hexadecanol = $\frac{1.005}{100} \times 44.5 = 0.447\ m^3$.

The cost of materials used in the experiment was prohibitive. Hence, cost analysis will be based on more realistic prices.

a. Hexadecanol: The powdered material used in the experiment was procured at a cost of \$3.10 (9.35 L.L.) per pound. However commercial hexadecanol such as AQUASAVE could be procured at a cost of 45 cents (1.48 L.L.) per pound.

b. Styropor beads: The heat-expanded beads were bought locally at a cost of 8 L.L. per kilogram. However, the price paid was very high in view of the fact that the batch was especially prepared for the purpose of the experiment. Commercial heat-expanded Styropor beads could be bought at a much lower price. The raw Styropor granules could be procured at a cost of less than 1 L.L. per kilogram. Assuming expansion by heat costs 1 L.L./kilogram, then the total cost of heat-expanded Styropor could be 2 L.L./kilogram.

A. Amount of hexadecanol used at a dosage of 0.3 lbs/acre/day during the 10-day period $= \frac{0.3 \times 44.5}{4047} \times 10 = 0.0331$ lbs.

(1 Acre $= 4047\ m^2$)

Cost of material (at 1.48 L.L. per lb) $= 0.0331 \times 1.48$

$= 0.049$ L.L.

Cost of labour involved in application:

One man, 5 minutes daily for 10 days @ 1 L.L./manhour

$= \frac{5 \times 10}{60} \times 1 = 0.835$ L.L.

Total cost of hexadecanol $= 0.049 + 0.835$

$= 0.884$ L.L.

Cost of water saved by hexadecanol $= 0.884 \div 0.447$

$= 1.98$ L.L. per cubic meter

Cost of 1000 gallons of water saved $= \frac{1.98 \times 1000 \times 3.785}{1000}$

$= 7.5$ L.L. (\$2.45 per 1000 gallons)

B. Amount of Styropor beads used at a dosage of 100 gm/m^2

$= 44.5 \times 0.1 = 4.45$ kilograms

Cost of material (at 2 L.L. per kilogram) $= 2 \times 4.45 = 8.90$ L.L.

Cost of application,

One man, one hour @ 1 L.L./manhour $= 1.00$ L.L.

Total cost of Styropor beads $= 8.90 + 1.00 = 9.90$ L.L.

The Styropor beads are durable and could last for one year. Assuming they become useless at the end of one year, then the 10-day cost of the material is equal to the depreciation of the material over a 10-day period assuming its value becomes zero at the end of 360 days.

$\therefore$ Total cost of Styropor beads used

in the experiment $= \frac{10}{366} \times 9.9 = 0.275$ L.L.

Cost of water saved by Styropor $= 0.275 \div 0.8 = 0.344$ L.L. per cubic meter.

$$\text{Cost of 1000 gallons of water saved} = \frac{0.344 \times 1000 \times 3.785}{1000}$$

$$= 1.30 \text{ L.L.} (\$0.43 \text{ per 1000 gallons}).$$

The cost of water saved by the Styropor beads is approximately equal to the cost of the treated water in Beirut city municipal water supply.

It should be mentioned here that the cost of municipal water supplied in most cities and towns in the Middle East area is higher than the cost in Beirut. Furthermore, the cost of water in rural areas in almost any country in this area is generally higher than that in towns and cities due to the prevailing aridity. Many towns, villages, and small community centers that are located in semi-arid zones, with their water supplies coming from small impounding and domestic supply reservoirs, suffer from the lack of adequate water supplies during the dry season. It appears that the use of Styropor beads in such instances is a possible and an economically justifiable method of increasing these meager water supplies by conserving an appreciable part of the water that would normally be lost by evaporation.

As a matter of fact, the cost of water saved by the application of Styropor beads in the experiment under consideration is considered acceptable for irrigation purposes in many parts of the world. Hence the use of such material as an evaporation retardant to cover exposed water surfaces in ranch and farm ponds could be economically justified in areas having limited water supplies and high evaporation losses.

Summary and Conclusions

Control of water evaporation by hexadecanol and octadecanol monolayers has serious limitations: (a) continuous and rapid depletion of the monolayer by sublimation, suspension, and biologic decomposition which necessitates daily or continuous replenishment--a fairly costly operation particularly for small reservoirs and ponds; (b) the method of application and the form in which the material is to be applied; the problem of maintaining reasonable water surface coverage by a monolayer, the detrimental effect of wind-borne dusts, rain, wind, temperature, sand storms and water turbidity; and (c) the relatively low water savings, reportedly ranging from 10 percent to 30 percent in most cases.

The findings obtained in this study provided further evidence on the feasibility of using heat-expanded Styropor beads to suppress evaporation from exposed water surfaces in small reservoirs. The results indicate superiority of a layer of white floating Styropor beads over a hexadecanol monolayer in several ways: simplicity in application, durability, weatherability, resistance to chemical and biological attack, lasting effect, lower cost, higher efficiency in suppressing evaporation, and its favourable side effect in discouraging algae growth and controlling mosquito breeding.

Styropor beads in the optimal dosage of 100 gm/m^2 resulted in a cumulative saving of about 50 percent in water evaporation losses when applied for a 10-day period to a small pond about 50 square meters in area. The cumulative relative water saving of Styropor beads in this dosage over that of hexadecanol applied at the desirable rate of 0.3 lbs/acre/day, for a 10-day test period, was about 28 percent when compared under almost identical conditions. Chemical tests conducted on daily samples from the water covered with Styropor, over a 10-day period, indicated that this material did not interfere with normal gas transfer, or react with any impurities present in the water. The water thus treated could meet drinking standards.

The raw Styropor granules could be heat-expanded locally, under controlled conditions, to produce Styropor beads satisfying certain requirements of sieve analysis and bulk density to meet specific demands.

It is not claimed that the results obtained are conclusive in every respect. However, sufficient evidence has been gathered to justify small scale applications of this material in farm ponds and small reservoirs for water evaporation reduction purposes. Further research would be necessary to supplement this study and to evaluate the effectiveness of Styropor layers on algae and mosquito control as well as to investigate other aspects not covered in this study.

Further Research Needs

The study conducted in the twin experimental ponds on the use of white Styropor beads for water evaporation reduction was a preliminary step which needs to be supplemented by more research under field conditions. More observations is needed regarding the over all water savings that could be realized by long term applications of the layer and its life time under field conditions.

Other side effects of the use of the Styropor beads' layer such as its effect on gas transfer between the covered water surface and the atmosphere and on Algae and mosquito control have to be investigated further. The fact that the use of this material, judging by the results of the experimental work conducted, might prove to be of practical value for water evaporation reduction purposes in impounding reservoirs located in natural depressions necessitates a study of the behaviour of the floating Styropor beads under conditions of gradual lowering of the water surface as a result of water loss with consequent reduction of the surface area of the reservoir. A potential danger lies in the possibility that some of the beads may adhere to the sloping sides of the reservoir along the periphery as a result of the reduction in water surface area and eventually be lost. Hence the effect of earth side slopes of a reservoir on the Styropor layer under actual field conditions has to be investigated together with a comparison of the effects of different side slopes.

The determination of the effect of wind action on the Styropor beads when applied to a natural water surface, under field conditions, is of importance because this aspect is directly related to the surface coverage provided by the layer and its useful life time. This will provide more dependable results for economy considerations and essential information on the feasibility of the application of the material as a water evaporation retardant.

Styropor beads, which are produced as a result of expanding the Styropor granules by the application of heat, could be produced under controlled conditions to satisfy certain sieve analysis and bulk density requirements. The experimental work conducted was concerned with one variety of the beads. Further investigation with different bead sizes is indicated and comparison of the results obtained may prove of value for the determination of the most suitable and effective variety for field applications.

APPENDIX I

METEOROLOGICAL DATA RECORDED AT THE SITE OF THE TEST FACILITY DURING THE INVESTIGATION

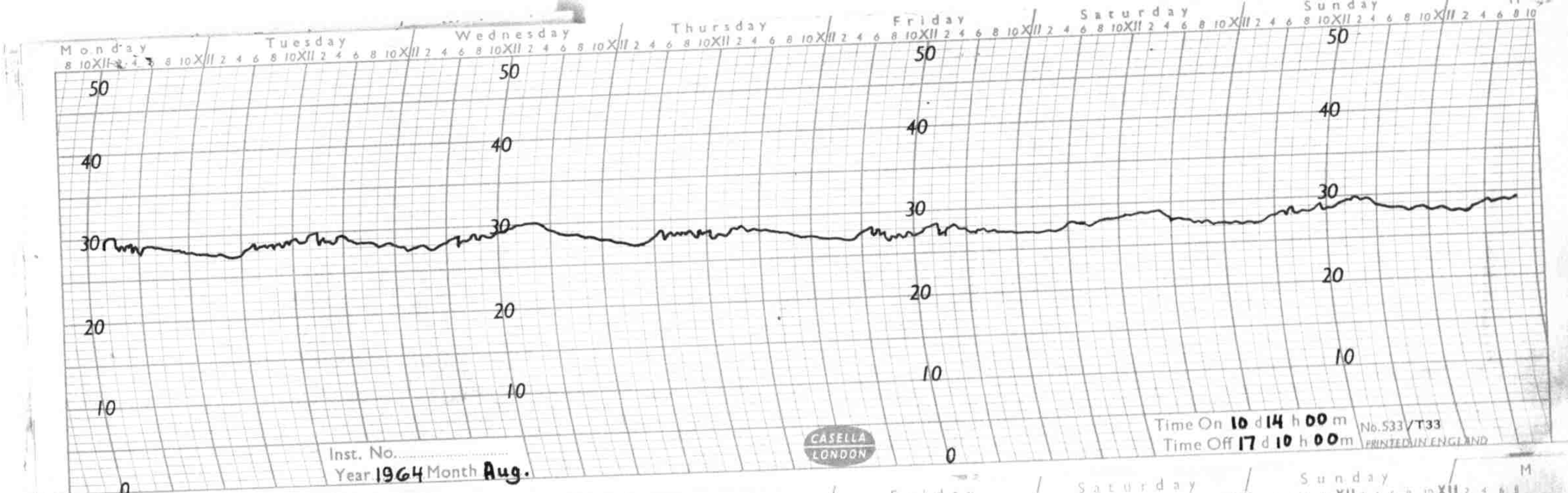


FIG. 1 - Thermograph Record covering the period August 10 to 17, 1964.

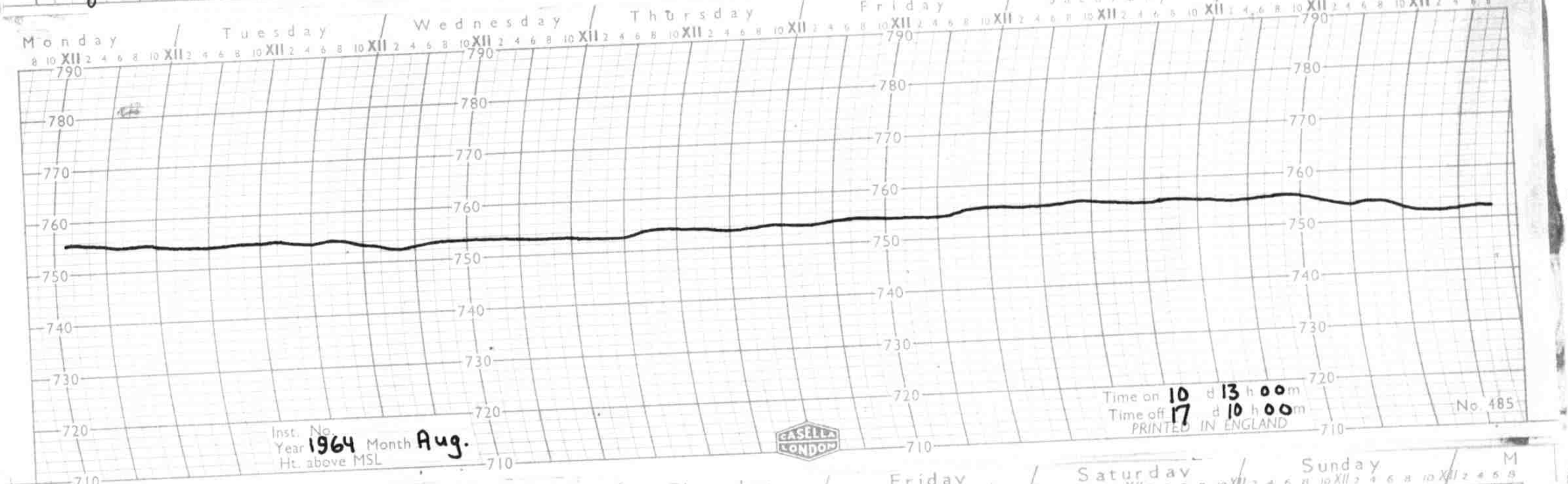


FIG. 2 - Barograph Record covering the period August 10 to 17, 1964.

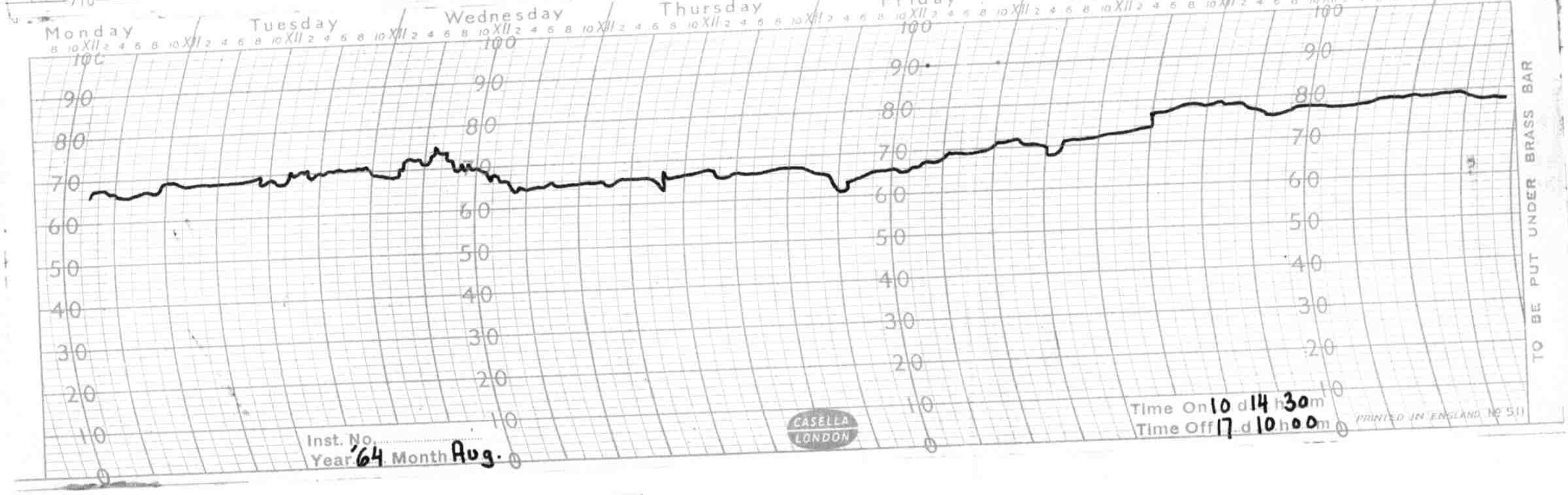


FIG. 3 - Hygrograph Record covering the period August 10 to 17, 1964.

