THE USE OF A MONOMOLECULAR FILM TO RETARD

EVAPORATION FROM WATER SURFACES

by

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II   ABSTRACT

With the increasing demands on water for agricultural, domestic and industrial purposes, water conservation has become an essential feature of our economy in Western Canada.

Water conservation has been under study for many years, and research workers have been experimenting with various conservation methods. Lately, the use of monomolecular films has shown great promise in providing an economical means for retarding the rate of evaporation from water surfaces.

This study was undertaken to test the effectiveness of cetyl alcohol films in retarding the rate of evaporation from free water surfaces.

Four circular tanks were installed at the Summerland Experimental Station and the rate of evaporation was recorded daily for each one of these tanks. The study was carried out during the summer of 1958.

Varying quantities of cetyl alcohol were added to the water surface and their effect on the rate of evaporation was recorded.

Besides recording the rate of evaporation, other meteorological information was also collected and used in evaluating and in interpreting the experimental results.

It became evident from the experimental results that a twenty to thirty per cent retardation in the rate of evaporation can be achieved with the use of cetyl alcohol films.

Department of Agricultural Mechanics

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Date _May 4 1959_

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Date _13 April, 1959_

I ACKNOWLEDGEMENTS

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IV LIST OF NOMENCLATURE

B — Mean barometric reading in inches of mercury at 32° Fahrenheit

C — constant coefficient

E — evaporation in inches per twenty-four hours

E_c — evaporation in centimeters per twenty-four hours

E_{30} — evaporation in inches per thirty days

e^1 — saturation pressure of aqueous vapour at the temperature recorded by the wet bulb

e_d — mean pressure of saturated vapour at the temperature of the dew point in inches of mercury

e_s — mean vapour pressure corresponding to temperature of water surface in inches of mercury

e_w — vapour pressure at the mean wet bulb temperature in inches of mercury

I — incoming radiation in calories per square centimeter of horizontal surface

L — latent heat of water in calories per cubic centimeter

O — correction for the interchange of heat through the walls surrounding water

P — barometric pressure in millimeters of mercury

P_o — barometric pressure of air in inches of mercury

P_1 — vapour pressure of saturated vapour at t_1 in millimeters of mercury

P_2 — partial pressure of actual vapour in air in millimeters of mercury

pa — vapour pressure in air in inches of mercury

pw — maximum vapour pressure corresponding to temperature of water in inches of mercury

Q   —   relative humidity

R   —   Bowens ratio, ratio of sensible heat to latent heat

S   —   heat storage in water in calories per square centimeter, cross-section to full depth of water

t   —   temperature in degrees Fahrenheit

t_1 —   water temperature at the surface in degrees centigrade

t_2 —   ambient air temperature in degrees centigrade

t_a —   mean temperature of air above water surface in degrees Fahrenheit

t_d —   dry bulb temperature in degrees Fahrenheit

t_s —   mean temperature of the water surface in degrees Fahrenheit

t_w —   wet bulb temperature in degrees Fahrenheit

V   —   maximum vapour pressure corresponding to the monthly mean air temperature in degrees fahrenheit

W   —   monthly mean wind velocity in miles per hour thirty feet above ground surface

w   —   mean velocity of wind at the surface of ground or water in miles per hour

v   —   actual vapour pressure in the air in inches of mercury

y   —   insolation in gram calories per square centimeter per twenty-four hours

V TABLE OF ILLUSTRATIONS

VI   INTRODUCTION

Future increases in human and livestock populations in the world will create increasing demands upon water supplies. In many areas, including the semi-arid and arid regions of Western Canada, the available water supply is limited. In order to utilize the water resources to their maximum efficiency, water conservation becomes a necessity.

Water is lost through the process of evaporation from free water surfaces, evaporation from moist soil surfaces and is utilized by plants in their process of transpiration.

To conserve moisture we must concentrate on eliminating its unnecessary waste. Evaporation from the soil surface can usually be considered pure waste. Water is lost through the process of transpiration. For every pound of dry matter produced by plants several hundred pounds of water are required.[27] Evaporation from plants occurs primarily because the stomata have to be open to allow adequate entry of CO_2 into the leaves. Moisture by moving up the plant and evaporating carries plant nutrients up from the roots. During the transpiration process large quantities of water are released as water vapour.

The losses from free water surfaces perform little useful function except replenishing the air vapour storage with moisture necessary to complete the hydrologic cycle. In s emi-arid and in arid regions the potential evaporation

losses exceed the total precipitation. In order to produce crops water conservation in those areas becomes a necessity.

There are several ways to control the evaporation losses from natural and artificial reservoirs.

1.   The construction of reservoirs with maximum depth and minimum surface area.

2.   The concentration of water into single reservoirs.

3.   The elimination of shallow areas in the existing reservoirs.

4.   The storage of water in the ground-water reservoirs.

5.   The construction of reservoir roofs and floating covers.

6.   The construction of windbreaks.

7.   The use of a monomolecular film on the surface.

The last item of the above seven methods has received particular attention in this study.

VII   HISTORICAL

The effect of oil films to smooth the waves has
been known to mariners for 2,000 years. It is also a well
known fact that a film of oil on the water surface reduces
the rate of evaporation. Unfortunately the amount of oil
to prevent evaporation from a large water reservoir is very
great and the cost becomes prohibitive in addition to the
undesireable effect of oil on the fauna and flora. Obviously
water so treated would not be fit for recreational nor
domestic consumption.

The first attempts to use the monomolecular film
technique to reduce evaporation were made in the United States
in 1924 which, however, were not successful.

The first successful results were reported by
Langmuir in 1927. The use of a hexadecanol film gave a fifty
per cent reduction in the rate of evaporation.[2] Since that
time, many experiments have been conducted using various
chemical substances in creation of monomolecular films. The
most widely known work has been done by the East African
Meteorological Department under W. W. Mansfield working with
the Commonwealth Scientific and Industrial Research Organiza-
tion in Australia.[21] The results have been encouraging and
the cost has been small per volume of water saved.

VIII . THEORY OF EVAPORATION

A Evaporation from Free Water Surfaces

1. Dalton's Law

Evaporation is a process by which a liquid or solid is changed into vapour. Any body consists of a large number of molecules, each one being in constant motion at varying velocities and in different directions. The average velocity of all the molecules determines the temperature of the body. Usually at lower temperature the velocity of molecules decreases.

In any given mass, molecules are attracted to other molecules by various forces. Many of the forces are included in the term "van der Waal's forces". In water the most important van der Waal's force is the orientation effect which results from dipole-dipole interactions. The molecules that are closest to the surface of a liquid are acted upon by more of those forces from underneath than from above. Molecules that are near the surface must overcome this additional force in order to escape into the air as water vapour. It appears that only the rapidly moving molecules escape. As a result the average mass will have a lower temperature than before, this explains why evaporation is a cooling process.

Although molecules are continuously leaving the water surface others are returning and the rate of evaporation is determined by the excess rate of those leaving over

those returning. If more molecules are returning than leaving, condensation is taking place.

Immediately adjacent to a water surface is a thin layer of air whose temperature is the same as that of the water. This layer quickly becomes saturated with water vapour. If the vapour pressure of the air above the layer is equal to that of the layer, there can be no further evaporation. However, if the vapour pressure in the air above is less than that in the layer, the vapour near the surface will be dispersed by diffusion, convection and wind action and consequently the evaporation process will continue. The rate of evaporation depends upon the two pressure differences or the pressure gradient. This principle is known as Dalton's law and is expressed by the formula:

$$E = C \left(p_W - p_a \right) \quad (17)$$

E   -   evaporation in inches per 24 hours

p_W -   maximum vapour pressure corresponding to the temperature of water in inches of mercury

p_a -   vapour pressure in air in inches of mercury

C   -   coefficient depending upon wind velocity, barometric pressure, etc.

2. Meteorological Definition of Evaporation

Evaporation can be defined in terms of meteoro-
logical factors which control it. Such a definition involves
a wetted surface amply supplied with water and exposed to
the elements in such a manner so that a maximum response in
evaporation is produced by changes in the meteorological
factors with a minimum of influence being produced by the
evaporating surface itself. Such a surface would of neces-
sity have to be flat, horizontal and constructed of total
light absorbing material. Surfaces of any other shape and
inclined to the horizontal would give an artificial variation
in the rate of evaporation, depending upon the angle of
inclination to the horizontal. Surfaces other than black
would not absorb all incident energy and would, therefore,
introduce arbitrary variation in the rate of evaporation.

Latent or potential evaporation can be defined as
"the maximum possible rate of change of water to water
vapour from a black horizontal surface fully exposed to all
meteorological factors."[22]

Such a definition would possibly be more correctly
termed the "latent drying ability of the air", since the
process so defined is almost entirely dependent upon the
existing weather conditions. Measurements of latent evapora-
tion would be relative and for specific problems the
relationship of actual evaporation to latent evaporation
would have to be determined.[22]

3.   Effect of diffusion versus turbulent transfer

Molecules of water move away from the vicinity
of an evaporative surface by the phenomenon of diffusion.
Diffusion is a very slow process and as a result, there
would be almost as many molecules returning as leaving the
free water surface if these molecules were not removed by
the turbulent transfer and carried into higher layers of air.
The effect of turbulent transfer is by far the most effec-
tive factor in carrying water molecules away from an evapor-
ating surface.

Transfer by turbulence is usually at least 25,000
times more effective than molecular diffusion and it may be
considered wholly responsible for any loss of moisture from
an evaporating surface freely exposed to the air.[23]

4.   Effect of salts on the rate of evaporation

Various substances dissolved in water will lower
the vapour pressure by different amounts. In all cases, as
shown in the following table, the equilibrium is maintained
at less than one hundred per cent relative humidity.

Relative Humidity maintained at specified temperatures
by various saturated saline solutions.[29]

Temperature	Relative Humidity obtained by using a saturated solution of:				
	KNO_3	NaCl	$Mg(NO_3)_2$ $6H_2O$	$MgCl_2$ $6H_2O$	LiCl
104	90%	75%	51%	33%	16%
95	92%	75%	51%	33%	16%
86	94%	75%	52%	33%	16%
77	95%	75%	52%	32%	16%
68	95%	75%	53%	32%	16%
59	95%	76%	53%	31%	16%
50	95%	76%	53%	31%	16%
41	96%	76%	54%	30%	16%
32	96%	76%	54%	30%	16%

Generally, the evaporation from a free water surface will be
reduced in proportion to the salt concentration. This results
from the fact that the salt ions are at the water surface and
interfere with a free movement of the water molecules. The
suppression of evaporation may also be due to the attraction
that may exist between the solute and water molecules. Also
there are less water molecules on the surface reducing the
potential evaporating area.