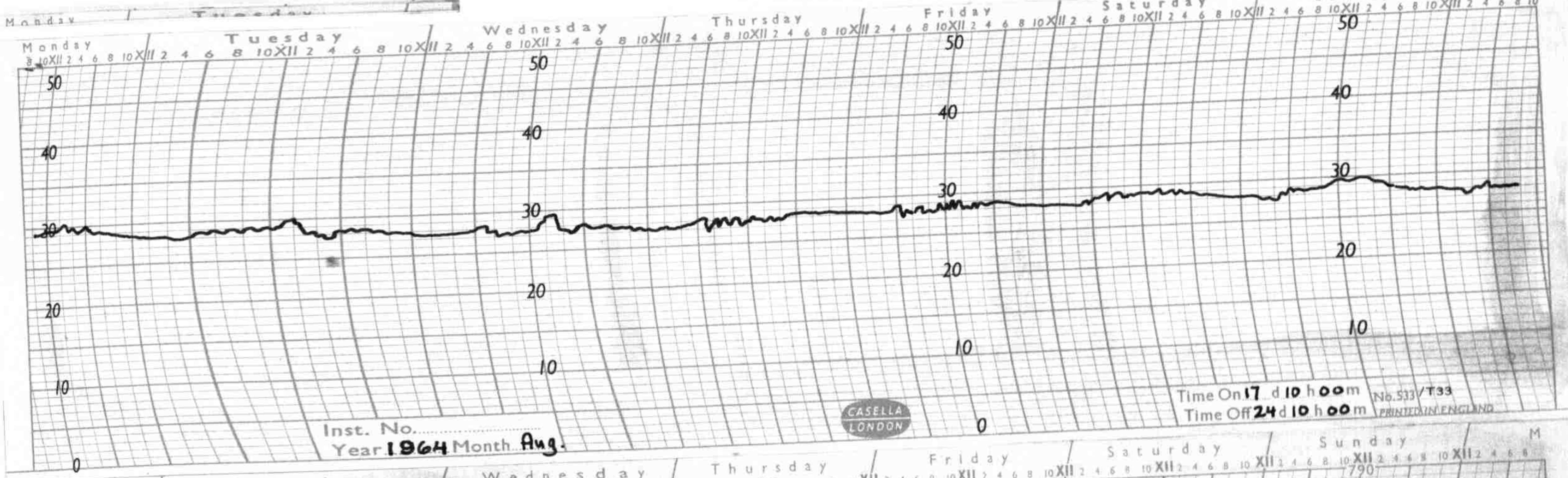


FIG. 4 - Thermograph Record covering the period August 17 to 24, 1964.

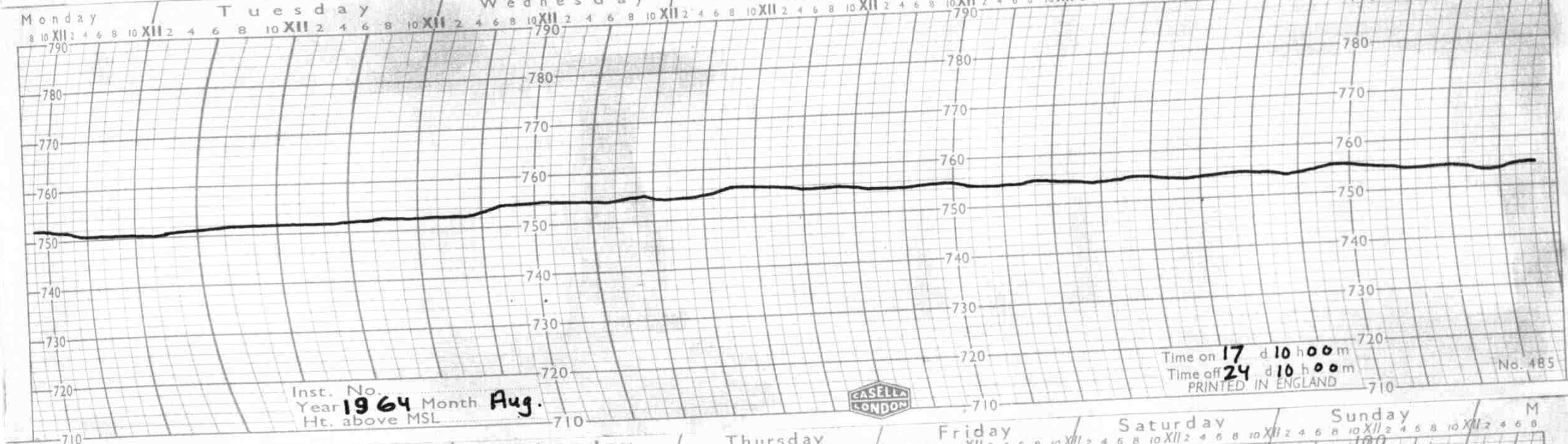


FIG. 5 - Barograph Record covering the period August 17 to 24, 1964.

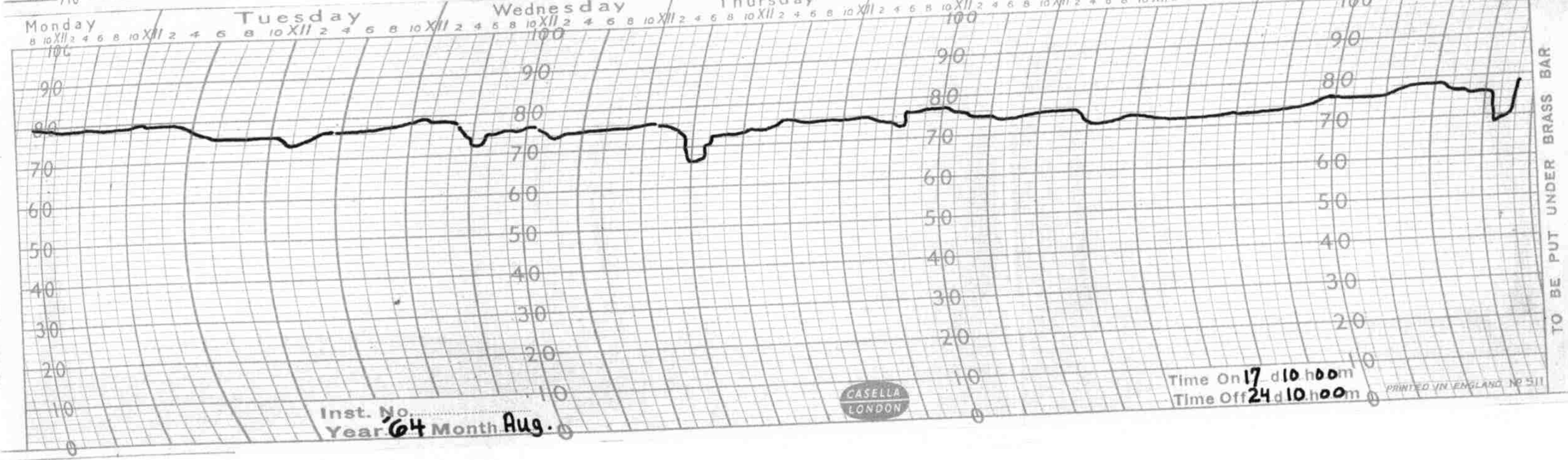


FIG. 6 - Hygrograph Record covering the period August 17 to 24, 1964.

FIG. 7 - Thermograph Record covering the period August 24 to 31, 1964.

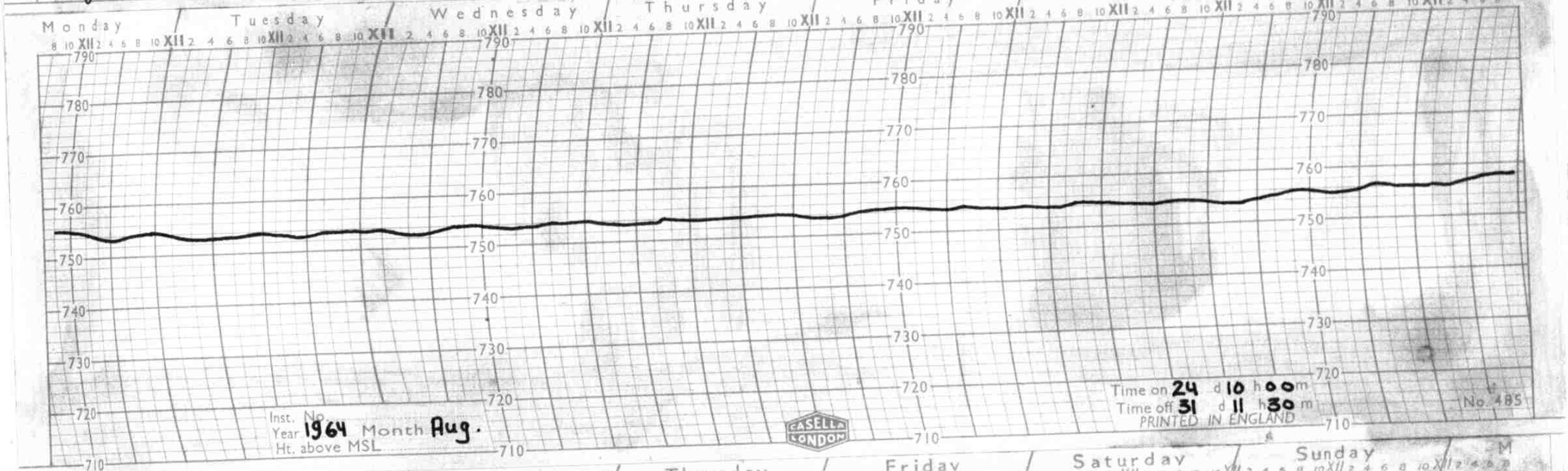


FIG. 8 - Barograph Record covering the period August 24, to 31, 1964.

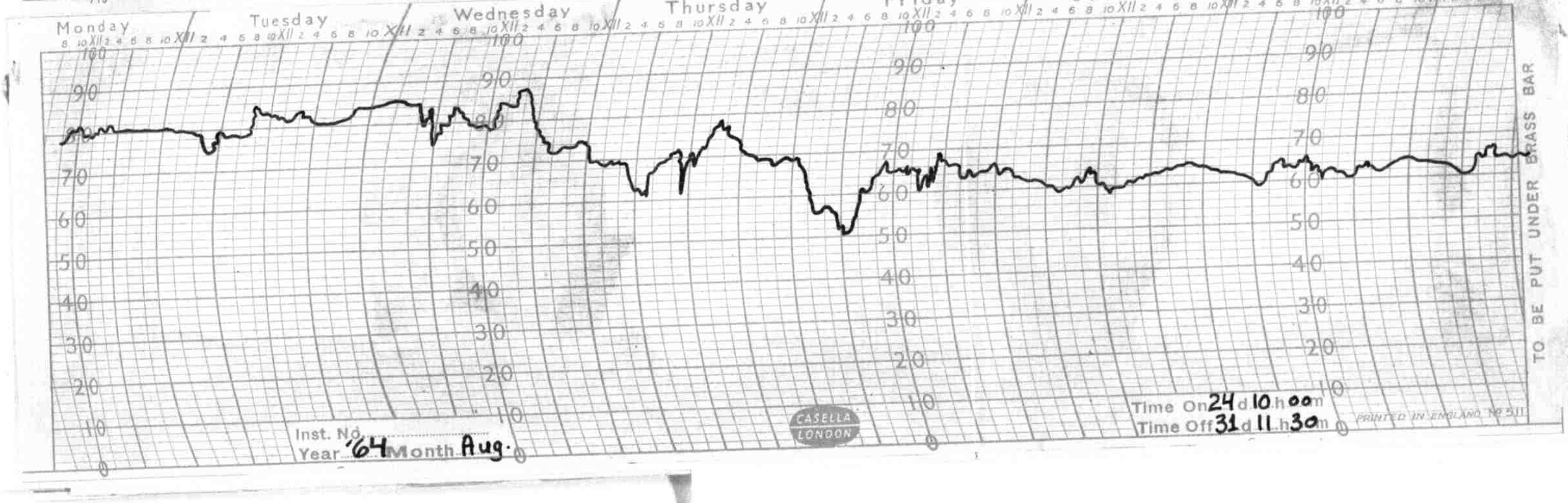
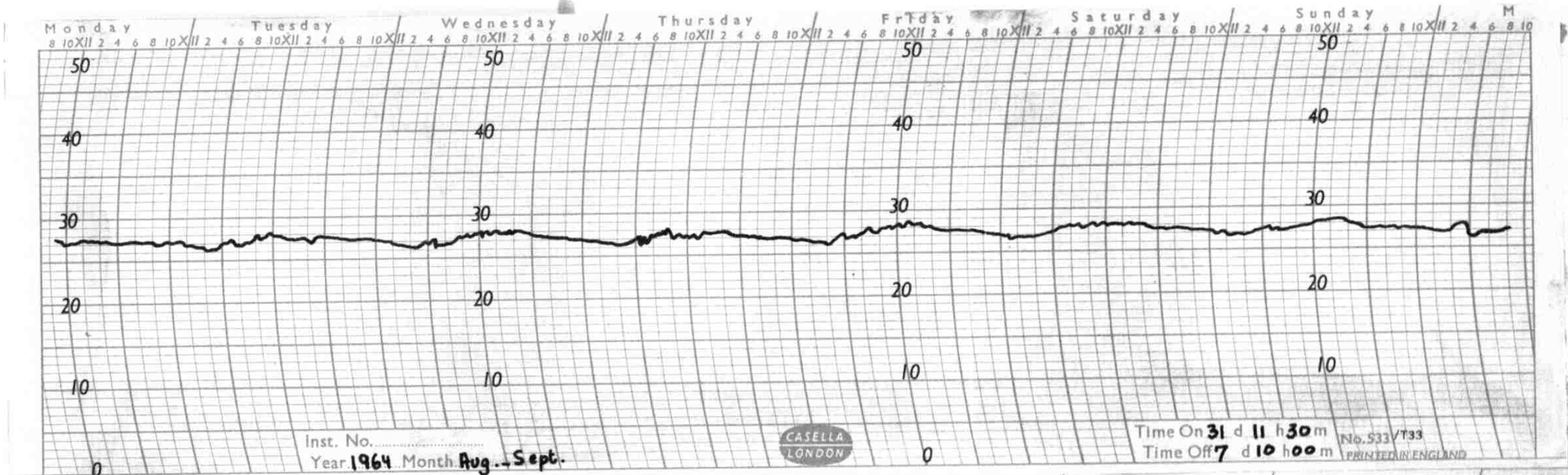


FIG. 9 - Hygrograph Record covering the period August 24 to 31, 1964.