There is always an exchange of water molecules be-
tween the liquid water and the water vapour in the air. The
return of molecules from the air is not influenced by dis-
solved solute; however, the movement from the water surface
is suppressed which accounts for saturation at lower relative
humidities.

Sea water has a rate of evaporation two to three
per cent less than similarily exposed fresh water.[17]

5. Variation of evaporation with altitude.

At higher elevations evaporation should increase as the result of the decreasing barometric pressures; however, due to the decrease in temperature, the rate of evaporation frequently decreases with an increase in elevation because the temperature of the air and water are usually lower at higher altitudes.

VARIATION OF EVAPORATION WITH ALTITUDE.
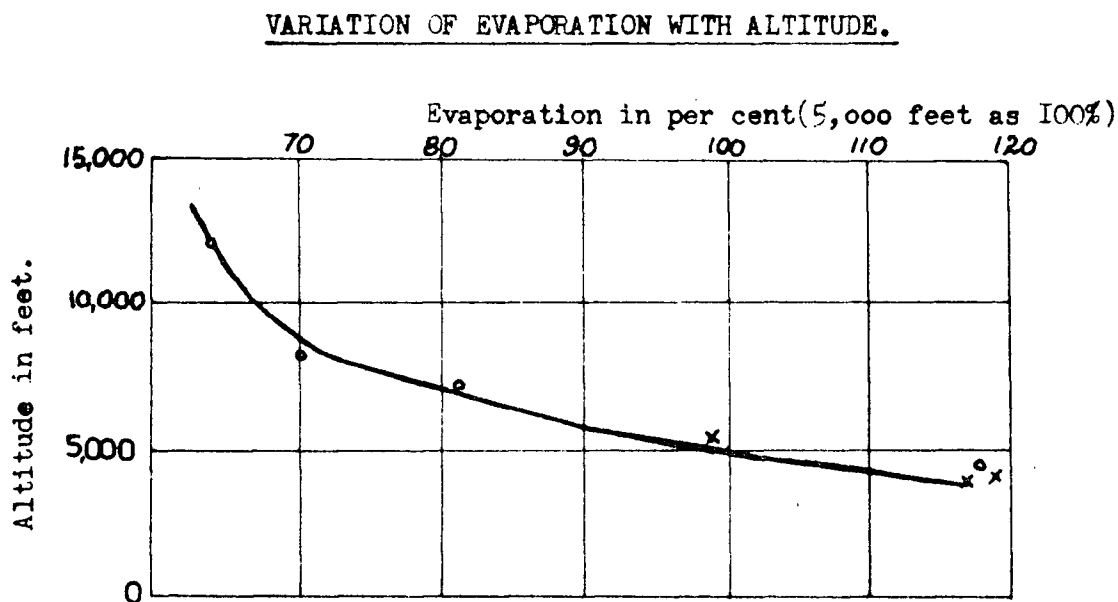
Diagram from O.E.Meinzer" Hydrology ",page 65.

Figure No. 1   Variation of evaporation with altitude.

B   Monomolecular Theory

Certain types of organic compounds (fatty acids, fatty amides, fatty alcohols)possess the property of forming a film of one molecule thickness when applied to the water surfaces. These molecules have in their molecular structure a hydrophilic portion which is attracted by the water and a hydrophobic portion attached to one of the above hydrophilic radicals which is repelled by the water.

When packed together, the molecules stand on end closely and form a film which helps resist evaporation of the water thus covered.[2] An excess of the film forming material is necessary at all times to keep the film tightly packed and to repair it if it should be broken.

The rate of spreading of the monomolecular film depends on the surface temperature of water and the characteristics of the chemical compound. The average rate of spreading for alcohols recommended for water conservation is approximately twenty to thirty centimeters per second at twenty degrees Centigrade.

The film of cetyl alcohol is about two millionths of a millimeter thick, is not visible to the naked eye but it reduces ripples on the water surface so that the extent of spreading can be observed. As the spreading proceeds, the surface pressure increases and the rate of spreading decreases until an equilibrium pressure of forty dynes per square centimeter is reached.

To be practical, a surface film must meet the following requirements:

1. To form an unbroken surface film over the entire water surface.

2. To be impervious to water vapour.

3. To be able to regenerate the film when broken.

4. To be invisible, odorless and non-toxic.

5. To be easily generated by using chemicals of reasonable cost.

In addition, it must not seriously retard the diffusion of oxygen into and carbon dioxide out of water. A reduction in the rate of movement of such gases would seriously upset the biological balance of bodies of water so treated.

Scientists have reported conflicting results regarding the effect of monomolecular films, some report even to the extent where fish and wildlife will suffer. South African reports indicate a reduction in the oxygen supply in water due to monomolecular films to the extent where the biological balance is upset.[9] Other research workers from Australia report no harmful effects to living organisms from the monomolecular film.[2] This difference in results is doubtless due to the type of film used.

IX   REVIEW OF LITERATURE

A   Type of Evaporimeter versus Rate of Evaporation

1.   "Gross" and "net" evaporation.

Evaporation is usually measured from small metal
pans and translated to equivalent evaporation for large
water areas through the use of reduction coefficients, which
must first be determined experimentally. Evaporation
recorded from pans is the true evaporation, with rain falling
on the pan accounted for as water added. This is the
common method of calculating pan evaporation. In some cases,
evaporation from reservoirs is designated as "gross" or "net"
evaporation. Gross evaporation is the actual depth of water
lost to the atmosphere. Net evaporation is the gross evapor-
ation minus the depth of water falling on the water surface.
Gross evaporation is always positive but net evaporation is
negative in months when true evaporation is less than the
rainfall. The terms "gross" and "net" are used in connection
with estimating reservoir losses but not in connection with
pan evaporation.[17]

2.   Size of evaporimeter versus evaporation rate.

Evaporation is controlled by the nature of the
container through its response or reaction to the meteorolog-
ical factors. A deep body of water absorbs a large percentage
of the solar and sky radiation incident upon its surface.
This energy is distributed throughout a large mass of water to

a depth of several feet. The result is that the diurnal
temperature variation of the water surface is small. The
warming of such depths of water in the early part of the
summer utilizes some of the heat supply that would otherwise
be available for evaporation. Also the release of the
stored heat in the fall and winter makes available a heat
supply in excess of that received at such times from the sun.

SIZE OF PAN VERSUS EVAPORATION RATE.
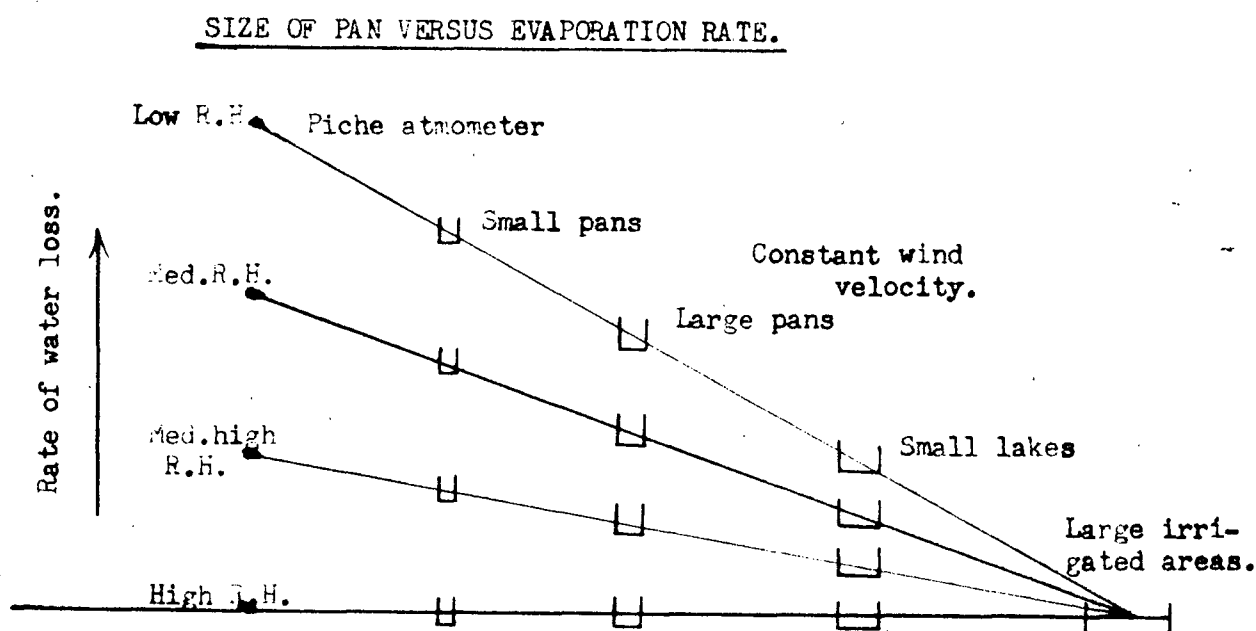
Diagram from C.W.Thornthwaite "The Water Balance"
Drexel Inst.of Technology 1955.

Figure No. 2   Size of pan versus evaporation rate.

The preceding diagram shows that the size of the pan does not affect the evaporation to a great extent when the relative humidity is high. As the relative humidity decreased, the size of the pan became more important since it has been shown that higher losses occurred from smaller areas.

The overall evaporation rates from deep and shallow bodies of water of the same area are approximately identical but the deeper bodies of water have their rate of evaporation delayed in the early part of the summer. This same phenomenon is evident when the Class A Land Pan is compared with the Four Foot Ground Tanks.

COMPARISON OF EVAPORATION FROM TANKS OF DIFFERENT DIAMETERS.

Diameter of tank in feet.	Mean Coefficient to be applied to each size to get evaporation from 12 foot tank.	Deviation of coefficient from annual mean (in %)			
		Weekly		Monthly	
		Range	Mean	Range	Mean
9	99.0	-8 to +15	3.8	-5.5 to +4.5	2.2
6	91.3	-10.5 to +18.0	4.2	-10.7 to+4.6	3.8
3.39	82.9	-15.6 to +17.0	4.7	-19.8 to+7.8	5.3
2	77.9	-15.9 to +9.6	4.1	-13.0 to+5.3	4.2
1	64.5	-19.5 to +28.6	3.6	-14.0 to+13.0	5.6

Data by R.B.Sleight at Denver for 12 months 1915/1916 using round
tanks three feet deep.