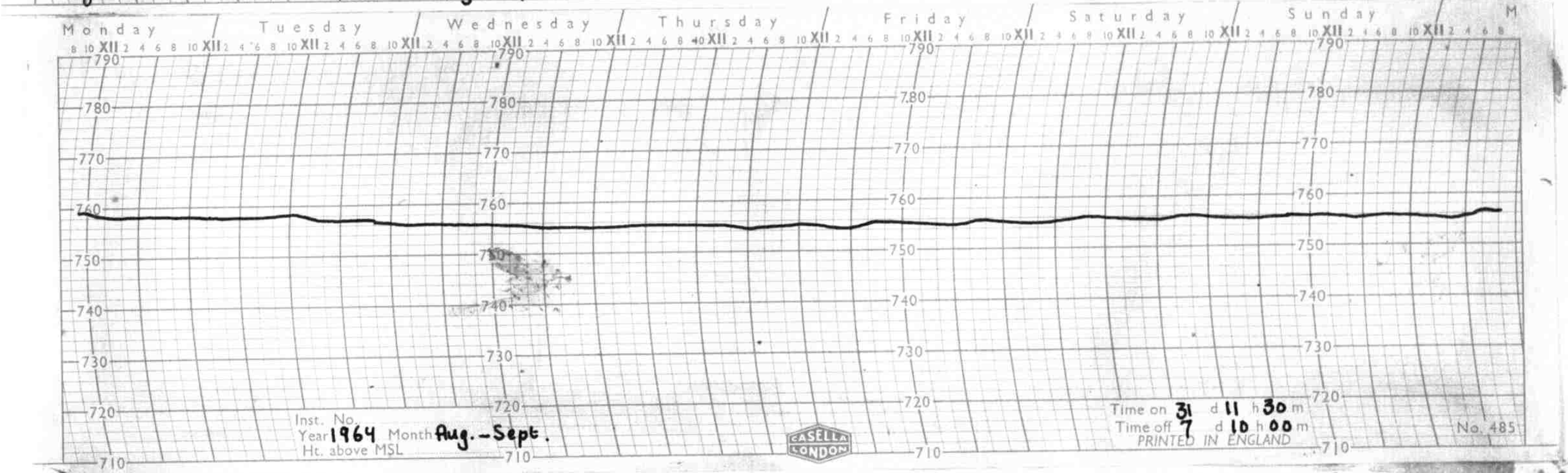
Inst. No.

Year 1964 Month Aug.-Sept.

Time On 31 d 11 h 30 m

Time Off 7 d 10 h 00 m

FIG. 10 - Thermograph Record covering the period Aug. 31 to Sept. 7, 1964.



Inst. No.

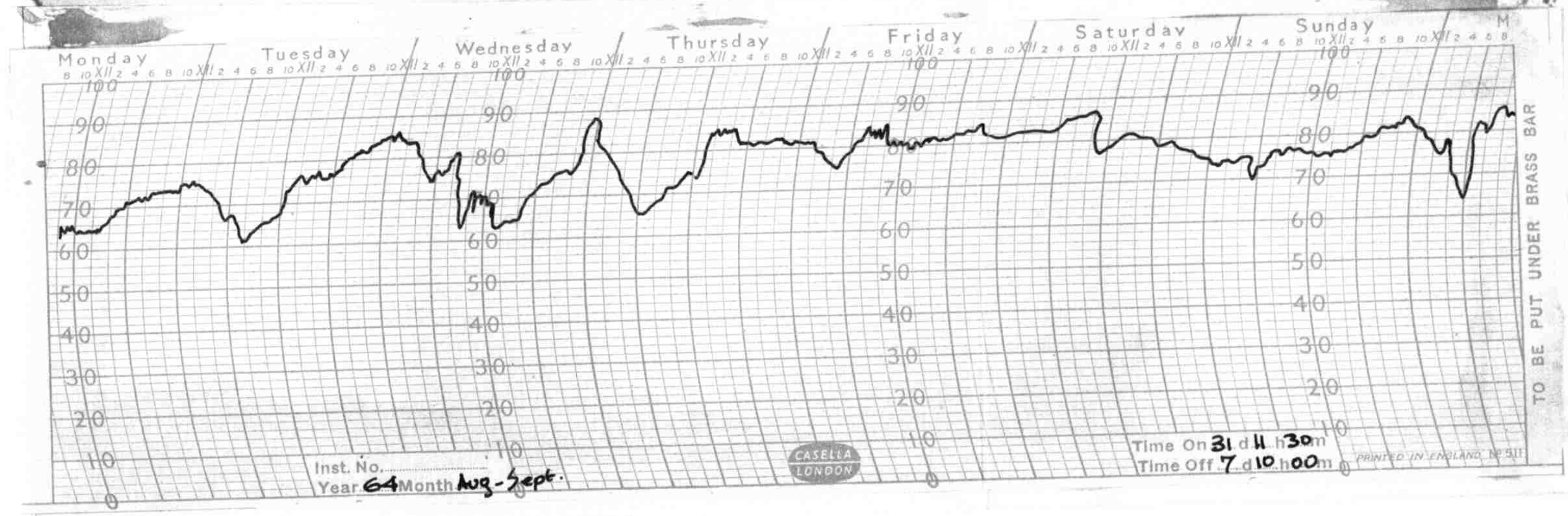
Year 1964 Month Aug.-Sept.

Ht. above MSL

Time on 31 d 11 h 30 m

Time off 7 d 10 h 00 m

FIG. 11 - Barograph Record covering the period Aug. 31 to Sept. 7, 1964.



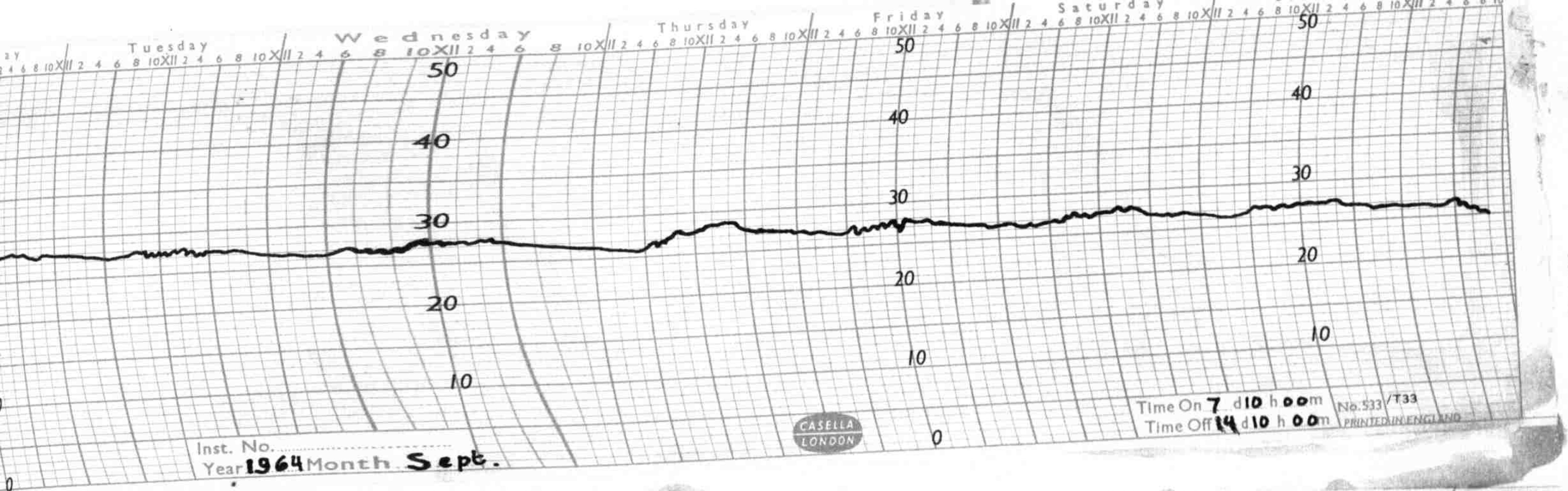
Inst. No.

Year 64 Month Aug-Sept.

Time On 31 d 11 h 30 m

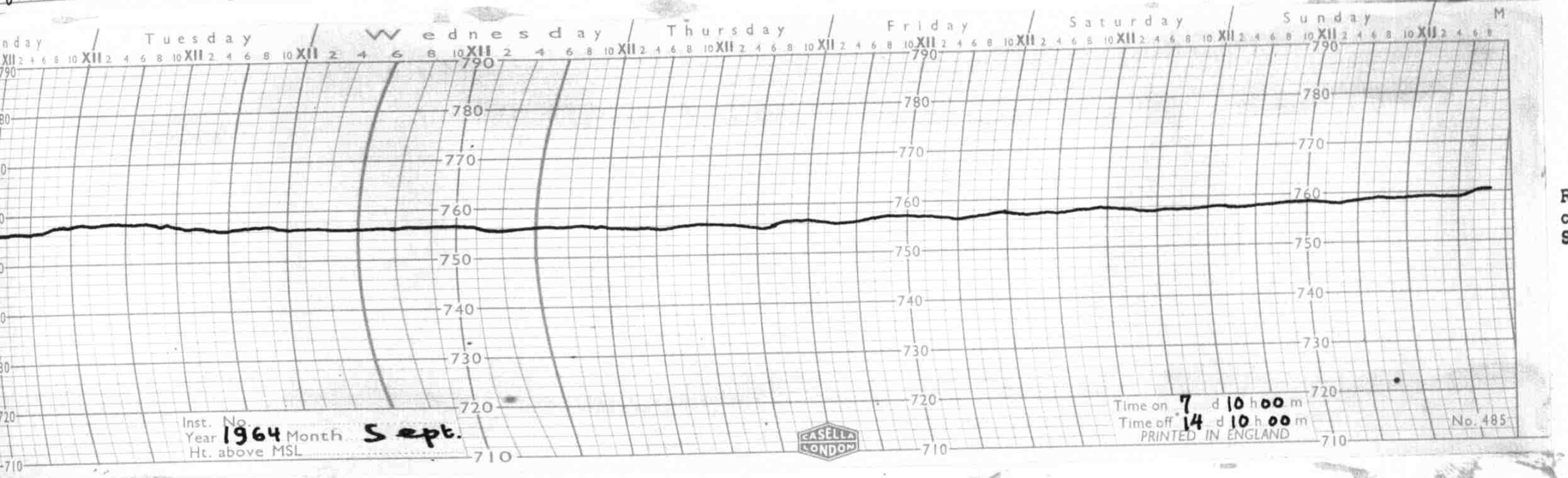
Time Off 7 d 10 h 00 m

FIG. 12 - Hygrograph Record covering the period Aug. 31 to Sept. 7, 1964.



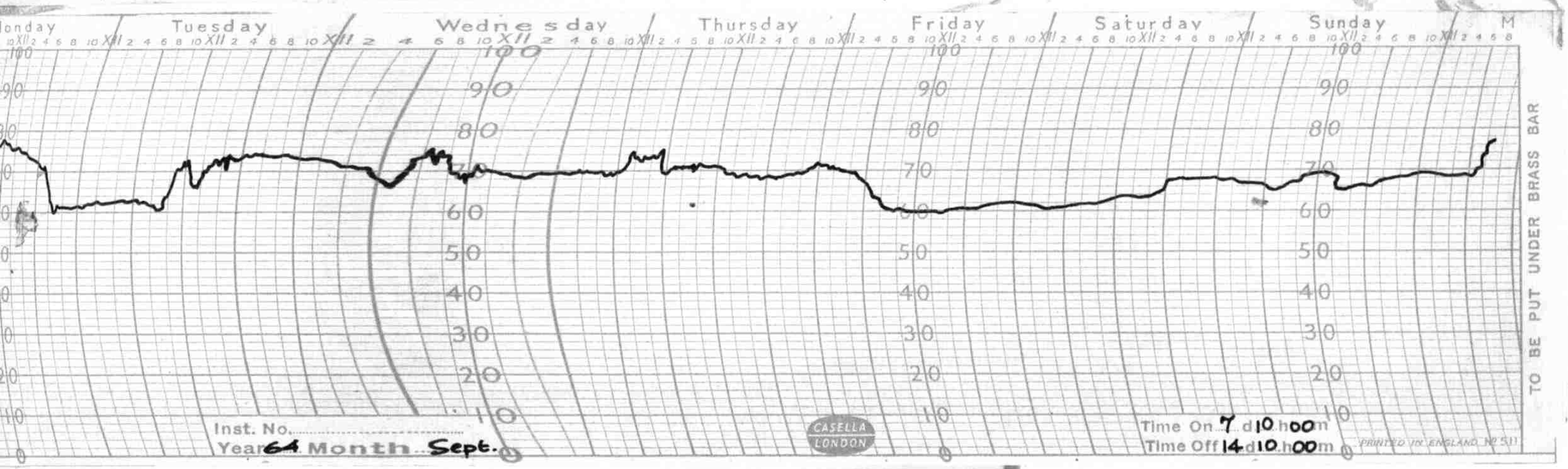
Inst. No.
Year 1964 Month Sept.
Time On 7 d 10 h 00 m
Time Off 14 d 10 h 00 m

FIG. 13 - Thermograph Record covering the period Sept. 7 to 14, 1964.



Inst. No.
Year 1964 Month Sept.
Ht. above MSL
Time on 7 d 10 h 00 m
Time off 14 d 10 h 00 m

FIG. 14 - Barograph Record covering the period Sept. 7 to 14, 1964.



Inst. No.
Year 64 Month Sept.
Time On 7 d 10 h 00 m
Time Off 14 d 10 h 00 m

FIG. 15 -Hygrograph Record covering the period Sept. 7 to 14, 1964.

FIG. 16 - Thermograph Record covering the period Sept. 14 to 21, 1964.