Figure No. 3   Comparison of evaporation from tanks
of different diameters.

Generally, the smaller pans tend to show a higher
rate of evaporation than the larger ones. This is due to
the higher relative humidity which exists above a larger
body of water. The wind more effectively removes the satur-
ated surface layer of water vapour from smaller pans. Where
the relative humidity is high the difference in rate of

evaporation between smaller and larger pans is reduced.

B   Evaporimeters

1.   Class A U.S. Weather Bureau Land Pan.

Different types and sizes of evaporation pans are in common use. The most popular one in North America, and with the most extensive list of records, is the Class A U.S. Weather Bureau Land Pan. It is circular, four feet in diameter with a depth of ten inches. The bottom of the pan is raised six inches above the ground surface.[31] The Water surface is maintained within two or three inches of the top of the pan. Evaporation is measured with a hook gauge in a stilling well.

2.   Bureau of Plant Industry Sunken Pan.

Second in popularity in the United States is the Bureau of Plant Industry Sunken Pan which is six feet in diameter and two feet deep. The upper edge protrudes four inches above the ground surface and the water level is maintained within one half of an inch of the ground level. Evaporation is measured with a point gauge in a stilling well.

3.   Colorado Sunken Pan.

The Colorado Sunken Pan is three feet square and one and one-half to three feet deep, its upper edge is four inches above the ground and the water level is maintained within one inch of the ground surface.

4.   The United States Geological Survey Floating Pan.

The United States Geological Survey Floating Pan
is three feet square and one and one-half feet deep. It is
installed on a rectangular raft sixteen feet by fourteen
feet dimensions, in the lake or in the reservoir and it is
fitted with necessary baffles to damp out surges or splashes.
The upper edge of the pan is three inches above the water
surface. The level of water in the pan is maintained at the
same level as the level of the surrounding water.

5.   Four-foot Ground Tank.

The Experimental Farms Service in Canada use as
their standard a tank four feet in diameter and two feet
deep. It is sunk in the ground with the rim extending above
the ground level by two inches. The water level is maintained
at or close to the ground level.[22]

6.   Black Bellani Plate.

It consists of a black porous circular disc of
seven and one-half centimeters in diameter fitted over a
glazed porcelain funnel. Water is conducted to the funnel by
glass and rubber tubing from a reservoir below the level of
the plate. Because the whole system is airtight, the water
is held in contact with the plate by capillary tension. The
Black Bellani Plate Atomometer was suggested for this purpose
by the Field Husbandry Division of the Experimental Farm Ser-
vice at Ottawa.

GROUND LEVEL

2"-4"

47½"

24"

4-FOOT GROUND TANK

48"

2"-3"

WATER LEVEL

10"

6"

GROUND SURFACE
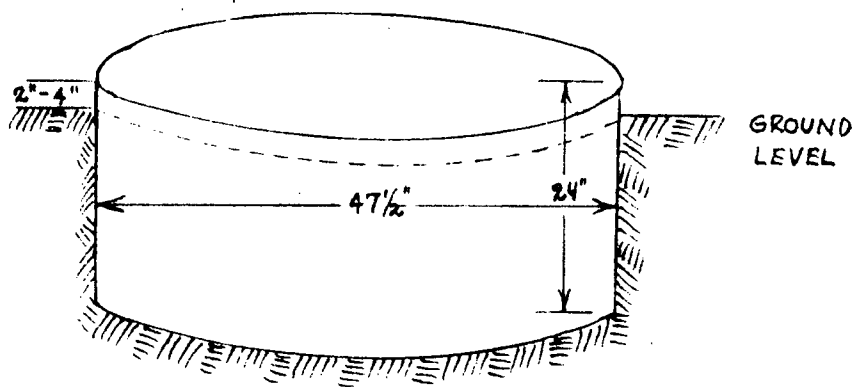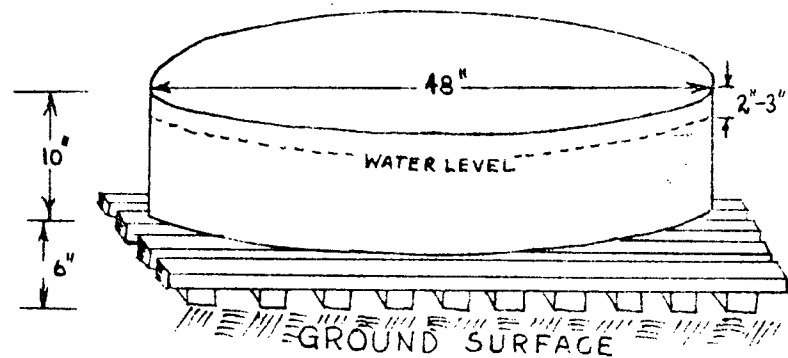
U.S. CLASS A WEATHER BUREAU LAND PAN

POROUS DISC

WATER SUPPLY IN GRADUATED CONTAINER
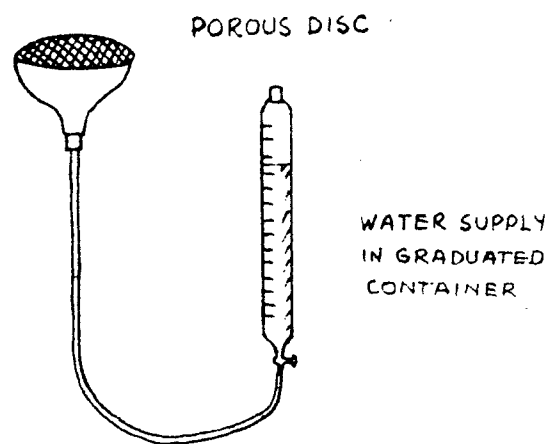
BELLANI PLATE

THREE WIDELY USED

EVAPORIMETERS.

7. White Bellani Plate.

The White Bellani Plate Atmometer is identical with the Black Bellani Plate in its construction with the exception of a white evaporating surface replacing the black as described in the former type.

8. Piche Evaporimeter.

This instrument consists of a graduated glass tube open at one end and closed at the other. The tube is filled with water and a porous paper disc is placed over the open end. The tube is then inverted. The popularity of this instrument has declined in recent years.

C   Comparison of Evaporimeters

As would be expected the Black Bellani Plate gave the highest actual evaporation rate.

Evaporimeter	Surface Area in Square Inches	Amount Evaporated in inches/month
Black Bellani Plate	6.85	8.18
White Bellani Plate	6.85	5.21
Piche Atmometer	1.60	4.81
Summerland Tank	113.10	4.67
Four-Foot Ground Tank	1809.56	3.44

Results for September 1953[1]

Black surfaces are believed to absorb solar energy more completely and thus should provide more energy for the conversion of water to water vapour.

1   G. W. Robertson, Latent Evaporation: Its Concept, Measurement and Application, pp. 4-5.

It is obvious that the measurement of evaporation
is only relative regardless of the instrument type. In
order to determine actual evaporation from measured latent
evaporation it is first necessary to determine the relation-
ship between the latent evaporation and the actual evapora-
tion.

D   Evaporation Formulae

There are several formulae for the calculation of
evaporation from water surfaces. Some of these formulae
include the barometric pressure but disregard the effect of
wind, others include the wind effects but ignore the baro-
metric pressure. The common part of each of the formulae
is the pressure gradient derived from the original Dalton
principle. As each of the following formulae was derived
under different climatic conditions, it is rather difficult
to find one equation that would meet universal requirements.
The most commonly used formulae are:[31]

Fitzgerald's

$$E = (0.40 \neq 0.199 \, w)(pw-pa)$$

Russel's

$$E = \frac{1.96 \, pw \neq 43.88}{B} \, (pw-pa)$$

Horton's

$$E = 0.4 \, (X \, pw-pa)$$
$$\text{Where } X = 2-e^{-0.2w}$$

Rohwer's

$$E = 0.771 (1.465 - 0.0186B)(0.44 \neq 0.118w)(pw-pa)$$

Meyer's

$$E = 15 (V-v)(1 \neq \frac{W}{10})$$

See Nomenclature as listed on page 1-2.

The formula proposed by Meyer is recommended to be used for calculating evaporation rates from small bodies of water including evaporation pans.

In order to compare the above formulae, the meteorological information from the Vancouver Airport Meteorological Station for the month of August 1956 was used and the evaporation rates were calculated by using the above mentioned formulae. The calculated values differed as much as one inch to fifteen inches per thirty days.

Where the wind velocity at the ground surface was required, it was necessary to calculate such information that was not normally recorded at the Vancouver Meteorological Station. The standard height of the wind measuring instruments was thirty to seventy feet above the ground surface. By using a graph prepared by Carl Rohwer [23], the recorded wind velocity was converted to the wind velocity at the ground level.