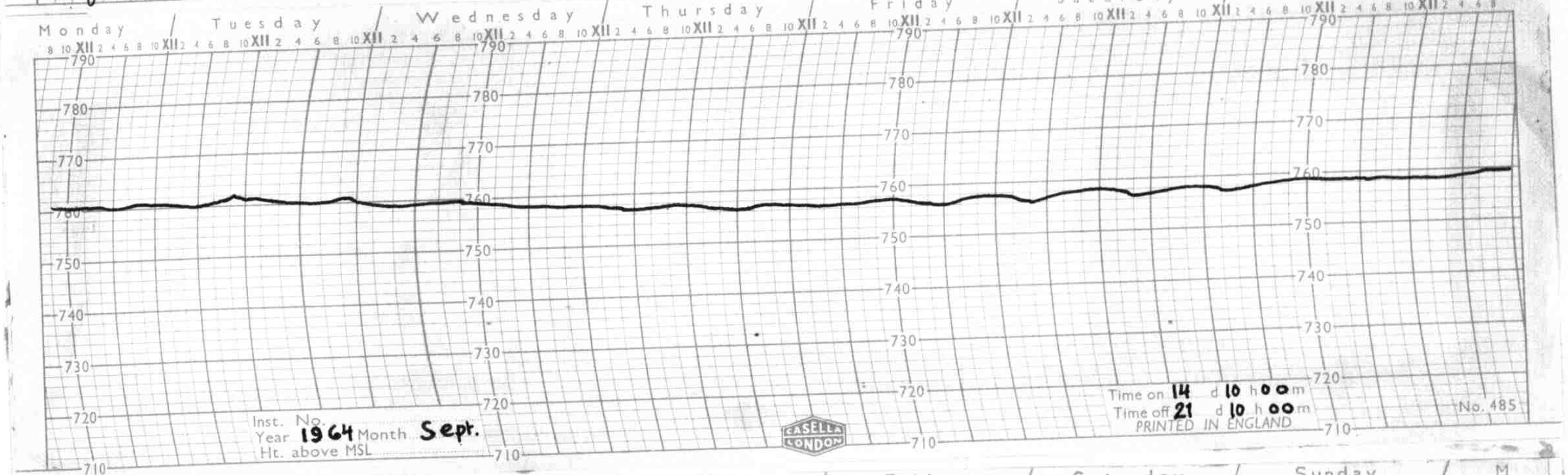


FIG. 17 - Barograph Record covering the period Sept. 14 to 21, 1964.

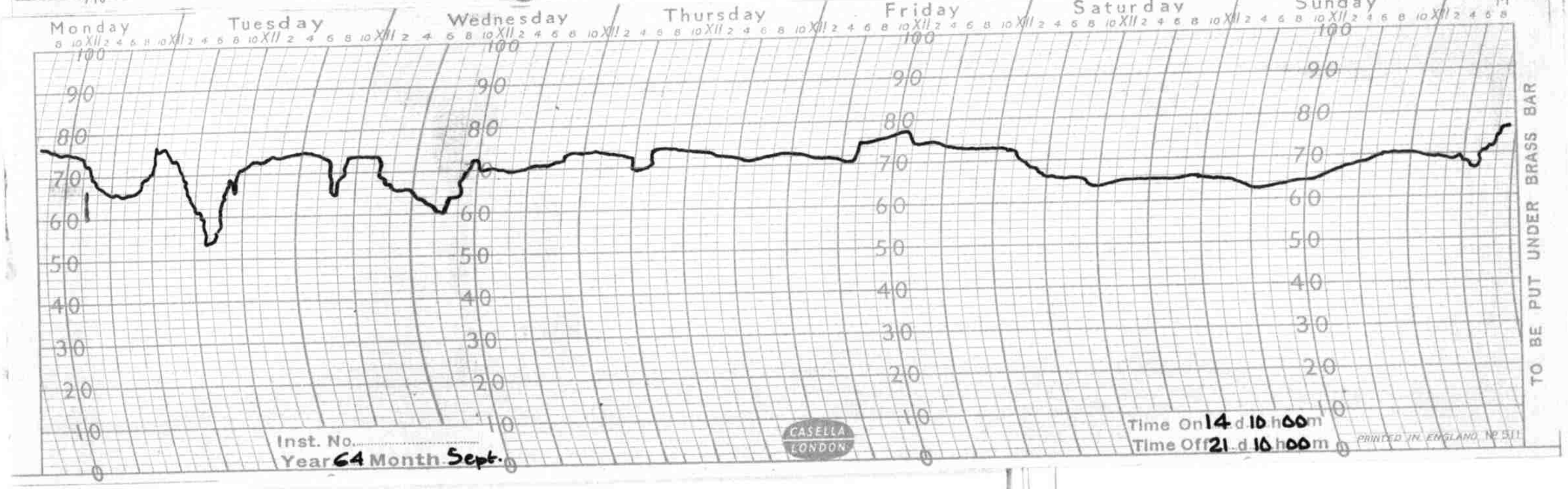


FIG. 18 - Hygrograph Record covering the period Sept. 14 to 21, 1964.

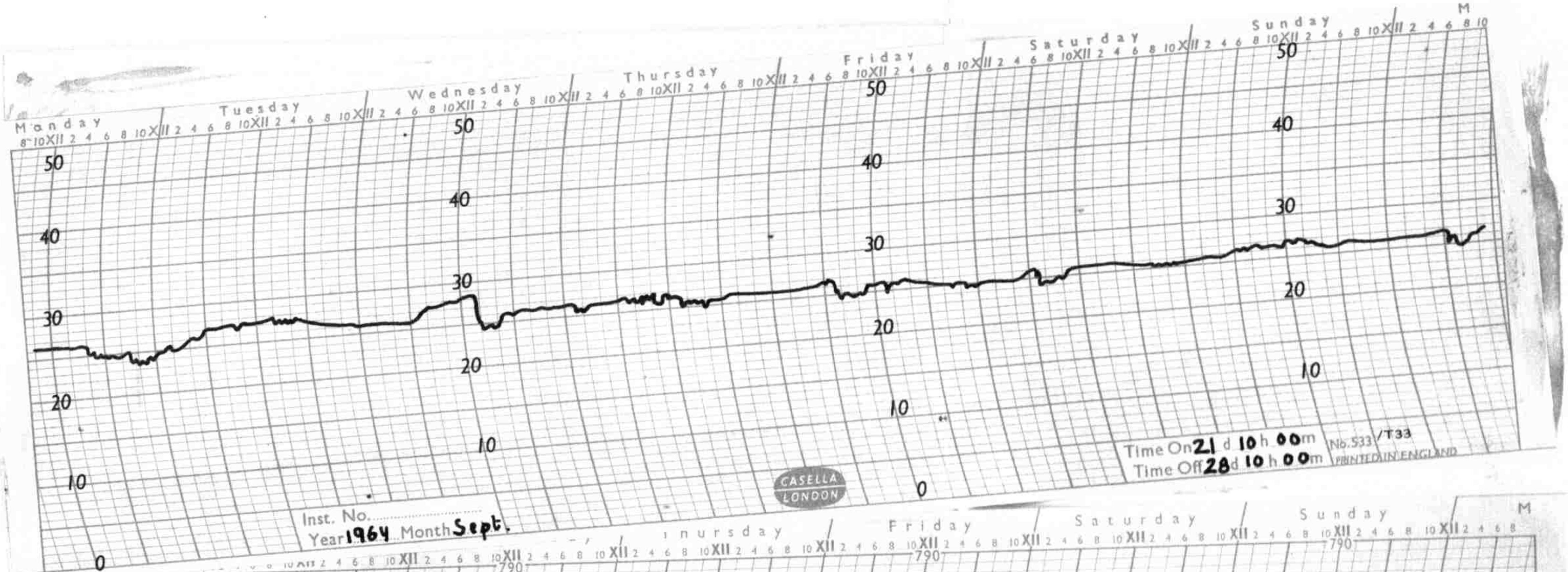


FIG. 19 - Thermograph Record covering the period Sept. 21 to 28, 1964.

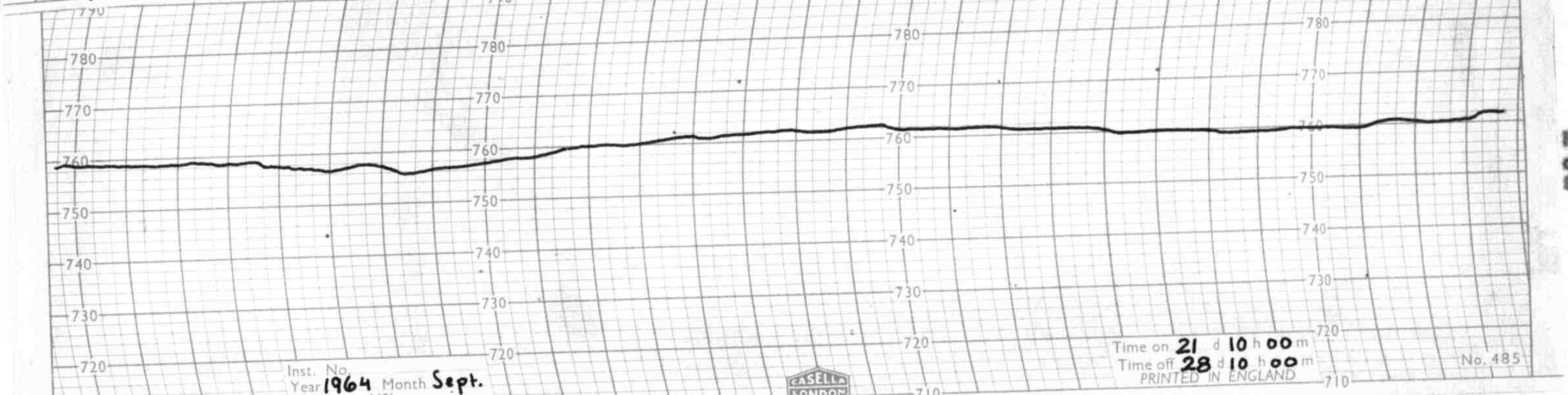


FIG. 20 - Barograph Record covering the period Sept. 21 to 28, 1964.

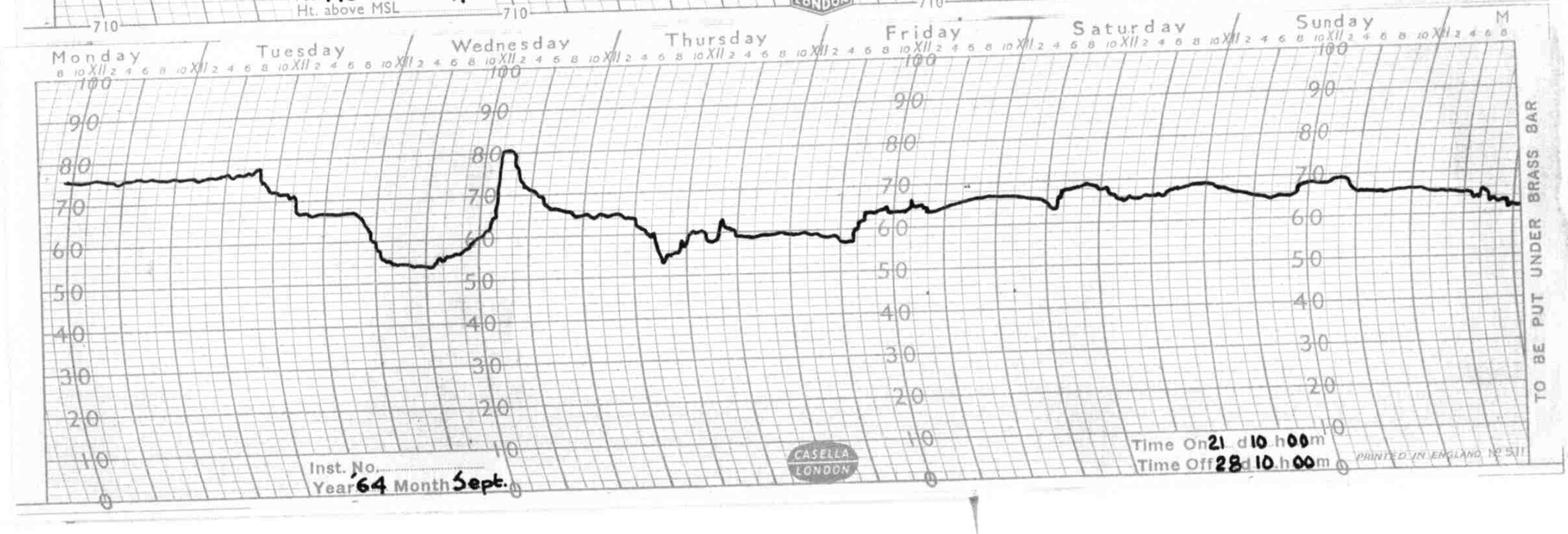


FIG. 21 - Hygrograph Record covering the period Sept. 21 to 28, 1964.

FIG. 22 - Thermograph Record covering the period Sept. 28 to Oct. 5, 1964.

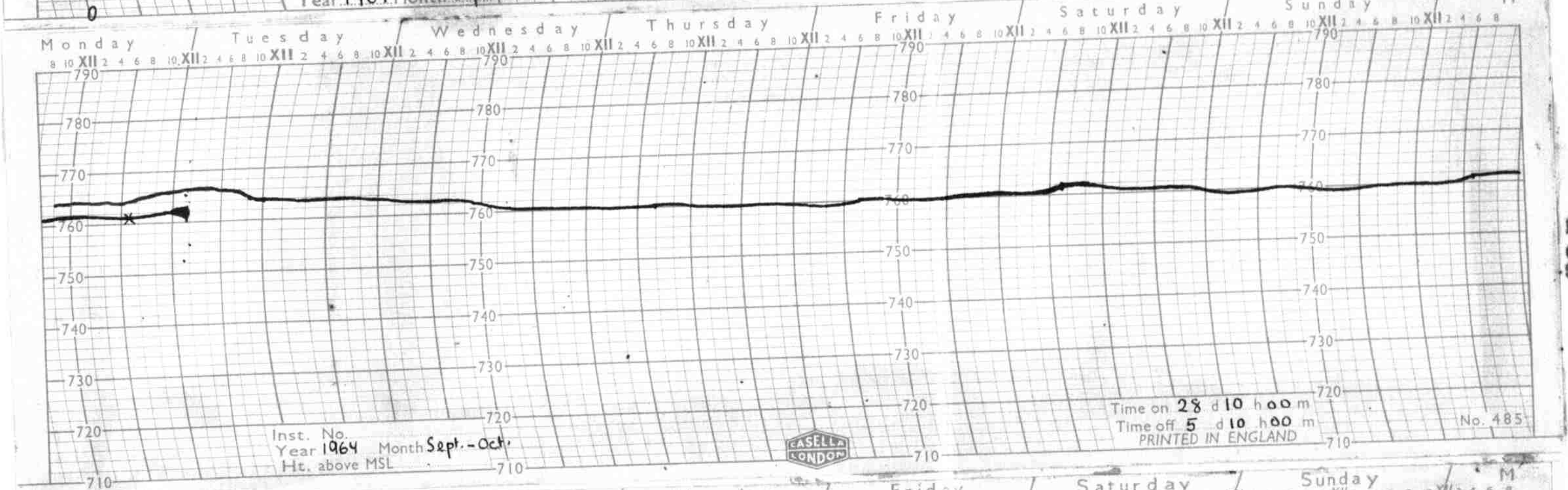


FIG. 23 - Barograph Record covering the period Sept. 28 to Oct. 5, 1964.