Ratio of Observed Wind to Ground Wind

Height versus wind speed
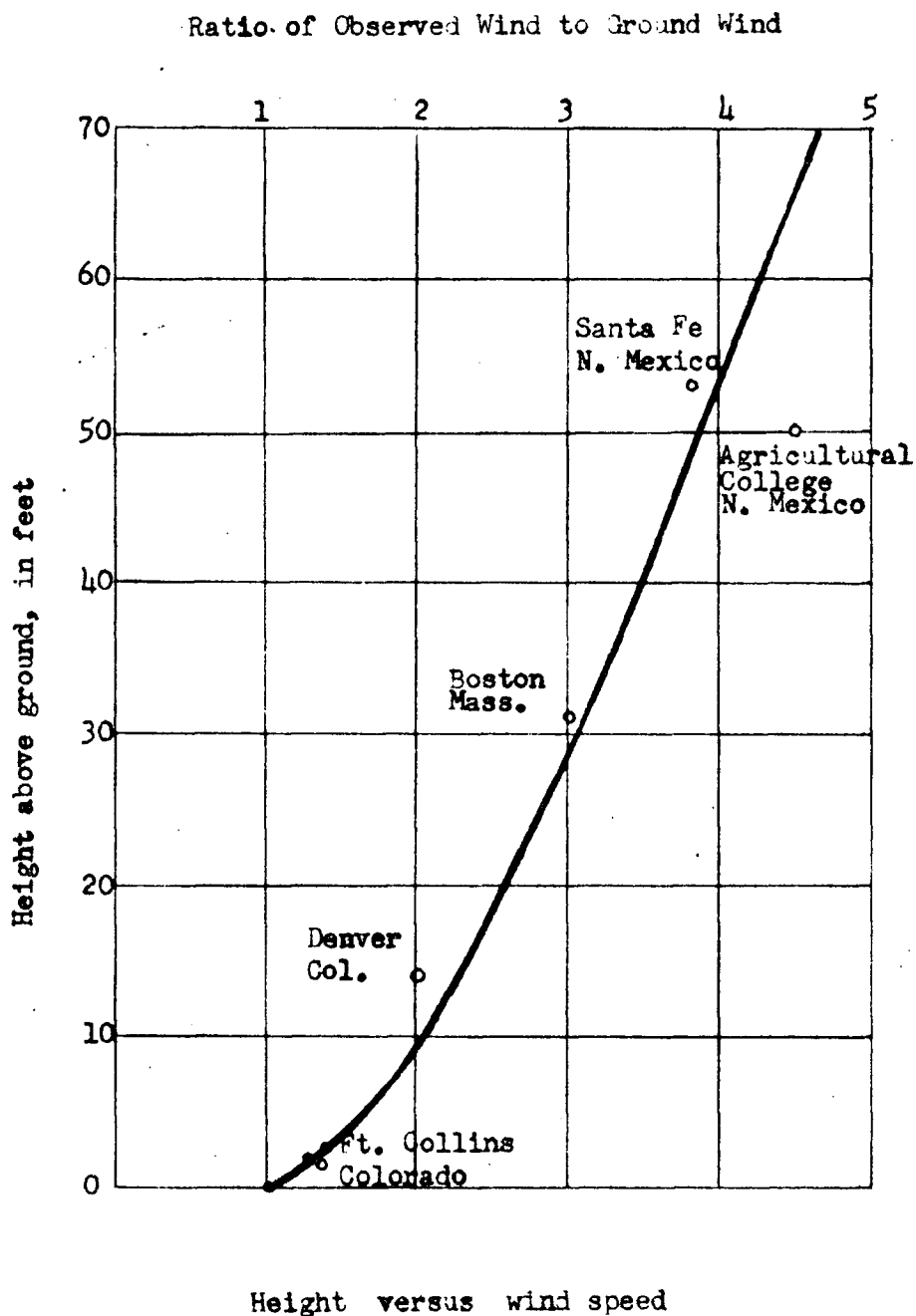
Figure No. 5   The relationship between recorded wind
velocity and ground wind velocity.

E   Insolation Method

Another approach in calculating evaporation is the Insolation Method. This method is based on the principle of conservation of energy in a body of water. A balance must exist between (a) insolation, (b) heat transferred by the water surface by radiation, conduction or convection, (c) the heat required to raise or lower the water temperature and (d) the heat dissipated by evaporation or acquired by condensation. Factors a, b and c can be measured and d can be calculated.

For example, Cummings and Richardson[23] have proposed a formula for calculating evaporation:

$$E_c = \frac{I - S - O}{L(1 \mp R)}$$

R - Bowen's Ratio is a ratio of sensible heat
    to latent heat computed by using a formula:

$$R = \frac{0.46(t_1 - t_2)P}{(P_1 - P_2)\ 760}$$

This formula is independent of the wind but contains terms that are affected by the altitude.

X   MATERIALS AND METHODS

A   Materials

1.   Four-foot tanks.

For the field experiment, four separated four-foot diameter galvanized tanks as shown in Figure No. 6, were installed in the ground within the enclosure of the Summerland Experimental Station Weather Station.

Two of the tanks were in use previously and the other two were installed for use in this experiment.
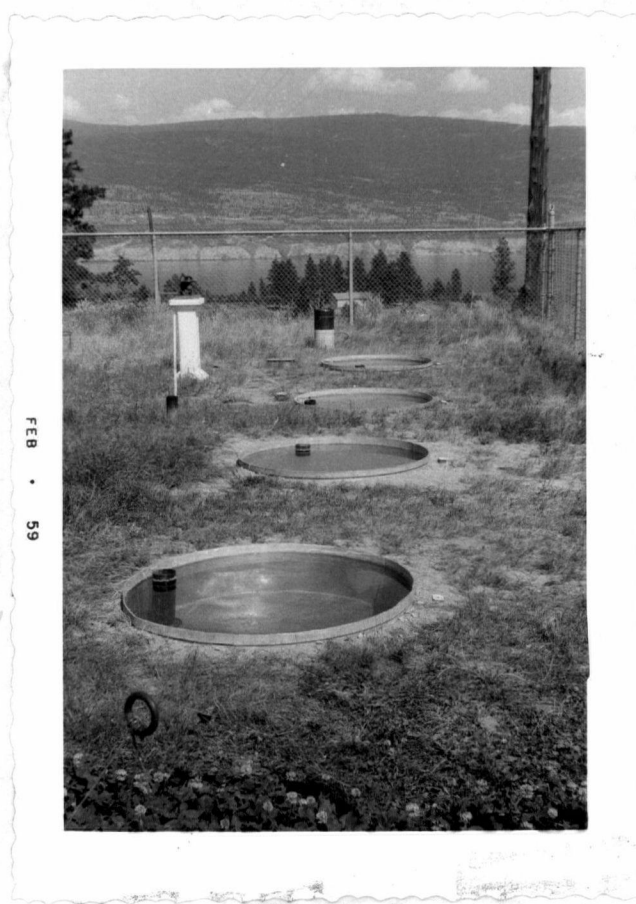
Figure No. 6   Row of tanks at the Summerland Experimental Station.

The tanks were of cylindrical design - twenty-four inches deep with an inside diameter of 47-1/2 inches. The upper edge was two inches above the ground surface when the tanks were in position. For each tank a stilling well was made and the fixed point was installed exactly two inches below the upper edge of the tank, which corresponded to the ground level around the tank. The amount of water evaporated every day was determined by adding water from a plastic gauge. One division of the plastic gauge was equivalent to one hundredth of an inch of evaporation. The readings were taken to the nearest one hundredth of an inch.

The time of filling the tanks, which was between seven A.M. and seven thirty A.M. Pacific Standard Time, coincided with the time the other meteorological equipment was read. The experimental tanks were filled every morning and any floating foreign matter was removed from the surface except during the periods when the effect of the impurities upon the cetyl alcohol film was being studied.

Water for filling the tanks was obtained from the domestic supply, which was pumped from the Okanagan Lake. There was a water hydrant located within the Weather Station enclosure.

Tanks were installed in a row approximately in an East-West direction and numbering started from the East side.

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Tanks were installed in a row approximately in an East-West direction and numbering started from the East side.

2. Solar radiation recordings

Radiant solar energy is the ultimate source of practically all energy on the earth. The study of radiation from the sun is of great value in the field of meteorology.

Solar energy is received at the outer edge of the atmosphere at an average rate of 1.94 gram calories per square centimeter per minute. This rate is known as the "solar constant". Only a portion of the total energy reaches the earth's surface. Insolation is the term used for the amount of energy received on the horizontal surface. It depends upon the solar constant, altitude of the station, inclination of the incident rays to the horizontal (influenced by latitude, time of the day and time of the year), moisture in the air, dust and cloud effect and depletion while passing through the atmosphere. All these factors influence the rate of insolation.

Figure No. 7   MSC Type G Bimetal Actinograph at the
                 Summerland Experimental Station.

For recording the solar radiation the MSC Type G
Bimetal Actinograph was used at the Summerland Experimental
Station Weather Station. It was a continuous self record-
ing instrument indicating the rate of radiation in gram
calories per square centimeter per minute. From the graph
the rate of solar radiation can be determined for each
hour. The column of hourly values totalled to give the
total radiation per day.

3.   Sunshine Recorder.

The chief purpose of sunshine recorders is to enable the hourly totals of the duration of bright sunshine to be measured accurately to the nearest tenth of an hour.

At the Summerland Experimental Station Weather Station a Campbell-Stokes Recorder was used. The recorder consisted essentially of a glass sphere four inches in diameter, mounted concentrically in a section of a spherical bowl, the diameter of which is such that the sun's rays were focused sharply on a card held in grooves in the bowl. The focused rays from the sun burned a trace in the chart. The movement of the trace is opposite to that of the sun. Three overlapping grooves were provided in the bowl to take cards suitable for different seasons of the year. Cards in the recorder were changed daily between seven and seven thirty A.M. Pacific Standard Time.

4.   Wind velocity recordings.

Wind mileage passing the anemometer was recorded daily. A three-cup anemometer recorded continuously the wind mileage within one one-hundredth of a mile. By dividing the daily total wind mileage by twenty-four the average wind velocity was calculated for each twenty-four hour period.
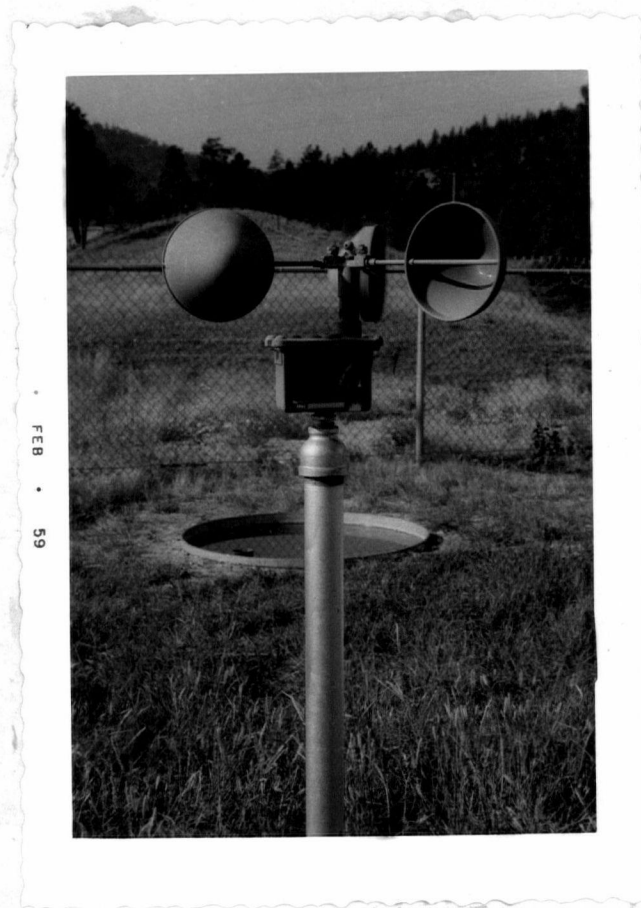
Figure No. 8 The anemometer located within the
Weather Station enclosure.