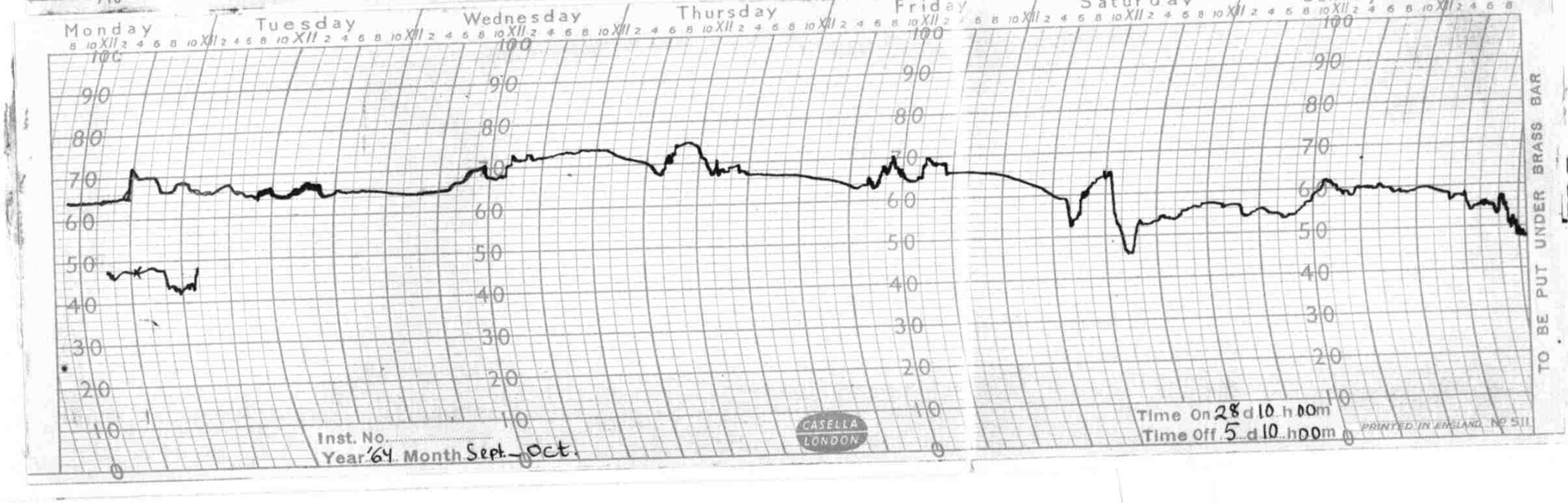
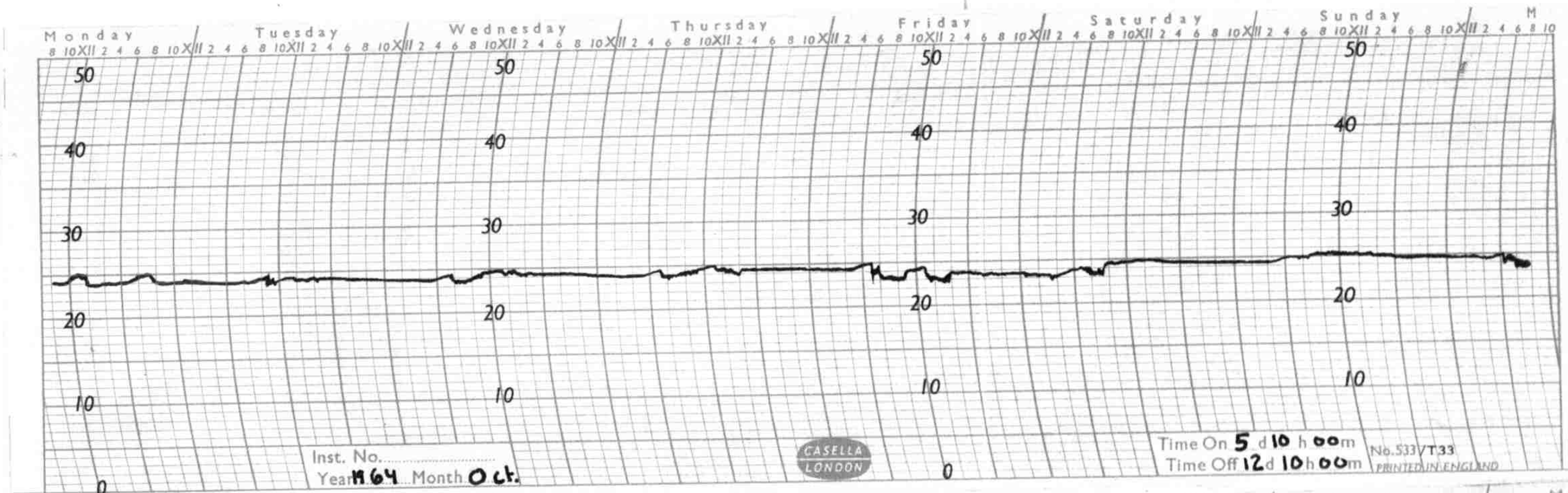
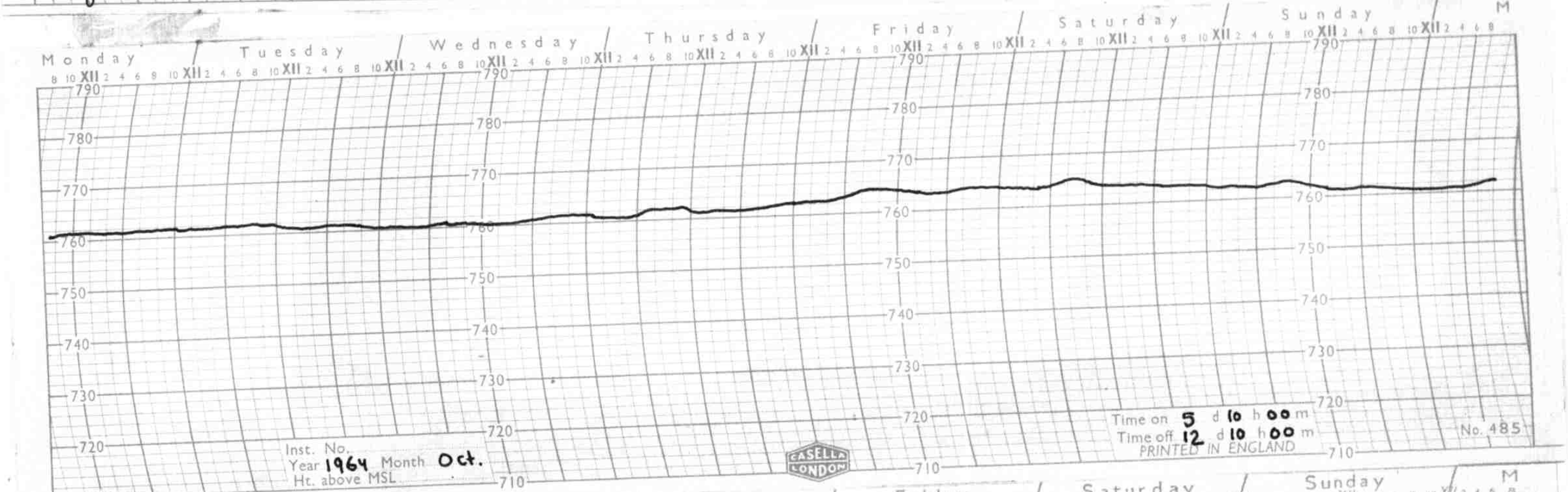


FIG. 24 - Hygrograph Record covering the period Sept. 28 to Oct. 5, 1964.



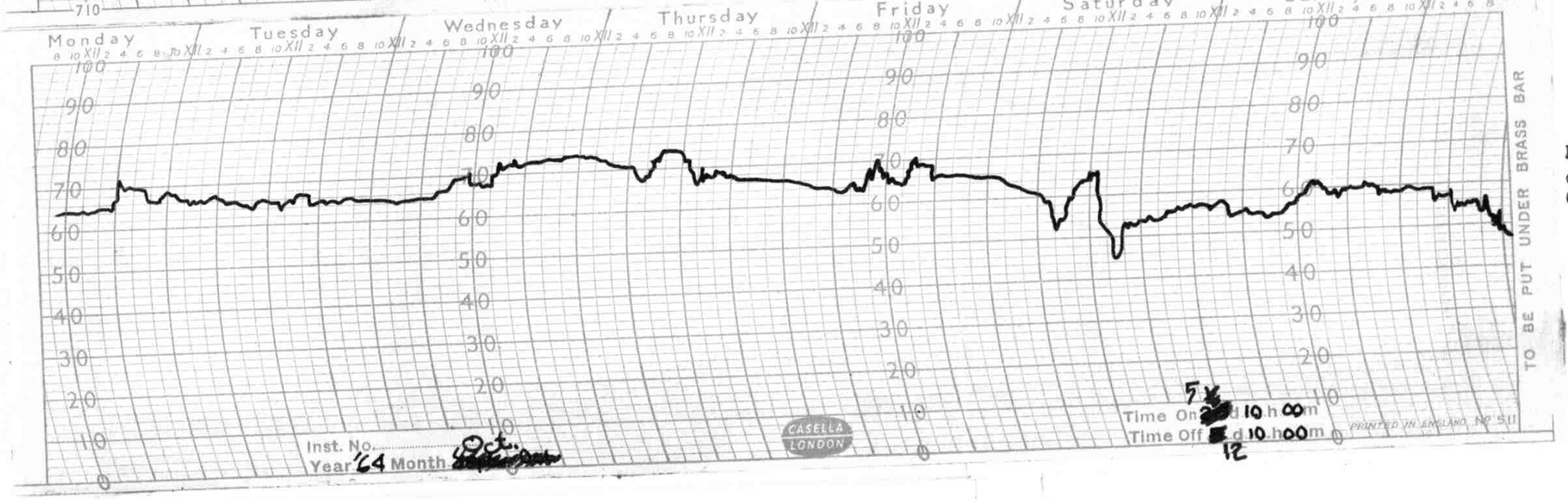
Inst. No.
Year 1964 Month Oct.
Time On 5 d 10 h 00 m
Time Off 12 d 10 h 00 m

FIG. 25 - Thermograph Record covering the period Oct. 5 to 12, 1964.



Inst. No.
Year 1964 Month Oct.
Ht. above MSL
Time on 5 d 10 h 00 m
Time off 12 d 10 h 00 m

FIG. 26 - Barograph Record covering the period Oct. 5 to 12, 1964.



Inst. No.
Year '64 Month Oct.
Time On 5 d 10 h 00 m
Time Off 12 d 10 h 00 m

FIG. 27 - Hygrograph Record covering the period Oct. 5 to 12, 1964.

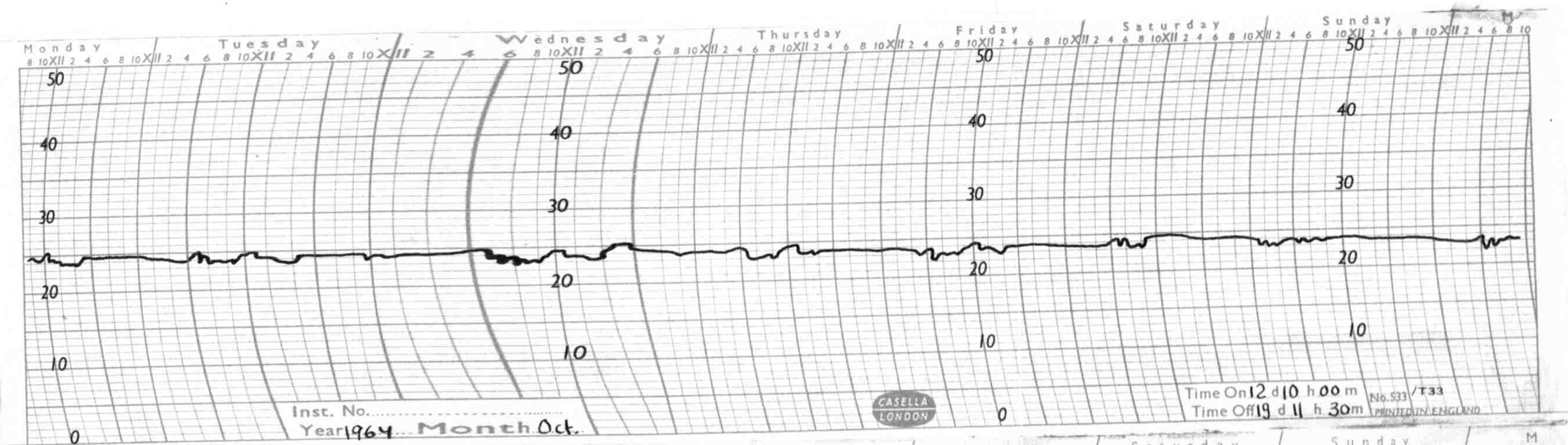


FIG. 28 - Thermograph Record covering the period Oct. 12 to 19, 1964.

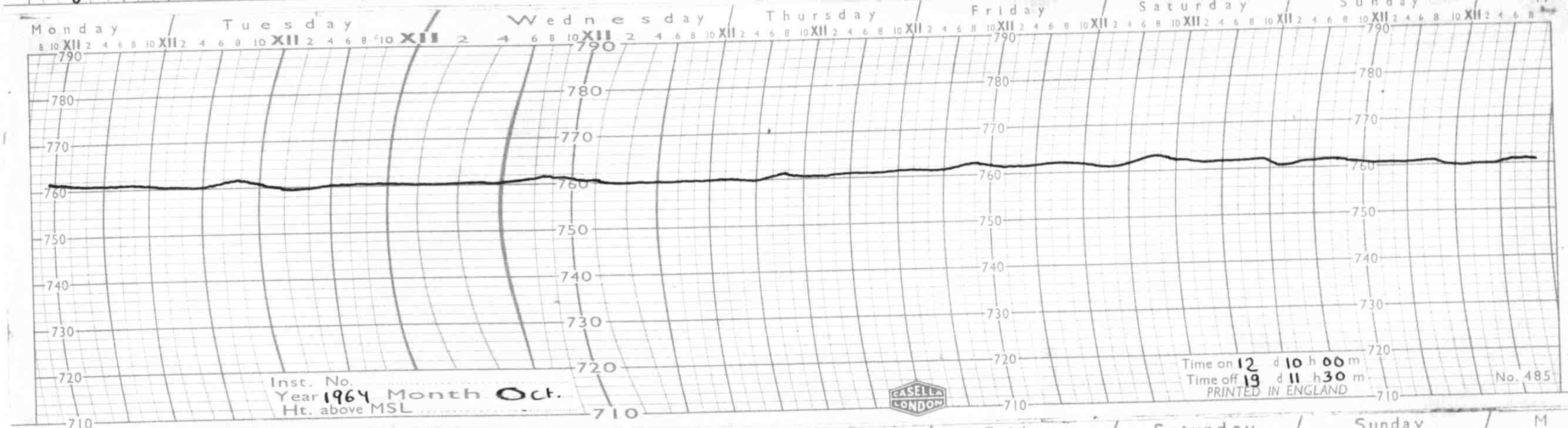


FIG. 29 - Barograph Record covering the period Oct. 12 to 19, 1964.

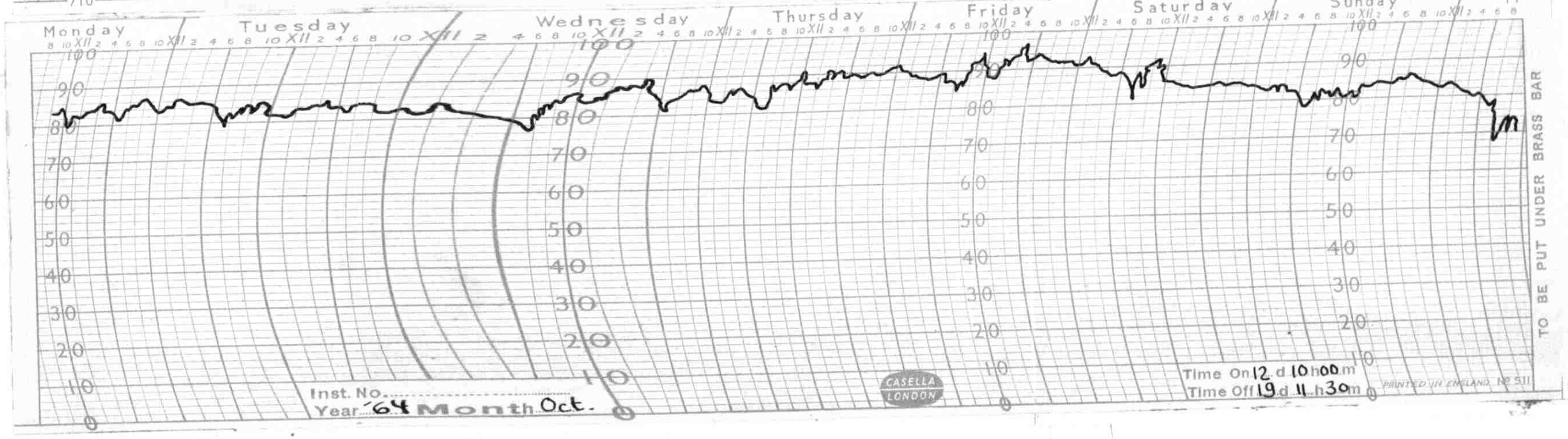


FIG. 30 - Hygrograph Record covering the period Oct. 12 to 19, 1964.

APPENDIX II

METEOROLOGICAL DATA IN SIX CITIES IN THE MIDDLE EAST,[31] AND TEN STATIONS IN THE H.K. OF JORDAN[29]

TABLE

Baghdad, Iraq / Elevation 111 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall, Inches	Days 0.1 Inche or more
	Max	Min	Max	Min			
Jan.	60	39	77	18	51	1	4
Feb.	64	42	86	23	42	1	3
Mar.	71	48	90	27	36	1	4
April	85	57	104	37	34	1	3
May	97	67	112	51	19	T	1
June	105	73	119	58	13	T	0
July	110	76	121	62	12	T	0
Aug.	110	76	120	64	13	T	0
Sept.	104	70	116	51	15	T	0
Oct.	92	61	107	39	22	T	1
Nov.	77	51	94	29	39	1	3
Dec.	64	42	79	20	52	1	5
Year	87	59	121	18	29	6	24

(1) Measured at 3.00 P.M.
T Trace – Less than 1/2 inch.

TABLE

Beirut , Lebanon / Elevation 111 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall Inches	Days 0.1 Inches or more
	Max	Min	Max	Min			
Jan.	61	51	77	31	70	8	15
Feb.	63	51	87	30	70	6	12
Mar.	66	54	97	36	69	4	9
April	72	58	99	43	67	2	5
May	78	64	107	56	64	1	2
June	83	69	104	56	61	T	*
July	87	73	98	64	58	T	*
Aug.	89	74	99	62	57	T	*
Sept.	86	73	99	60	57	T	1
Oct.	81	69	101	52	62	2	4
Nov.	73	61	91	41	61	5	8
Dec.	65	55	84	30	69	7	12
Year	75	63	107	30	64	35	68

(1) Measured at 3.00 P.M.

* Less than 1/2 .

T Trace _ Less than 1/2 inch.

TABLE

Cairo, U.A.R. / Elevation 381 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall Inches	Days 0.1 Inches or more
	Max	Min	Max	Min			
Jan.	65	47	88	35	40	T	1
Feb.	69	48	92	35	33	T	1
Mar.	75	52	101	38	27	T	1
April	83	57	113	42	21	T	*
May	91	63	116	49	18	T	*
June	95	68	117	55	20	T	*
July	96	70	109	61	24	0	0
Aug.	95	71	109	63	28	0	0
Sept.	90	68	108	58	31	T	0
Oct.	86	65	109	51	31	T	*
Nov.	78	58	100	42	38	T	1
Dec.	68	50	87	34	41	T	1
Year	83	60	117	34	29	1	5

(1) Measured at 2.00 P.M.

* Less than 1/2

T Trace – less than 1/2 inch.

TABLE

Damascus, Syria / Elevation 2362 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall Inches	Days 0.1 Inches or more
	Max	Min	Max	Min			
Jan.	53	36	69	21	57	2	7
Feb.	57	39	86	23	53	2	6
Mar.	65	42	83	28	42	T	2
April	75	49	95	33	32	1	3
May	84	55	101	44	26	T	1
June	91	61	102	48	22	T	*
July	96	64	108	55	19	T	0
Aug.	99	64	113	55	21	0	0
Sept.	91	60	102	50	24	1	2
Oct	81	54	93	42	31	T	2
Nov.	67	47	86	28	46	2	5
Dec.	56	40	69	23	59	2	5
Year	76	51	113	21	36	9	33

(1) Measured at 2:30 P.M.
* Less than 1/2
T Trace _ Less than 1/2 inch.

TABLE

Jerusalem, Jordan / Elevation 2485 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall Inches	Days 0.1 Inches or more
	Max	Min	Max	Min			
Jan.	55	41	77	26	66	5	9
Feb.	56	42	80	27	58	5	11
Mar.	65	46	87	30	57	3	3
April	73	50	102	36	42	1	3
May	81	57	103	42	33	T	1
June	85	60	107	47	32	T	*
July	87	63	100	50	35	0	0
Aug.	87	64	103	52	36	0	0
Sept.	85	62	103	50	36	T	*
Oct.	81	59	97	47	36	1	1
Nov.	70	53	88	39	50	3	4
Dec.	59	45	79	27	60	3	7
Year	73	53	107	26	45	21	39

(1) Measured at 1:30 P.M.
* Less than 1/2
T Trace – Less than 1/2 inch.

TABLE

Kuwait City, Kuwait / Elevation 16 feet.

Month	Temperature °F				Relative Humidity (1)	Precipitation	
	Average		Extreme			Average Monthly Fall Inches	Days 0.1 Inches or more
	Max	Min	Max	Min			
Jan.	61	49	82	33	61	1	2
Feb.	65	51	78	36	61	1	2
Mar.	72	59	90	40	61	1	2
April	83	68	103	54	55	T	1
May	94	77	109	60	55	T	*
June	98	82	119	72	49	0	0
July	103	86	118	78	41	0	0
Aug.	104	86	115	68	46	0	0
Sept.	100	81	117	67	51	0	0
Oct.	91	73	105	57	60	T	*
Nov.	77	62	100	43	59	1	1
Dec.	65	53	79	36	65	1	3
year	85	69	119	33	55	5	11

(1) Measured at 2:30 P.M.
* Less than 1/2
T Trace _ Less than 1/2 inch.

TABLE

Amman, H.K. of Jordan/ Elevation 766 m Above M.S.L.
Years 1952_1962

	Temperature (°C.)				Relative Humidity (Mean)	Average Rainfall mm.	Evaporation (Piche) mm (1)
	Average		Extreme				
	Max.	Min.	Max.	Min.			
Jan.	12.5	3.9	26.3	_ 6.1	69	67.7	4.10
Feb.	14.0	4.5	29.2	_ 7.5	65	59.4	4.35
Mar.	17.2	6.2	31.8	_ 3.0	59	44.1	6.45
April	227	6.9	361	0.0	48	12.5	8.00
May	28.0	13.7	40.5	44	37	4.9	8.90
June	30.8	16.3	42.8	8.0	36	T	14.05
July	32.0	18.4	41.7	11.6	37	T	13.10
Aug.	32.6	18.6	42.8	12.0	42	T	12.65
Sept.	30.5	16.3	40.6	8.9	46	0.7	10.15
Oct.	27.5	13.9	37.2	6.1	44	4.4	8.80
Nov.	20.8	9.8	33.0	_ 3.2	56	31.5	7.55
Dec.	14.7	5.4	27.2	_ 4.0	67	47.9	3.85
						Total 273.1 mm. 10.8 Inches.	

(1) Evaporation for the years 1962_1963
Average daily during the month.

T Trace.

Jerusalem Airport, / Elevation 755 m. Above M.S.L.
H.K. of Jordan. years : 1952 - 1962.

	Temperature (°C)				Relative Humidity	Average Rainfall	Evaporation (piche)
	Average		Extreme				
	Max.	Min.	Max.	Min.		mm.	mm. *
Jan	12.7	4.6	26.9	−3.5	75	127.7	3.3
Feb.	14.0	5.0	26.0	−3.0	74	108.5	3.5
Mar.	15.8	6.2	31.5	−1.6	71	120.6	4.3
April	20.8	9.4	32.5	0.0	60	16.4	7.5
May	25.7	12.4	35.3	5.9	49	5.4	9.8
June	28.2	15.5	39.1	9.9	53	T	10.9
July	29.5	17.1	38.4	12.4	58	0	10.5
Aug.	30.4	18.0	39.2	12.6	61	0	9.9
Sept.	28.3	16.4	37.0	10.2	61	0.7	8.0
Oct.	26.0	14.2	34.5	8.0	58	3.7	7.5
Nov.	19.5	10.0	29.0	0.5	60	79.2	5.6
Dec.	14.5	6.2	27.1	−0.5	72	115.9	3.4
						Total 578.1 mm. 22.7 inches	

* Evaporation for the years 1952 - 1959.
Average daily during the month.

T Trace.

TABLE.

Maán, H.K. of Jordan / Elevation 1006 m. Above M.S.L.
Years 1960-1964.

	Temperature (°C)				Relative humidity (Mean)	Average Rainfall mm. *	Evaporation (Piche) mm. (1)
	Average		Extreme				
	Max.	Min.	Max.	Min.			
Jan.	15.0	2.6	27.6	-6.6	66	5.8	6.0
Feb.	16.1	2.8	29.0	-4.0	65	8.0	6.9
Mar.	20.1	5.6	35.4	-2.4	53	6.4	9.5
April	24.0	8.6	35.4	-1.4	42	3.7	11.0
May	30.0	13.8	36.2	5.6	39	2.4	12.7
June	33.8	16.4	40.0	4.6	36	–	15.2
July	35.2	17.6	41.0	11.2	32	∸	13.3
Aug.	35.5	18.4	39.8	10.0	31	–	13.8
Sept.	32.7	16.0	38.6	5.0	35	–	12.2
Oct.	29.1	12.4	36.0	-1.7	42	2.3	10.5
Nov.	29.1	7.6	29.4	-3.0	54	5.6	7.7
Dec.	17.2	5.0	28.0	-6.4	63	7.8	5.8
						Total 42.0 mm. 1.65 inches	

* Rainfall for the period 1938-1964.

(1) Evaporation for the years 1962-1963
Average daily during the month

Shuneh (North), Jordan / Elevation 197 m. Below M.S.L.
Rift Valley, H.K. of Jordan Years 1954 - 1964.

	Temperature (°C)				Relative Humidity (Mean)	Average Rainfall mm. (1)	Evaporation (Piche) mm. *
	Average		Extreme				
	Max.	Min	Max.	Min			
Jan.	19.4	9.6	28.0	2.0	67	72.5	3.6
Feb.	20.3	9.8	29.5	2.5	72	52.7	4.3
Mar.	23.4	11.3	36.0	2.5	65	45.9	5.5
April	28.4	14.3	41.5	5.5	57	21.7	6.7
May	32.9	17.6	45.0	8.0	52	11.6	7.9
June	36.6	21.5	45.5	15.0	49	–	9.8
July	37.5	23.6	46.5	19.0	52	–	9.9
Aug.	38.6	24.0	45.0	18.5	53	–	10.5
Sept.	36.4	22.1	44.5	15.0	53	?	8.5
Oct.	34.0	20.0	43.0	14.0	52	9.3	6.6
Nov.	27.8	16.0	36.0	7.0	50	38.7	6.4
Dec.	21.8	12.5	34.5	-1.5	67	8.6	3.5
						Total 261.0 mm 10.3 inches	

(1) Rainfall Jan - May 10 years average.
June - Dec. 9 years average.

* Evaporation for the years 1962 - 1963.
Average daily during the month.

Jericho, Jordan Rift Valley, H.K. of Jordan / Elevation 276 m. Below M.S.L.
Years 1960 - 1964.

	Temperature (°C)				Relative Humidity (Mean)	Average Rain fall mm.	Evaporation (Piche) mm. (1)
	Average		Extreme				
	Max.	Min	Max.	Min.			
Jan.	19.8	8.7	27.0	0.0	69	39	4.2
Feb.	20.9	9.4	31.6	3.6	67	31	5
Mar.	25.3	11.2	37.5	3.0	58	17	6.2
April	29.7	14.9	41.0	6.5	52	9	9.9
May	34.0	18.2	47.3	11.5	40	3	11.8
June	38.4	22.0	50.5*	15.6	36	-	13.7
July	39.1	24.3	45.8	18.5	40	-	13.5
Aug.	39.4	28.2	47.4	19.6	46	-	12.3
Sept.	36.1	22.1	43.7	17.5	48	-	10.4
Oct.	33.9	20.0	45.4	13.4	50	3	8.5
Nov.	29.0	14.8	37.0	5.4	49	20	6.6
Dec.	21.5	10.1	30.4	1.5	66	30	4.3
						Total 152.0 mm 6.0 inches	

* Recorded in June 1946.