5.   Relative humidity recordings

The relative humidity was determined by means of
a sling psychrometer. The wet and dry bulb temperatures
were recorded every morning and the relative humidity was
found by the use of United States Weather Bureau tables.

The relative humidity values in the United States Weather Bureau tables have been calculated by the formula:

$$e - e^1 = 0.000367 \ P_o(t_d - t_w)(1 \neq \frac{t_w - 32}{1571})$$

See List of Nomenclature on page 1-2

6.   Temperature Recordings.

a)   Ambient air temperature

The ambient maximum and minimum temperature was recorded as a part of the routine meteorological observations made at the Summerland Weather Station.

The thermometers were housed in a thermometer screen which keeps out the direct rays of the sun but enables air to circulate freely. The height of the thermometers above ground was five feet.

b)   Soil Temperature

Soil temperature readings were continuously recorded by automatic recorders at six inches, twenty-four inches and forty-eight inches of depth. For the purposes of this paper, only readings of six inches and twenty-four inches of depths were considered necessary. Mercury thermometers have been installed within the Weather Station enclosure and the wires were connected to the automatic recorders in the Weather House.

c)   Water temperature

Minimum and maximum water temperatures in the four-

foot diameter tanks were measured by a minimum and maximum thermometer supported on a stand holding the thermometers three inches below the water surface.

7. Barometric Pressure Readings.

Due to the absence of a barometer at the Summerland Experimental Station Weather Station, barometric readings in values of millibars were obtained from the Penticton Airport Weather Station.

B Methods

1. Temperature recordings.

During the early part of the recording period, neither minimum nor maximum temperature readings were taken in the tanks. Within the enclosure of the Weather Station recording of water temperature in a Class A Land Pan was carried out regularly. It was believed initially that the water temperatures in the Class A Land Pan and in the four-foot tanks were identical. This assumption was found to be wrong and minimum and maximum thermometers were installed in tank #1. The thermometers were supported by a stand holding them approximately three inches below the water surface. Following the installation of thermometers, water temperature was recorded every morning.

During the first two weeks, readings were taken without the addition of cetyl alcohol to the tanks. By com-

paring the evaporation figures the tanks were calibrated in
relationship to each other. (See appendix I) Following the
correlation between tanks, varying quantities of cetyl alcohol
were added.

   2.   Testing of surface film.

      When the surface pressure of the monomolecular
film is low the molecules are dispersed and do not form a
tight surface cover. At pressures below five dynes per square
centimeter there is little retardation of evaporation but it
increases until the effect reaches its maximum at approxi-
mately forty dynes per square centimeter. The surface pres-
sures can be tested by the use of indicator oils. Many oils
or oily substances when placed on the water surface spread
and their spreading pressures can be evaluated. If a drop of
such indicator oil is placed on the water surface covered with
cetyl alcohol film it will spread if its pressure is greater
than that of the film on which it is placed. The spreading
pressures of various oily substances are known and by test-
ing the treated surface with various oils the film pressure
can be determined.[21]

Name of Substance	Spreading pressure in dynes per square centimeter
Hexadecyl Acetate	34.4
Oleic Acid	30.0
Tri-Olein	22.0
Lauric Acid	21.0
Castor Oil	17.0
Myristic Acid	11.0
Carbon Disulphite	2.3
Stearic Acid	1.5

During this investigation Oleic Acid and Castor Oil were used as the testing substances. These two liquids were selected because it was believed that seventeen to thirty dynes per square centimeter represented a critical pressure range. Cetyl alcohol was dissolved in a gasoline which did not contain any lead compounds. The concentration of the cetyl alcohol varied between five per cent and thirty per cent by weight. The method of application of cetyl alcohol to water surface in gasoline solution has been referred to as the "Mansfield Process" which has been successfully used in Australia.[2]

XI   RESULTS AND DISCUSSIONS

A   The effect of impurities on the monomolecular film

As shown in Figure No. 11 the effectiveness of the monomolecular film on evaporation retardation is greatly reduced by the accumulation of floating organic material on the surface. It was found by trials that if the surfaces of the tanks were not cleaned daily, the differences in the evaporation rate from free water surfaces and from surfaces covered with a monomolecular film decreased rapidly and after a lapse of three days no difference could be observed in the evaporation rate. The observations were made during the month of July when during dry weather the amount of pollen, dust and airborne material was believed to be unusually high.

It seems that the impurities have a rapidly deteriorating effect upon the ability of cetyl alcohol to retard the rate of evaporation. It was also observed that the floating material accumulated more rapidly on the tanks covered with the cetyl alcohol film. Clusters of film and vegetable matter were formed which interrupted the continuity of the film upon being moved about the surface under the influence of the wind.

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Figure No. 9   Floating organic matter on the
water surface after twenty-four hours.

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Figure No. 10   Floating organic matter on the
water surface after seventy-two hours.
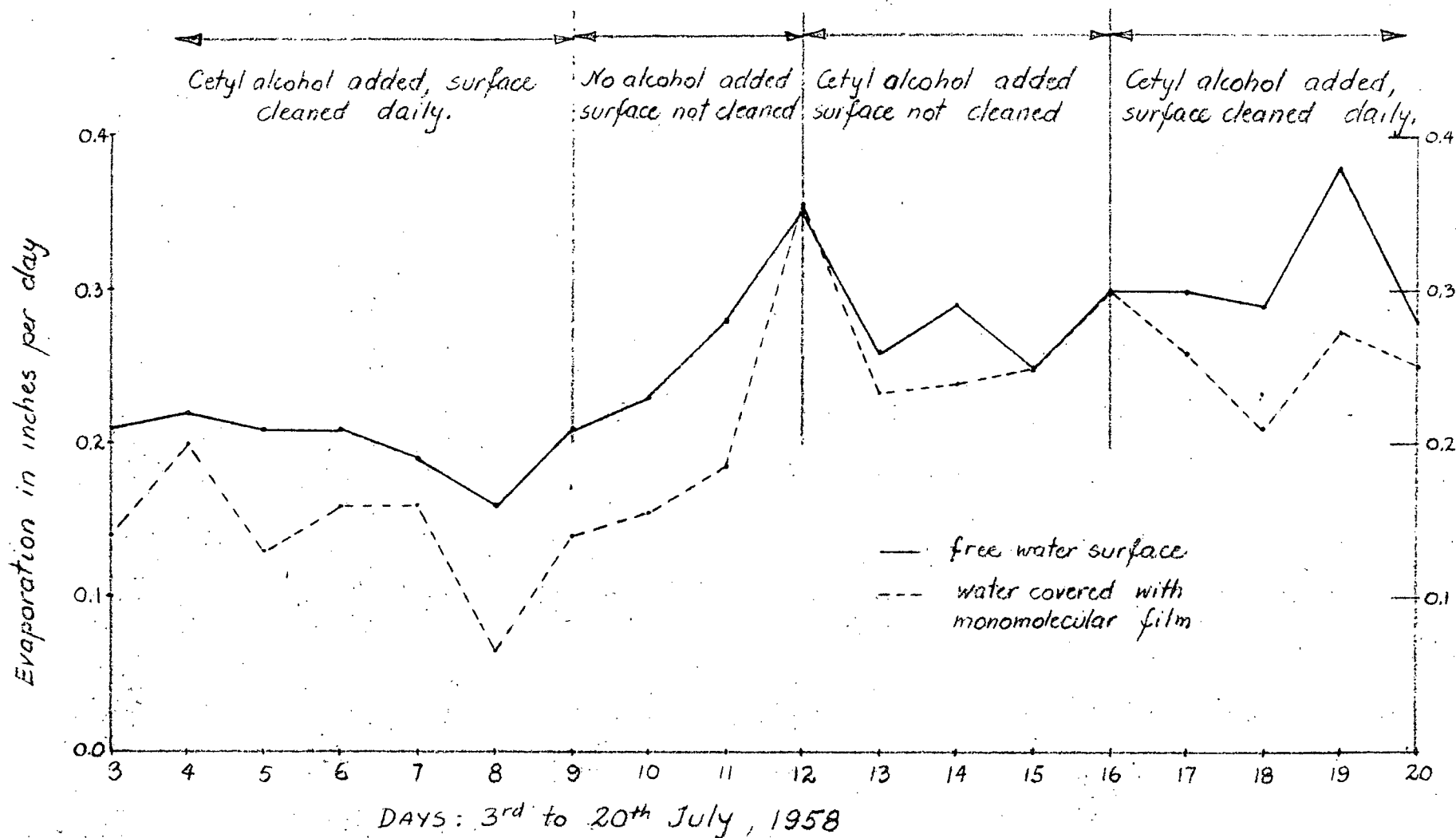
THE EFFECT OF IMPURITIES ON MONOMOLECULAR FILM.

Figure No. 11

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The impurities became heavily coated with the cetyl alcohol molecules, which may have resulted in the formation of an incomplete monomolecular film. Although when excess amounts of cetyl alcohol were added to the tanks, while covered with impurities, the reduction of evaporation was not increased to any appreciable extent.

B   Water temperature variation in ground tanks and

in a land pan

The high soil temperatures that prevailed during the summer kept the water temperature high in the ground tanks. There was a marked difference in the temperature range in the ground tanks and in the Class A Land Pan. The minimum water temperature in the ground tanks was found to be ten to fifteen degrees Fahrenheit higher than in the Class A Land Pan. The spread in the minimum temperatures was most noticeable when the air temperature dropped low at night and the Class A Land Pan without direct contact with warm soil did not receive any heat from it as compared with the ground tanks which were supplied with heat from a source of stored solar energy. (Refer to Appendix II)

Differences in the maximum temperatures between the two classes of evaporimeters varied a few degrees only, the temperature of water in the Class A Land Pan being slightly higher. This could be due to a smaller volume of water that would warm up more rapidly when receiving the same amount of

solar energy per unit area. Also the Class A Land Pan is insulated by an air layer and the ground tanks are in total contact with soil having a lower temperature than the maximum temperature of the water. The ambient air temperature and the temperature of the water in the Class A Land Pan were quite similar to each other, varying only a few degrees.