(1) Evaporation for the years 1941 - 1945
1961 - 1964
Average daily during the month.

Aqaba , Jordan Rift Valley, H.K. of Jordan / Elevation 8 m. Above M.S.L.
Years : 1959 - 1961

	Temperature (°C)				Relative Humidity (mean)	Average Rainfall mm.	Evaporation (Piche) mm. *
	Average		Extreme				
	Max.	Min	Max.	Min			
Jan.	22.5	10.0	31.5	1.4	51	4.4	9.2
Feb.	22.8	9.4	32.7	3.8	46	4.7	11.1
Mar.	26.0	12.2	38.5	6.6	39	5.0	15.4
April	31.4	16.8	44.7	10.8	32	2.3	15.5
May	36.2	21.5	44.7	15.9	31	0	21.6
June	39.0	22.9	47.2	17.8	29	0	30.0
July	40.4	25.1	47.6	22.5	30	0	23.6
Aug.	40.9	25.0	45.6	21.1	31	0	24.1
Sept.	37.3	23.1	43.8	18.0	33	0	21.2
Oct.	33.0	19.1	40.6	13.6	36	T	17.6
Nov.	29.3	15.8	39.0	7.3	49	3.1	16.0
Dec.	24.4	11.6	32.0	5.0	47	8.5	11.4
						Total 28.0 mm 1.11 inches	

* Evaporation for the years 1962 - 1963
Average daily during the month.

T Trace.

Desert :
Mafraq Airport, / Elevation 686 m. Above M.S.L.
H.K. of Jordan. Years : March '53 – July '56 ; July '59 - Jan '64

	Temperature (°C)				Relative Humidity	Average Rainfall mm.	Evaporation (Piche) mm. *
	Average		Extreme				
	Max	Min	Max	Min			
Jan	13.4	2.4	24.4	– 6.7	75	32.7	4.5
Feb	15.4	2.9	27.2	– 1.8	71	32.3	5.2
Mar.	17.1	4.7	32.6	– 3.3	63	26.2	8.4
April	23.0	6.9	34.2	– 0.5	55	9.5	10.3
May	28.0	11.6	37.6	4.0	44	3.8	12.5
June	32.5	13.9	40.2	4.9	43	—	17.6
July	33.6	15.2	41.1	9.6	47	—	14.8
Aug.	33.8	15.7	43.6	11.4	49	—	14.3
Sept.	32.4	13.1	39.0	7.4	52	—	12.1
Oct.	28.5	11.3	36.6	4.4	50	5.5	10.5
Nov.	20.9	6.5	31.0	– 6.5	49	18.1	9.6
Dec.	14.6	3.3	23.7	– 6.3	70	34.6	5.3
						Total 162.7 mm 6.4 inches	

* Evaporation for the years 1962 – 1963.
Average daily during the month.

Desert:

H.4 Station.
H.K. of Jordan.

Elevation 686 m. Above M.S.L.
Years: Jan.'60 – Jan.'64

	Temperature (°C)				Relative Humidity (1)	Average Rainfall mm. (2)	Evaporation (Piche) mm. *
	Average		Extreme				
	Max	Min	Max	Min.			
Jan.	15.9	3.4	23.6	−12.0	60	15	4.0
Feb.	16.8	4.2	26.3	−2.5	57	14	4.9
Mar.	21.4	6.4	30.4	−2.0	41	11	8.2
April	25.9	10.2	33.6	4.0	37	15	9.3
May	31.8	14.3	39.7	5.0	27	6	12.5
June	37.1	17.7	42.2	11.9	21	0	15.3
July	38.7	19.0	42.3	15.0	23	0	14.2
Aug.	39.4	19.5	44.0	15.0	25	0	14.3
Sept.	35.4	16.5	42.4	12.0	26	0	12.3
Oct.	30.7	13.3	37.7	6.3	32	2	9.4
Nov.	23.2	7.8	31.0	−4.0	43	11	6.0
Dec.	17.2	3.4	26.2	−8.7	52	13	4.5
						Total 87 mm 3.42 inches	

(1) Relative Humidity for the year 1963.
(2) Average Rainfall for the year 1963
* Evaporation for the years 1961 – 1963.
Average daily during the month.

Desert :
H.5 Station.
H.K. of Jordan.

Elevation 712 m. Above M.S.L.
Years : Mar. '43 - April '47, June '63-Jan'64

	Temperature (°C)				Relative Humidity *	Average Rainfall mm (1)	Evaporation (piche) mm (2)
	Average		Extreme				
	Max.	Min.	Max	Min			
Jan.	13.4	3.4	21.3	-6.8	58	8.4	3.4
Feb.	15.6	4.8	26.0	-0.5	62	12.4	4.3
Mar.	19.2	7.7	31.0	-2.0	47	1.8	7.1
April	24.9	12.8	37.2	2.5	42	T	9.5
May	29.5	15.6	37.7	7.5	30	T	12.1
June	34.5	18.5	39.8	10.2	27	T	15.1
July	36.4	20.5	41.7	16.0	33	o	16.1
Aug.	36.9	20.4	41.5	14.5	36	o	15.5
Sept.	35.3	19.5	42.3	14.0	35	T	14.2
Oct.	29.7	16.0	38.9	9.3	32	0.8	9.8
Nov.	22.9	11.0	30.3	5.4	44	T	6.5
Dec.	16.3	5.5	26.4	-3.0	51	6.1	3.6
						Total 29.5 mm 1.16 inches	

* Relative Humidity for the year 1963.
(1) Rainfall for the year 1963.
(2) Evaporation for the years 1944 - 1946.
Average daily during the month.
T Trace

Desert :
Shoumari Sta. Azraq /
H. K. of Jordan.

Elevation 533 m. Above M.S.L.
Years: Nov. '57_ Dec. '58,
July '60-Dec '61 & June '63_ Jan '64

	Temperature (°C)				Relative Humidity	Average Rainfall mm.(1)	Evaporation (Piche) mm. *
	Average		Extreme				
	Max	Min	Max	Min			
Jan.	14.5	2.3	23.0	-8.8	71	3.7	4.6
Feb.	17.4	4.4	26.2	-3.5	71	24.4	5.8
Mar.	20.7	6.4	32.0	-1.5	54	0.8	8.7
April	28.3	10.7	37.5	2.8	40	23.5	12.3
May	29.7	12.7	40.5	3.4	31	16.5	15.0
June	36.5	17.0	41.8	11.5	33	–	18.1
July	37.2	18.4	45.0	13.8	35	–	17.5
Aug.	38.3	18.9	45.0	15.0	43	–	17.5
Sept.	34.4	15.4	40.0	10.0	46	T	14.3
Oct.	31.0	12.4	38.5	6.0	39	?	10.8
Nov.	23.5	7.7	30.5	-5.0	48	5.5	6.5
Dec.	18.3	5.1	25.5	-7.7	62	27.8	4.9
						Total 102.2 mm 4.05 inches	

(1) Rainfall for the year 1963.

* Evaporation for the years 1961 and 1963.
Average daily during the month.

APPENDIX III

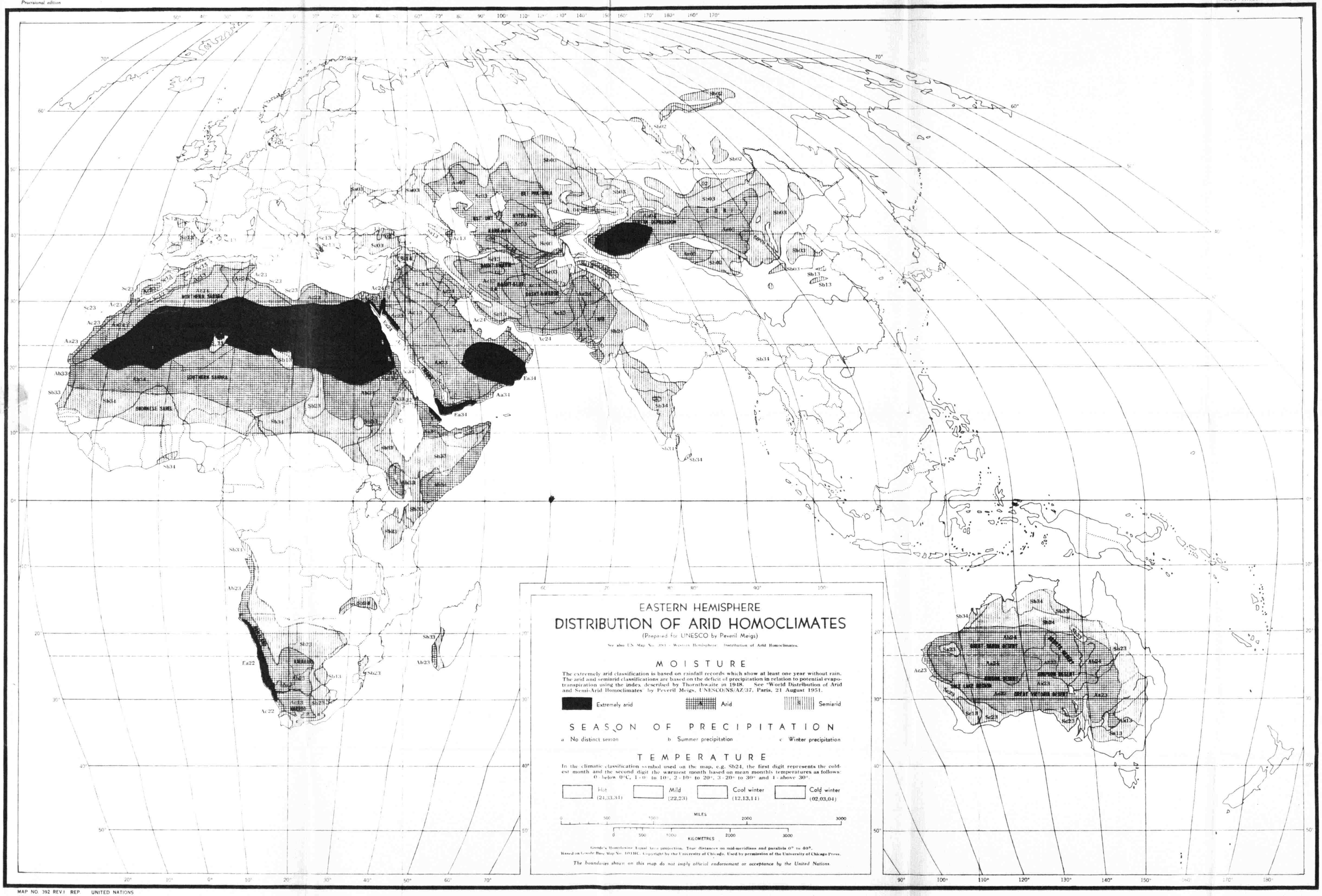
CLIMATOLOGICAL DATA ON THE RED SEA REGION

MAP 1. DISTRIBUTION OF ARID HOMO CLIMATES

MAP 2. MEAN ANNUAL POTENTIAL EVAPOTRANSPIRATION

MAP 3. MEAN ANNUAL WATER SURPLUS

MAP 4. MEAN ANNUAL WATER DEFICIT



EASTERN HEMISPHERE
DISTRIBUTION OF ARID HOMOCLIMATES

(Prepared for UNESCO by Peveril Meigs)

See also UN Map No. 393 - Western Hemisphere: Distribution of Arid Homoclimates.

MOISTURE

The extremely arid classification is based on rainfall records which show at least one year without rain. The arid and semiarid classifications are based on the deficit of precipitation in relation to potential evapotranspiration using the index described by Thornthwaite in 1948. See "World Distribution of Arid and Semi-Arid Homoclimates" by Peveril Meigs, UNESCO/NS/AZ/37, Paris, 21 August 1951.

■ Extremely arid ▦ A Arid ||| S Semiarid

SEASON OF PRECIPITATION

a No distinct season b Summer precipitation c Winter precipitation

TEMPERATURE

In the climatic classification symbol used on the map, e.g. Sb24, the first digit represents the coldest month and the second digit the warmest month based on mean monthly temperatures as follows: 0 - below 0°C, 1 - 0° to 10°, 2 - 10° to 20°, 3 - 20° to 30° and 4 - above 30°.

☐ Hot (24,33,34) ☐ Mild (22,23) ☐ Cool winter (12,13,14) ☐ Cold winter (02,03,04)

MILES 0 500 1000 2000 3000

KILOMETRES 0 500 1000 2000 3000

Goode's Homolosine Equal Area projection. True distances on mid-meridians and parallels 0° to 40°.

Based on Goode Base Map No. 101HC. Copyright by the University of Chicago. Used by permission of the University of Chicago Press.

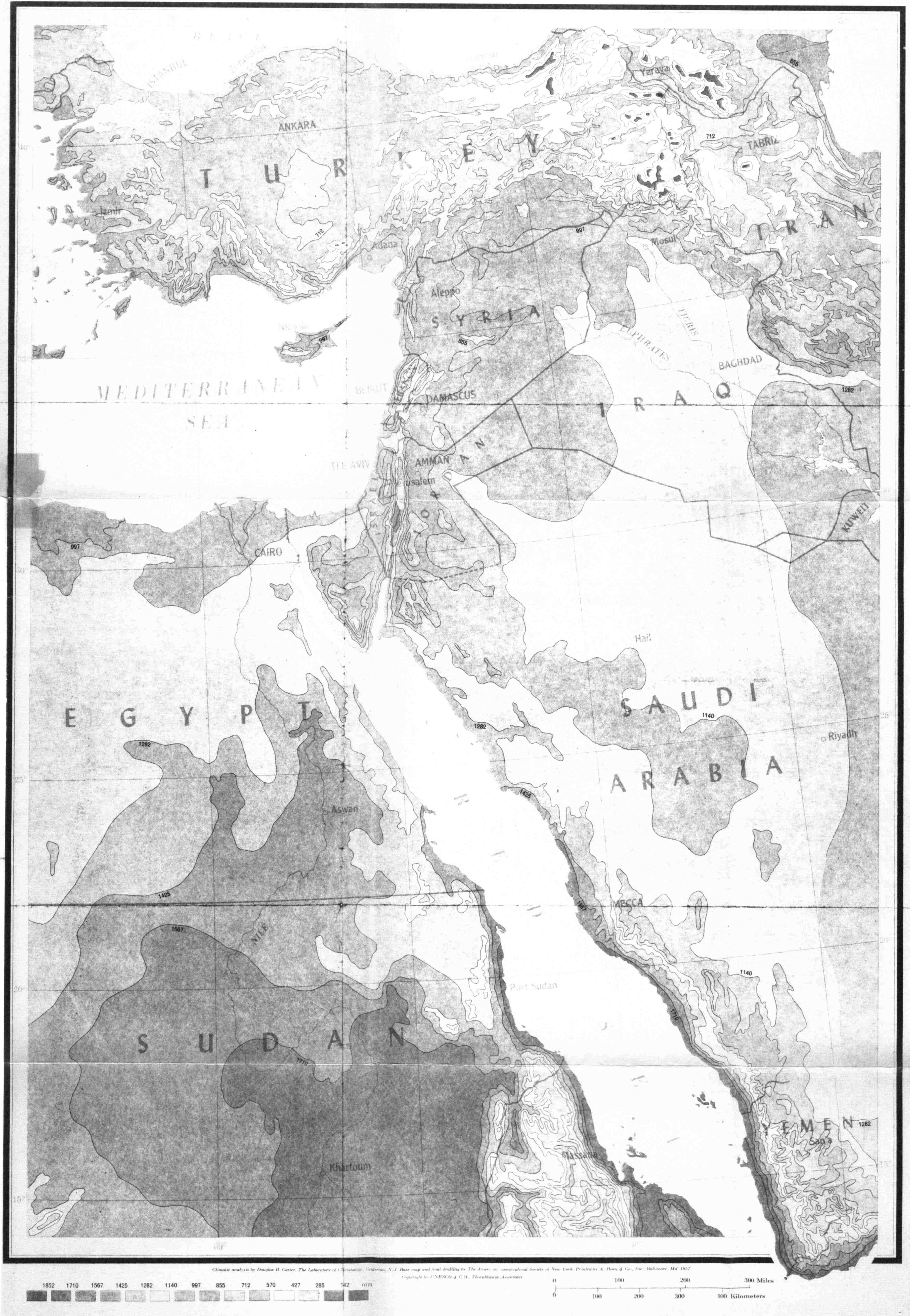
The boundaries shown on this map do not imply official endorsement or acceptance by the United Nations.

MAP NO. 392 REV.1 REP. UNITED NATIONS
OCTOBER 1960

MEAN ANNUAL
POTENTIAL EVAPOTRANSPIRATION

WORLD CLIMATIC ATLAS

SPECIAL SHEET B3-6: APE
RED SEA

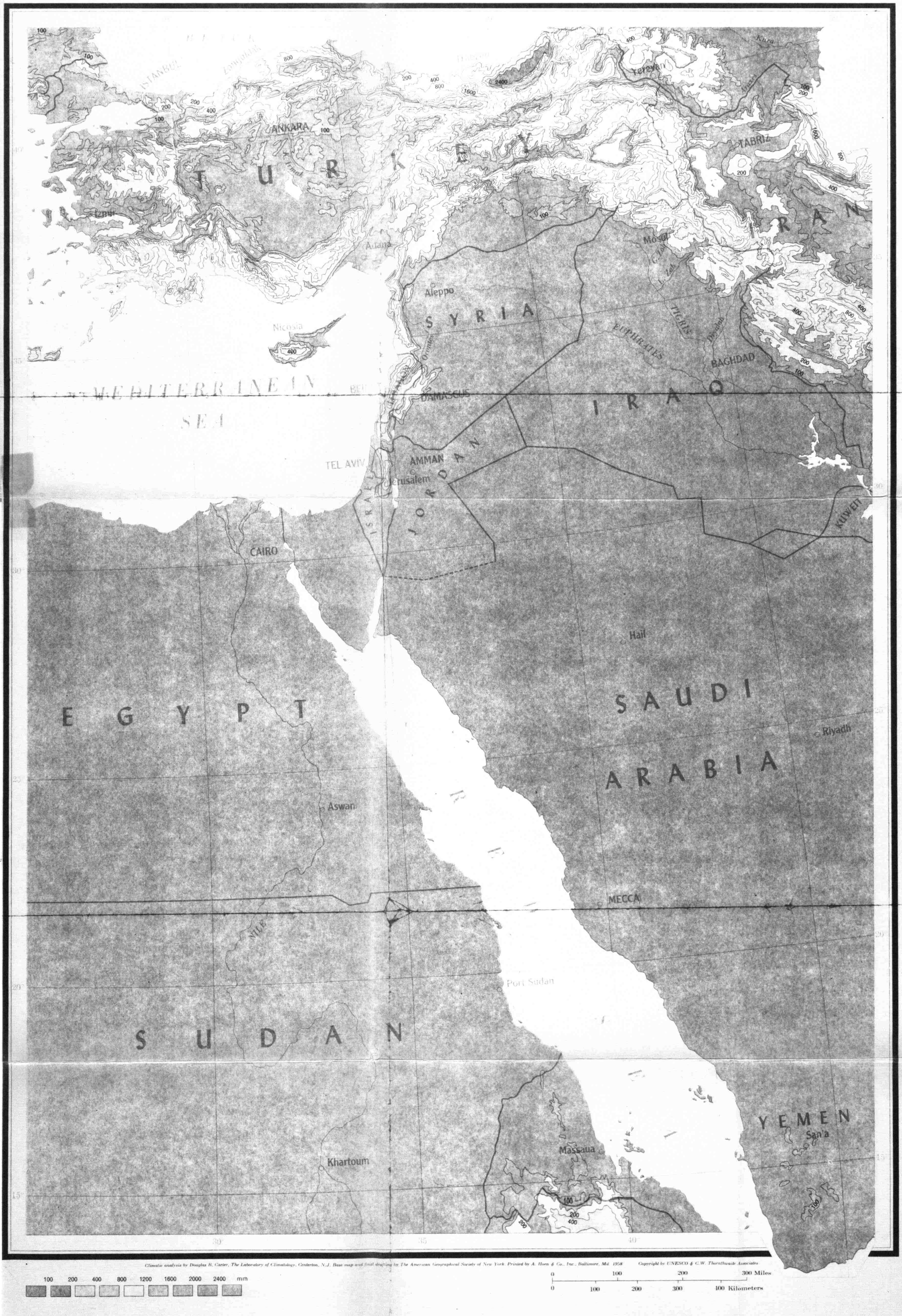


Climatic analysis by Douglas B. Carter, The Laboratory of Climatology, Centerton, N.J. Base map and final drafting by The American Geographical Society of New York. Printed by A. Hoen & Co., Inc., Baltimore, Md. 1957

MEAN ANNUAL
WATER SURPLUS

WORLD CLIMATIC ATLAS

SPECIAL SHEET B3-6: AWS
RED SEA

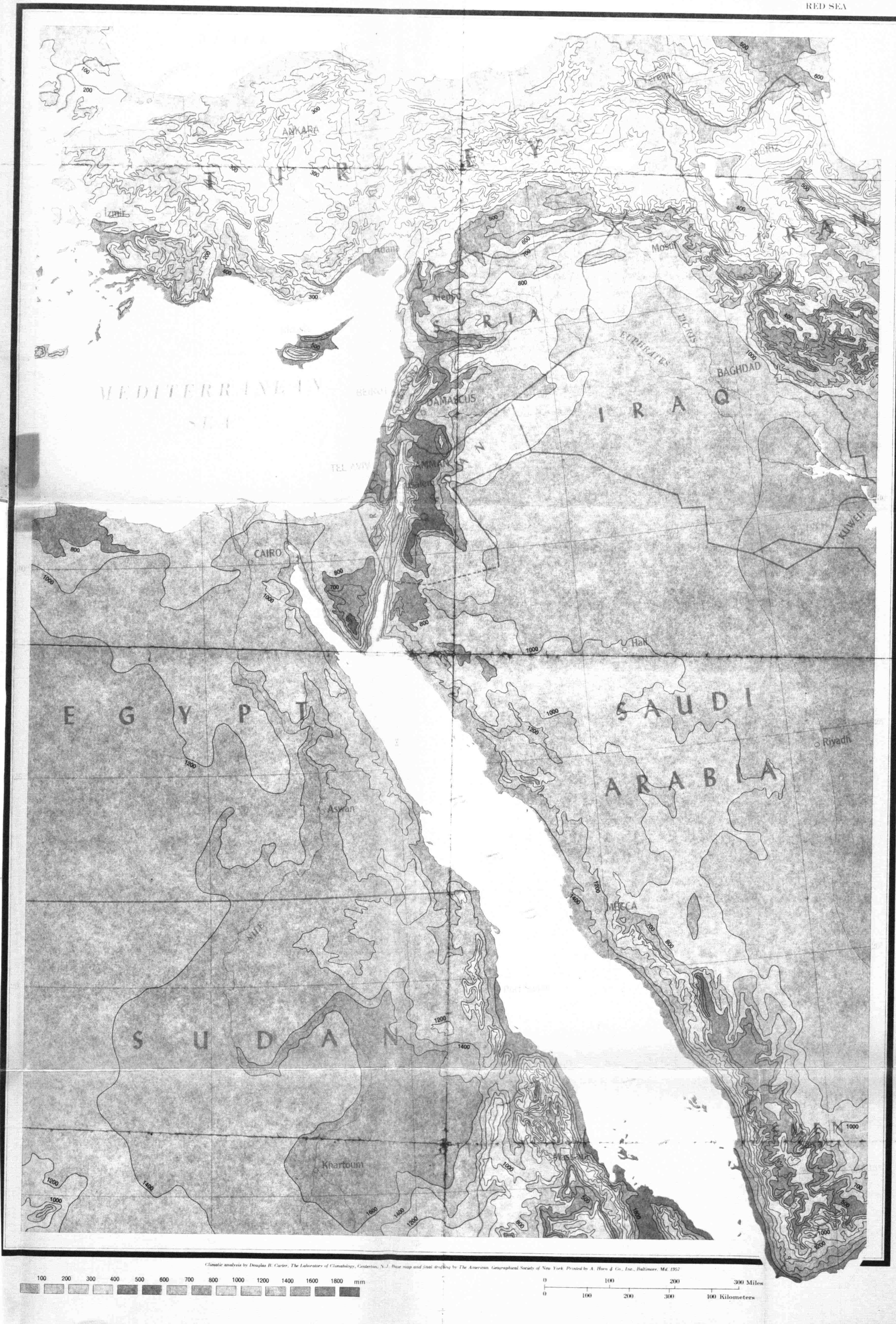


Climatic analysis by Douglas B. Carter, The Laboratory of Climatology, Centerton, N.J. Base map and final drafting by The American Geographical Society of New York. Printed by A. Hoen & Co., Inc., Baltimore, Md. 1958

MEAN ANNUAL
WATER DEFICIT

WORLD CLIMATIC ATLAS

SPECIAL SHEET B3-6: AWD
RED SEA

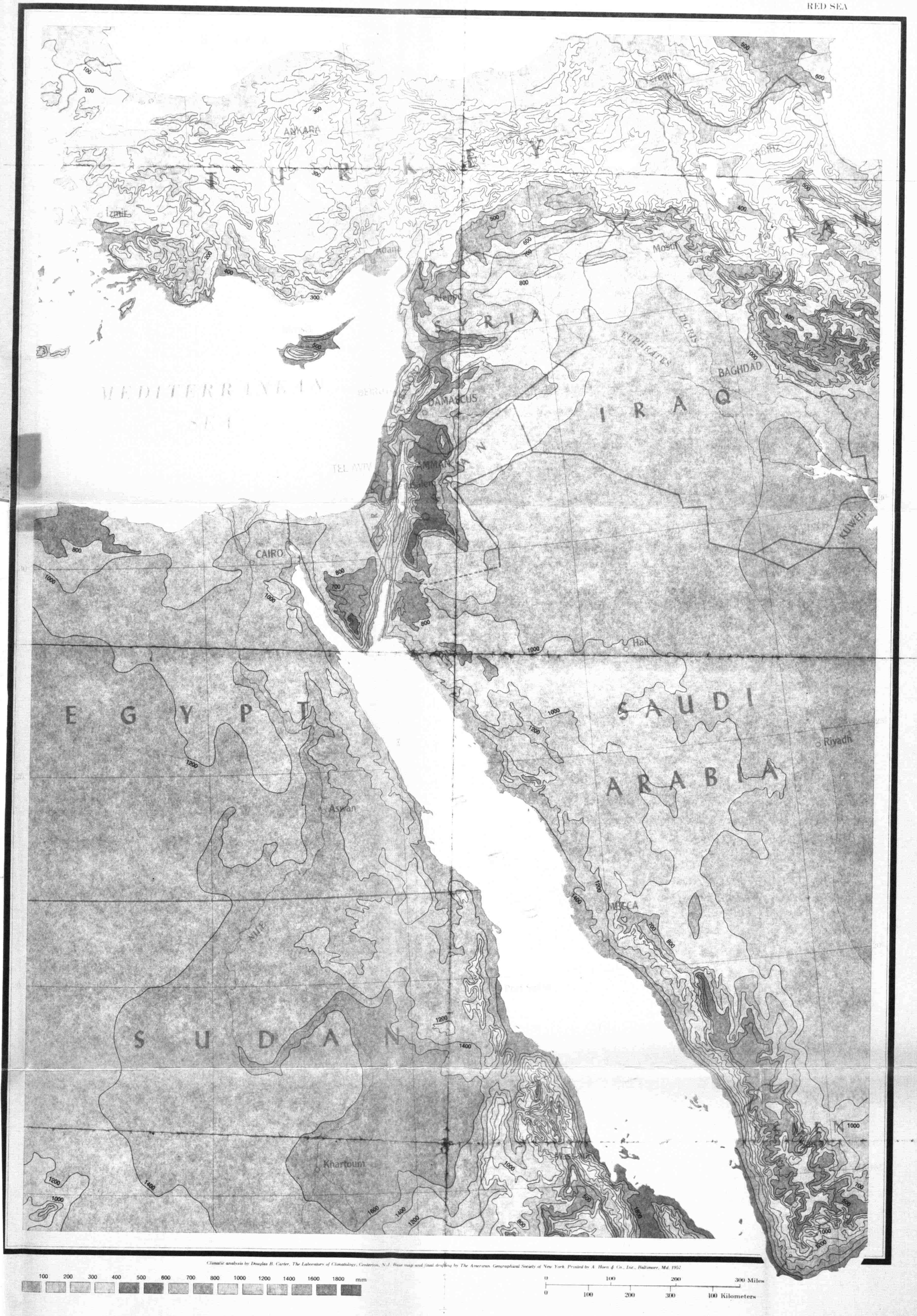


Climatic analysis by Douglas B. Carter, The Laboratory of Climatology, Centerton, N.J. Base map and final drafting by The American Geographical Society of New York. Printed by A. Hoen & Co., Inc., Baltimore, Md. 1957

MEAN ANNUAL
WATER DEFICIT

WORLD CLIMATIC ATLAS

SPECIAL SHEET B3-6: AWD
RED SEA



Climatic analysis by Douglas B. Carter, The Laboratory of Climatology, Centerton, N.J. Base map and final drafting by The American Geographical Society of New York. Printed by A. Hoen & Co., Inc., Baltimore, Md. 1957