Diurnal variations in the water temperature in the Class A LandPan are more pronounced than in the deeper Four-foot Tank, and consequently a relatively high percentage of evaporation occurs from the Four-foot Tank after the sunset.

C   The effect of a monomolecular film on the diurnal
    variation of the evaporation rate

The information obtained from the experiments revealed that a greater diurnal difference occurred in the rates of evaporation from the surfaces covered with a monomolecular film than in the evaporation rates from a free water surface (Refer to Appendix III).

There was a markedly lower evaporation rate during the day through a monomolecular film of cetyl alcohol than from an untreated surface. At night the rate of evaporation from a free water surface and from a surface covered with a monomolecular film were approximately the same, with the loss from free water surfaces being slightly higher. This observation applies to the four-foot ground tanks as these were used

as evaporimeters in the monomolecular film experiments. Readings were taken at 7:00 A.M. and 7:00 P.M. P.S.T., dividing a twenty-four hour period into day and night.

The duration of bright sunshine after 7:00 P.M. was negligible, mostly due to the shading effect of the mountains that surrounded the Weather Station in a southerly and westerly direction.

Since the rate of evaporation depends upon the vapour pressure gradient and the water temperature in the ground tanks the evaporation rate was at the maximum around 7:00 P.M. P.S.T. The higher evaporation rate during the early part of the night can be easily explained. At that time the water temperature was at its maximum and the greatest number of molecules escaped to the air due to their higher velocity.

Temperature of the Black Bellani Plate has been found to be usually between the ambient air temperature and the wet bulb temperature.[22] The temperature of the four-foot ground tank appeared to remain higher than air temperature when the latter was low. Thus at 8:30 A.M. the water temperature in the tank averaged one to four degrees above the ambient air temperature.

On the other hand the effect of retardation of evaporation depends upon the spreading pressures of the mono-molecular film. With an increase in temperature, the spreading pressure increased. During the hours of sunlight the dir-

ect rays of the sun penetrated the film and the water surface was warming up the total volume of water. As the energy passed through the surface, the highest temperature prevailed at and near the surface making the monomolecular film more effective in controlling evaporation.

During the night the cooling process started at the surface and first the film was rendered less effective due to lower temperature. Secondly, a continuous molecular movement within the water itself was taking place as the molecules closer to the surface cooled more rapidly and moved down due to the increase in their specific weight. As long as such a process continued, disturbance in the surface film can be expected, a fact that could have contributed considerably to the decrease of effectiveness of the surface film.

During the night, the effect of cetyl alcohol as a monomolecular film was comparatively ineffective in preventing evaporation. It can be concluded from the experimental results that the main effect of retardation of the rate of evaporation by cetyl alcohol occurred during the hours of sunlight when high air temperatures prevailed.

Unfortunately it was not possible to find experimentally the effect of a monomolecular film on the evaporation rate from a Class A Land Pan. That information could be of value from the research point of view. The practical importance of it would be limited to areas where the evaporation rate exceeded the annual precipitation as in shallow bodies

of water resembling the Class A Land Pan.

D   The minimum amount of cetyl alcohol required to

     affect materially the rate of evaporation

During this experiment various amounts of cetyl alcohol were added to the water surface and the resulting effects were observed. See table IV in Appendix.

Five drops of a twenty per cent solution by weight of cetyl alcohol were added to 12.30 square feet of water surface which is equivalent to 0.11 pounds of chemical per acre. This provided a film on tanks with a film pressure in excess of thirty dynes per square centimeter. Duration of the film formed with such an addition was short and the surface pressure dropped to less than thirty dynes per square centimeter pressure in a lapse of one day. It was therefore necessary to replenish the film daily and before the end of a twenty-four hour period it was sufficiently weakened to be only partially effective. It was also observed that the film became progressively less effective with the passing of time from the time of application even before the spreading pressure dropped below thirty dynes per square centimeter.

Part of the explanation of this phenomenon can be traced back to the variation in solubility of the cetyl alcohol. At a higher temperature the amount of cetyl alcohol dissolved in a gasoline solution was higher than at a lower temperature. Applications of cetyl alcohol and gasoline solutions to the water surface permitted the gasoline to

evaporate readily leaving the molecules of cetyl alcohol floating on the surface.

Any excess of cetyl alcohol seemed to form solid clots that floated on the surfaces of the water. As the temperature of the water decreased at night, more cetyl alcohol collected around the existing lumps formed on the inside surface of walls of tanks or formed new lumps. During the next day the water temperature increased, but since there was no solvent present, the process could not be reversed and only the amount of cetyl alcohol that remained on the surface as a monomolecular film during the lowest diurnal temperature was effective in retarding the rate of evaporation from a water surface during the following day.

There was a definite correlation, within limits, between the amount of cetyl alcohol added and resulting reduction in evaporation. After a complete monofilm was formed additional amounts of cetyl alcohol caused little, if any change in the rate of evaporation.

During the test period, an approximately 26 per cent reduction in evaporation rate was achieved with an application of two and one third pounds per acre. When smaller amounts than this were used, the surface film often dissipated in less than a 24 hour period and the rate of evaporation increased before additional solution was added. When the rate of two and one third pounds per acre was doubled the increase in the reduction of the evaporation

rate was quite small and the saving in water would hardly warrant the increased expense. Refer to Appendix IV.

XII   SUMMARY AND CONCLUSIONS

A   Summary

1.   Film pressure variation.

During the experimental period the results varied within a wide range from day to day. Some of the factors causing the variation were determined but still some questions remained unanswered.

As observed during this experiment it was quite difficult to correlate the effectiveness of the monomolecular film to the surface pressure of the film. The surface pressure was maintained in excess of thirty dynes per square centimeter but the evaporation rate varied greatly depending upon the total amount of cetyl alcohol added. When the film pressure dropped below thirty dynes per square centimeter there was little effect on the rate of evaporation and under these conditions the surface appeared to behave similarly to a free water surface. Instead of being able to measure the film pressure, some other way of assessing the effectiveness of the film is necessary. The use of indicator oils will indicate the presence or absence of the monomolecular film and will also make it possible to find the pressure range, but it does not help to evaluate the effectiveness of the film.

2.   The effect of wind.

The action of the wind had a definite effect on the monomolecular film as observed by visual inspection. There

were no means at the disposal of the author by which an accurate measurement could be made regarding the effect of the wind. The total wind mileage was recorded for each twenty-four hour period but the effect of sudden gusts of wind on the monomolecular film cannot be evaluated with the available information. It was observed that the monomolecular film was disturbed even more by these gusts of wind when floating organic matter was present, but there was no means available to correlate the duration and velocity of the wind and its effect on the monomolecular layer.

3.   The cumulative effect of a cetyl alcohol film.

Also the cumulative effect of cetyl alcohol was difficult to determine. By the nature of the experiment it was not possible to remove the old monomolecular film and apply a new one daily. As a rule the additional amount of cetyl alcohol was added to the existing film. There were no means for determining the amount of cetyl alcohol in the active monomolecular film left from the previous application, at the time a new application was made. As previously discussed a certain amount of cetyl alcohol was rendered ineffective due to its formation into solid clots, but the exact amount was impossible to determine. So it was therefore possible that a daily application, for example, of 1.09 pounds per acre, after a lapse of a few days, could have had the effect of a single application of 2.34 pounds per acre, due to the cumulative effect.

B   Suggestions for Further Studies

1.   Lack of experimental data with large bodies
      of water.

      In order to obtain results of a practical economic
value, tests need to be conducted with larger bodies of
water. A small lake or an artificial reservoir would be
satisfactory for that purpose.

2.   The effect of wave action.

      The effect of wave action on the stability of the
monomolecular film warrants further studies. It is antici-
pated that the waves will destroy the film and a more
frequent replenishment of the film would be necessary.
The effect of waves in relationship to monomolecular films
in larger bodies of water in Western Canada has not as yet
been determined experimentally.

3.   Need for continuous temperature recordings.

      Only the minimum and maximum air and water
temperatures were recorded for each twenty-four hour period.
Due to sudden overcast periods or rainshowers the tempera-
ture dropped occasionally for a short period and then in-
creased again soon after the previous reading. Such varia-
tions were left entirely unrecorded, regardless of the fact
that these had a definite affect on the rate of evaporation.

In future studies of evaporation an automatic continuous temperature recording device would enable one to evaluate the effect of temperature on the rate of evaporation more accurately.

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Statistical Analyses to Compare Individual
Evaporating Tanks with Each Other.

Calibration period from June 6 to 15, 1958.

Date	Tank #1	Tank #2	Tank #3	Tank #4	
June 6	0.23	0.23	0.25	0.21	92
7	0.29	0.28	0.27	0.30	114
8	0.18	0.19	0.19	0.18	74
9	0.16	0.16	0.16	0.16	64
10	0.07	0.07	0.07	0.07	28
11	0.11	0.11	0.16	0.16	54
12	0.07	0.07	0.07	0.07	28
13	0.18	0.17	0.19	0.18	72
14	0.15	0.15	0.15	0.14	59
15	0.24	0.24	0.25	0.24	97

ANALYSIS OF VARIANCE

Variation Due to:	Sum of Squares:	Degrees of Freedom	Mean Squares	F
Tanks:	5	3	1.666	Not significant
Days:	1769	9	196.555	Highly significant
Error:	38	27	1.407	-
Total:	1812	39		

The analysis was performed by Dr. T. H. Anstey at the Summerland Experimental Station, Summerland, B.C.

As a result of this analysis it was found to be unnecessary to apply any corrections to the measured evaporation values.

Table V.

Temperature Variation in Ground Tanks
As Compared with the Class A Land Pan.

Date	Minimum			Maximum			Solar Radiation in cal/cm^2 per day*	Hours of Bright Sunlight
	Air °F	Ground Tank Water °F	Land Pan Water °F	Air °F	Ground Tank Water °F	Land Pan Water °F		
June 24	72	73	58	79	85	79	640	11.2
25	64	70	59	80	77	76	636	13.5
26	60	70	53	85	78	80	650	11.3
27	60	65	51	69	73	67	693	13.1
28	50	67	54	68	72	66	497	8.8
29	54	66	54	68	75	71	167	9.8
30	52	66	54	71	77	71	417	5.0
July 1	53	71	56	76	82	80	414	9.7
2	59	73	58	81	81	79	661	13.2
3	58	74	59	89	83	85	697	13.2
4	59	73	61	87	83	86	565	11.6
5	64	68	60	83	82	83	628	9.0
6	58	69	62	81	82	84	590	13.5
7	62	70	61	81	80	77	737	14.4
8	62	69	56	80	79	79	723	14.2
9	56	69	59	85	80	84	712	14.3
10	61	70	63	90	84	89	697	12.9
11	68	74	61	91	83	86	562	7.7
12	64	68	52	84	80	78	700	13.8
13	53	67	58	77	80	75	685	13.5
14	55	69	55	84	80	83	614	13.0
15	57	69	57	86	82	86	717	11.3
16	61	67	61	95	85	89	736	14.1
17	65	72	64	98	84	90	717	11.7
18	65	72	61	97	82	86	520	11.1
19	64	72	58	97	85	89	688	13.1
20	63	71	61	94	84	88	720	13.2
21	68	73	64	98	82	85	436	6.6
22	73	68	54	87	82	84	-	7.4
23	61	68	55	85	79	82	-	13.5
24	58	68	61	89	82	87	664	13.3

* Approximate values before correction.

Diurnal Variation in the Evaporation Rates

| Date | Time | Ambient Air Temperature | | 4 FOOT GROUND TANK | | | | Evaporation Losses From | |
| | | | | Water Temp. | | Evaporation Loss | | | |
		Min. °F	Max. °F	Min. °F	Max. °F	Free Water	Monomolecular Film	Class A Pan	Black Bellani Plate
July 24	Day Night	58	89	68	82	44.8% 55.2%	35.0% 65.0%		
25	Day Night	68	89	71	80	50.0% 50.0%	30.0% 70.0%		
26	Day Night	70	88	72	82	51.5% 48.5%	37.4% 62.6%		67.5% 32.5%
27	Day Night	66	94	73	84	42.5% 57.5%	41.1% 58.9%	58.8% 41.2%	63.0% 37.0%
28	Day Night	67	89	72	80	46.8% 53.2%	30.0% 70.0%	52.0% 48.0%	75.0% 25.0%
29	Day Night	63	78	70	77	40.0% 60.0%	41.6% 58.4%	31.0% 69.0%	71.0% 29.0%
30	Day Night	59	90	80	81	56.5% 43.5%	46.0% 54.0%	58.4% 41.6%	75.0% 25.0%
31	Day Night	57	90	69	81	46.0% 54.0%	39.4% 60.6%	48.6% 51.4%	70.0% 30.0%
Aug. 1	Day Night	63	87	69	81	33.3% 66.7%	33.3% 66.7%	38.0% 62.0%	66.0% 34.0%
2	Day Night	59	93	67	81	45.0% 55.0%	47.6% 52.4%	44.0% 56.0%	60.0% 40.0%
3	Day Night	60	78	65	75	67.0% 33.0%	64.0% 36.0%	71.0% 29.0%	86.0% 14.0%

Day   From 7:00 A.M. to 7:00 P.M. P.S.T.
Night From 7:00 P.M. to 7:00 A.M. P.S.T.

The Effect of the Amount of Cetyl Alcohol
on the Rate of Evaporation.

Date	Evap. from Free Water (in.)	Air Temp. Min. °F	Max. °F	Evaporation rate in inches per day through a Monomolecular film and application in lbs./acre						Reduction in Evaporation %
				0.11	0.263	0.655	1.09	2.34	4.68	
June 20	0.26	65	90			.25*				3.8
21	0.30	62	96			.28*				6.7
22	0.295	67	97			.275*				6.7
23	0.31	72	90			.30*				3.3
24	0.28	64	85				.23*			17.8
25	0.26	60	84					.245*		5.8
26	0.26	60	79					.215*		17.3
27	0.18	50	72					.12*		33.3
28	0.14	54	73					.11*		21.4
29	0.10	52	71					.08*		20.0
July 3	0.21	58	89					.14*		33.3
4	0.22	59	87					.20*		9.1
5	0.21	64	83					.13*		38.0
6	0.21	58	81					.16*		23.8
7	0.19	62	81					.16*		15.8
8	0.16	62	80					.065*		58.3
9	0.21	56	85					.14*		33.3
10	0.23	61	90					.155		32.4
11	0.28	68	91					.185		34.0
23	0.36	61	85					.25		30.5
24	0.29	58	89					.215		25.9
25	0.30	68	89					.205		31.6
26	0.33	70	88					.245		25.8
27	0.25	66	94					.255		22.7
28	0.25	67	89					.205		18.0
Aug. 2	0.365	59	93	.345						5.5
3	0.295	60	78	.295						0.0
4	0.265	50	78		.220*					17.0
5	0.26	56	88		.230*					11.5
6	0.29	66	92	.270						6.9
7	0.325	64	86	.30*						7.7
8	0.31	57	86	.29						6.4
9	0.35	62	90	.30*						14.3
10	0.27	60	89	.25						7.4
11	0.26	63	87	.245*						5.8
12	0.28	59	88	.26						7.2
13	0.31	59	87	.28						9.7
14	0.285	60	86			.26*				8.8
15	0.295	61	90			.275				6.8

The Effect of the Amount of Cetyl Alcohol on the Rate of Evaporation.

Date	Evap. from Free Water (in.)	Air Temp. Min. °F	Max. °F	Evaporation rate in inches per day through a Monomolecular film and application in lbs./acre						% Reduction in Evaporation
				0.11	0.263	0.655	1.09	2.34	4.68	
Aug. 16	0.25	63	85			.22				12.0
17	0.24	63	89			.22				8.4
18	0.30	63	89				.29			3.3
19	0.32	65	91				.29*			9.4
20	0.315	61	93				.29			7.9
21	0.285	62	92				.275			3.5
22	0.305	67	93					.220*		27.8
23	0.295	62	93					.200		32.2
24	0.255	65	95					.210		17.6
25	0.28	65	97					.225		19.2
26	0.275	67	84				.21*			23.8
27	0.145	59	72				.12*			17.2
28	0.205	53.	77				.17			17.1
29	0.185	53	74						.10*	46.0
30	0.185	52	77						.10*	46.0
31	0.20	61	78						.12	40.0

* A new application of Cetyl Alcohol Film.

WEATHER RECORDS MAY 21ST to AUGUST 31ST / 1959.

DATE	R.H.	AIR TEMPERATURE MAX.	MIN.	MEAN	SOIL TEMP. 6"	24"	SOLAR RADIATION	HOURS OF SUNSHINE	AVERAGE WIND SPEED MPH	WATER TEMP IN GROUND TANK MIN.	MAX.	WATER TEMP IN WHITE TANK MAX.	MIN.	BAROMETRIC PRESSURE (MILLIBARS)	EVAP. FREE WATER SURFACE WATER ADDED	RAIN	NET EVAP.	MONOMOL. FILM NET EVAPORATION	AMOUNT ADDED	REDUCTION IN %
MAY 21	37%	85°F	58°F	77°F	79°F	68°F	615cal/cm²	13.0	2.91	-	-	83°F	56°F	975.1	0.26		0.26			
22	46	87	59	77	80	70	720	14.3	2.66			85	56	973.2	0.23		0.23			
23	48	91	58	77	82	71	613	14.3	3.05			84	57	971.0	0.23		0.23			
24	46	86	58	79	82	72	714	14.3	2.36			84	57	976.9	0.23		0.23			
25	69	89	58	76	75	70	669	13.2	2.65			85	58	973.1	0.32		0.32			
26	51	90	59	76	85	73	589	14.4	2.98			86	57	972.9	0.30		0.30			
27	48	93	59	68	81	74	719	13.0	3.76			86	59	973.4	0.30	T	0.30			
28	66	90	65	67	75	73	448	9.1	-			78	56	973.3	0.07	.22	0.29			
29	60	73	52	64	72	72	557	7.7	-			78	51	975.8	0.18		0.19			
30	72	67	50	57	68	71	-	4.9	3.03			69	51	972.1	0.21	.03	0.24			
31	67	59	50	64	68	69	167	1.2	1.46			60	52	970.6	-0.20	.37	0.17			
JUNE 1	69	70	50	68	70	68	560	10.2	2.77			76	52	972.6	0.17		0.17			
2	69	73	50	71	75	68	675	13.1	3.20			77	54	972.6	0.21		0.21			
3	68	79	52	71	75	70	664	9.3	3.70			79	56	973.0	0.00	.21	0.21			
4	68	75	56	74	76	70	591	10.5	2.87			80	55	982.2	0.23		0.23			
5	63	84	54	78	78	71	706	14.3	3.01			84	57	982.0	0.25		0.25			
6	52	81	60	67	74	71	465	4.0	2.56			78	59	970.5	-0.27	.51	0.24			
7	94	72	58	69	71	70	459	5.8	2.56			78	55	972.4	0.19		0.19			
8	10	75	53	76	76	70	471	5.4	2.43			75	57	970.6	0.16		0.16			
9	51	81	62	70	75	71	687	10.5	3.44			82	60	967.5	0.07	.16	0.23			
10	89	75	57	60	70	71	530	7.3	3.44			79	60	972.2	0.14	.03	0.17			
11	90	63	57	73	72	70	180	2.0	1.48			67	55	968.4	0.07	.04	0.11			
12	79	78	53	75	76	70	605	10.5	2.90			80	55	969.5	0.18		0.18			
13	66	80	53	71	77	71	625	10.5	2.62			84	55	973.3	0.15	.04	0.19			
14	58	77	53	73	79	72	648	13.2	2.74			84	55	976.7	0.24		0.24			
15	75	80	52	77	82	73	631	12.1	2.35			82	56	977.9	0.23		0.23			
16	61	85	55	80	84	74	713	14.3	2.84			85	58	979.0	0.27		0.27	0.26	10 drops 5% sol.	3.7%
17	54	91	58	86	87	75	623	11.2	2.50			88	57	976.6	0.26		0.26	0.26		0.0
18	47	90	64	83	88	76	701	15.2	3.55			87	59	974.6	0.34		0.34	0.31	20 drops 5% sol.	8.8
19	58	61	63	82	89	78	703	14.6	3.27			88	51	971.9	0.31		0.31	0.31	2 gms in solid form	0.0
20	52	90	64	83	90	78	684	14.0	2.20			89	53	976.2	0.25		0.25	0.25	50 drops 5% sol.	3.8
21	45	90	65	87	91	80	668	14.7	2.45			88	61	977.0	0.30		0.30	0.28	— " —	6.7
22	5	96	62	88	85	80	249	14.7	2.50			91	64	972.0	0.29		0.29	0.275	— " —	6.7
23	46	97	67	79	90	81	645	10.6	2.90			92	68	967.8	0.31		0.31	0.30	— " —	3.3
24	46	79	72	75	85	80	333	3.1	5.23	73°F	85°F	79	58	964.6	0.28		0.28	0.23	20 drops 30% sol.	17.8
25	68	80	64	78	84	80	390	8.3	4.67	70	77	76	59	975.6	0.26		0.26	0.245	1 ml 30% solution	5.8
26	59	85	60	63	79	79	567	8.3	4.05	70	78	80	53	974.9	0.10	.16	0.26	0.215	— " —	17.3
27	80	69	60	63	72	78	271	4.4	2.32	65	73	67	51	975.9	0.08	.10	0.18	0.12	— " —	33.3
28	47	68	50	63	73	76	408	2.7	3.22	67	72	66	54	970.5	0.14		0.14	0.11	— " —	21.4
29	62	68	54	65	75	74		1.8	-	66	75	71	54	972.4	0.10		0.10	0.08	— " —	20.0
30	53	71	52	67	76	74	439	3.1	-	66	77	71	54	972.6	0.12		0.12	0.14	— " —	-16.7
JULY 1	54	76	53	68	78	74	640	11.2	2.50	71	82	80	56	972.6	0.17		0.17	0.175	— " —	-2.9
2	65	81	59	74	82	75	636	13.5	3.15	73	81	79	58	975.4	0.21		0.21	0.215	— " —	-4.3
3	55	89	58	80	84	76	650	11.3	2.50	74	83	85	59	978.2	0.21	T	0.21	0.140	— " —	33.3
4	58	87	59	79	86	77	693	13.1	2.31	73	83	86	61	979.7	0.22		0.22	0.200	— " —	9.1
5	54	83	64	79	87	78	497	8.8	3.11	68	82	83	60	977.0	0.03	0.18	0.130	0.130	— " —	38.0
6	64	81	58	73	82	78	167	9.8	2.27	69	82	84	62	977.3	0.21		0.21	0.160	— " —	23.8
7	68	81	62	75	81	78	417	5.0	2.28	70	80	77	61	972.1	0.19		0.19	0.160	— " —	15.8
8	59	80	62	72	81	78	414	9.7	2.44	69	79	79	56	973.8	0.14	0.02	0.16	0.065	— " —	58.3
9	57	85	56	76	80	78	661	13.2	2.53	69	80	84	59	976.9	0.21		0.21	0.140	— " —	33.3
10	61	90	61	81	86	78	697	13.2	2.32	70	84	89	63	977.3	0.23		0.23	0.155		32.4
11	64	91	68	82	87	79	565	11.6	2.77	74	83	86	61	973.7	0.22	.06	0.28	0.185		34.0
12	46	84	64	80	84	79	628	9.0	4.52	68	80	78	52	976.8	0.35		0.35	0.355		-1.4
13	52	77	53	71	82	79	590	13.5	4.24	67	80	75	58	976.8	0.26		0.26	0.235	1 ml 30% solution	9.6
14	62	84	55	75	84	79	737	14.4	3.31	69	80	83	55	980.2	0.29		0.29	0.240		17.2
15	51	86	57	77	86	79	723	14.2	2.42	69	82	86	57	977.0	0.25		0.25	0.245	— " —	2.0
16	57	95	61	82	89	79	712	14.3	3.04	67	85	89	61	972.8	0.30		0.30	0.300	— " —	0.0
17	49	98	65	87	91	80	697	12.9	2.86	72	84	90	64	972.8	0.30		0.30	0.260	— " —	13.3
18	51	97	65	84	90	82	562	7.7	2.18	72	82	86	61	972.4	0.29		0.29	0.210	— " —	27.6
19	47	97	64	88	90	82	700	13.8	3.36	72	85	89	58	972.9	0.38		0.38	0.275	— " —	27.6
20	46	94	63	87	91	82	685	13.5	2.73	71	84	88	61	974.8	0.28		0.28	0.250	— " —	10.7
21	50	98	68	87	91	82	614	13.0	2.78	73	82	85	64	974.1	0.32		0.32	0.215	— " —	32.8
22	46	87	73	83	91	83	617	11.3	4.89	68	82	84	54	971.3	0.45		0.45	0.255	2 ml 30% solution	43.4
23	40	85	61	80	89	83	736	14.1	3.94	68	79	82	55	976.8	0.36		0.36	0.250	1 ml 30% sol.	30.5
24	45	89	58	79	89	83	717	11.7	2.50	68	82	87	61	976.9	0.29		0.29	0.215	— " —	25.9
25	48	89	68	85	89	83	520	11.1	3.66	71	80	81	61	974.2	0.30		0.30	0.205	— " —	31.6
26	45	88	70	84	92	83	688	13.1	3.88	72	82	84	62	977.5	0.33		0.33	0.245	— " —	25.8
27	48	94	66	86	93	84	720	13.2	3.05	73	84	89	62	976.0	0.33		0.33	0.255	— " —	22.7
28	42	89	67	80	90	84	436	6.6	3.10	72	80	82	63	973.3	0.00	0.25	0.25	0.205	— " —	18.0
29	76	78	63	73	84	84	-	7.4	2.25	70	77	76	60	970.8	0.13	0.02	0.15	0.110	none added	20.0
30	63	90	59	80	81	82	-	13.5	3.24	70	81	85	57	972.2	0.27		0.27	0.260	— " —	3.7
31	47	90	57	82	82	81	664	13.3	4.57	69	81	83	59	974.8	0.37		0.37	0.330	— " —	10.8
AUGUST 1	47	87	63	82	87	81	724	13.1	3.32	69	81	85	56	975.7	0.30		0.30	0.30	— " —	0.0
2	50	93	59	81	85	82	713	13.0	3.86	67	81	84	55	974.6	0.365		0.365	0.345	— " —	5.5
3	31	78	60	75	83	82	519	10.8	4.16	65	75	73	51	969.2	0.295		0.295	0.295	4 drops 30% sol.	0.0
4	57	78	50	71	84	82	712	12.4	2.82	65	77	80	53	980.1	0.265		0.265	0.22		17.0
5	61	88	56	78	86	81	212	10.9	3.27	67	77	80	57	979.8	0.26		0.26	0.23	10 drops 20% sol.	11.5
6	40	92	66	86	87	81	152	6.3	4.13	71	78	82	63	974.1	0.29		0.29	0.27		6.9
7	69	86	64	79	85	82	596	12.8	4.72	67	79	81	54	971.3	0.325		0.325	0.30	10 drops 20% sol.	7.7
8	61	86	54	76	87	82	639	11.9	4.08	67	79	82	57	971.7	0.31		0.31	0.29		6.5
9	50	90	62	81	87	82	683	13.0	3.86	68	79	83	56	972.5	0.35		0.35	0.30	5 drops 20% sol.	14.3
10	47	89	60	81	87	82	599	10.7	2.96	69	80	84	58	976.1	0.27		0.27	0.25		7.4
11	52	87	63	76	87	82	487	9.7	3.26	69	78	81	58	975.9	0.26		0.26	0.245	5 drops 20% sol.	5.8
12	54	88	59	80	88	82	661	12.8	2.76	69	81	81	57	978.6	0.28		0.28	0.26		7.2
13	49	87	59	81	88	82	647	12.4	3.62	69	80	86	57	976.6	0.31		0.31	0.28	10 drops 20% sol.	9.7
14	56	86	60	79	88	82	696	12.9	2.98	70	80	84	58	978.8	0.285		0.285	0.26	20 drops 20% sol.	8.8
15	54	90	61	82	86	83	614	12.9	2.79	69	81	86	59	978.6	0.295		0.295	0.275	— " —	6.8
16	48	85	63	79	87	83	428	6.8	2.38	59	76	78	59	975.5	0.25		0.25	0.22	— " —	12.0
17	48	89	63	84	88	83	606	12.8	2.36	69	81	86	60	972.6	0.24		0.24	0.22	— " —	8.4
18	41	89	63	79	90	83	571	10.4	3.00	69	81	85	58	972.7	0.30		0.30	0.29	— " —	3.3
19	43	91	65	83	90	83	602	12.8	3.25	68	81	86	57	976.2	0.32		0.32	0.29	50 drops 20% sol.	9.4
20	46	93	61	82	89	83	613	12.7	4.06	68	81	86	58	980.1	0.315		0.315	0.29		7.9
21	46	92	62	82	90	84	577	12.2	2.90	68	80	85	59	977.5	0.285		0.285	0.275		3.5
22	42	93	67	88	88	84	590	11.9	3.24	69	81	85	58	976.4	0.305		0.305	0.22	1 ml 30% solution	27.8
23	58	93	62	82	89	84	583	12.5	3.04	69	81	86	59	977.6	0.295		0.295	0.20	— " —	32.2
24	39	95	65	86	91	84	572	11.8	2.48	70	80	87	61	977.3	0.255		0.255	0.21	— " —	17.6
25	62	97	65	84	89	84	529	9.7	2.84	71	81	85	63	971.8	0.280		0.280	0.225	— " —	19.2
26	54	84	67	77	83	84	354	6.3	3.88	68	75	76	57	969.1	0.275	T	0.275	0.21	50 drops 20% sol.	23.8
27	66	72	59	65	81	84	219	2.5	2.48	65	70	69	55	972.4	0.145	T	0.145	0.12	— " —	17.2
28	47	77	53	71	78	82	539	7.6	3.67	65	72	75	55	972.3	-0.035	0.24	0.205	0.17	— " —	17.1
29	79	74	53	64	73	81	426	10.0	3.29	63	71	54	53	968.3	0.185		0.185	0.10	2 ml 30% sol.	46.0
30	63	77	52	69	75	80	362	3.4	2.47	58	70	69	53	976.7	0.185		0.185	0.10	— " —	46.0
31	47	78	61	71	76	78	336	6.5	3.14	60	73	70	51	975.5	0.20		0.20	0.12	— " —	40.0

Barometric Pressure readings supplied by Dept. of Transport for Penticton Airport.
All other meteorological data collected at the Summerland Experimental Station, BC.