T H E S I S

EVAPORATION FROM LAKES

by

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ABSTRACT

Evaporation can be determined by the aid of the first law of thermodynamics in such a way that wind velocity need not enter the calculation. Air temperature and humidity enter only as terms in a correction which can have a relatively small average value under typical conditions. A method of finding the difference between incoming and outgoing radiation, from observations on a well insulated pan is described, and also a method of finding the ratio of sensible heat to latent heat transmitted through the air-water surface. These quantities can be used in estimating evaporation from an actual lake if proper corrections are made for storage of heat in the water, expansion of the water, and heat conveyed by inflowing and outflowing water. Two proposed engineering applications are outlined.

EVAPORATION FROM LAKES

Introduction

The purpose of this investigation is to develop a method of finding the evaporation from an actual lake. The reason for desiring such knowledge is twofold: (1) This is an important meteorological phenomenon which from the standpoint of pure meteorological science should be studied as thoroughly as possible; (2) the problem has engineering applications in connection with water supply and hydro-electric power.

It has long been customary to estimate evaporation from lakes on the basis of observations on pans in the vicinity, but there has been no means of showing conclusively that the error thus involved is not excessive. Thus pans of different sizes are known to have different depths of evaporation[1] and this obviously means that the depth of evaporation from a lake cannot in general be the same as that from any particular pan. If the theory described in this paper proves to be correct, substantial progress in the evaluation of evaporation from lakes will have been made.

Theory

It will be assumed that evaporation is uniquely determined by the energy that is rendered available for that purpose. Expressed as an equation this is

1. R. B. Sleight, Jour. Ag. Res. X 209 (1917)

$$E = \frac{I - B - S - K - C}{L} \quad (1)$$

where E is the evaporation expressed in centimeters of depth, I is the incoming radiation, B the back radiation to the sky, S the heat consumed in warming the water, K a correction due to heat derived from the air or given up to the air as sensible heat, C a combined correction for heat leakage through the walls of the container, expansion of the water and, in the case of a lake, for heat carried by flowing water. It is supposed that all the quantities in the numerator are expressed in gram calories per square centimeter of open water surface and are to be integrated over the same time interval as E.[2] The heat of vaporization of water expressed in gram calories per cubic centimeter is denoted by L.

If it is possible to observe all the elements on the right side of (1) except K, then to compute K by means of a certain equation derived by Mr. I. S. Bowen, which will presently be stated, and finally to compare the right side with the observed evaporation placed on the left side, the agreement between the right and left sides will not only constitute a check on Bowen's equation, but it will also show whether or not evaporation can be computed without making any measurements on wind velocities as the general theory demands. The elimination of wind from evaporation calculations is one of the fundamental ideas previously outlined by the present writer.[3]

2. It may not be obvious that S and C can be thus expressed, but if the total amount of heat stored in the entire lake or entering by the methods to which C refers be divided by the lake surface area, then a definite part of each of these total quantities of heat will be allocated to a column under each square centimeter. By thus centering attention on a column of water having a square centimeter cross-sectional area and a depth equal to the average depth of the lake we make all the quantities in the numerator comparable and can express them in the same units.

3. Journal of Electricity vol. 46, p 491 May 15, 1921.

Such a comparison has virtually been made, though in order to avoid the necessity for measuring I and B directly, a slight variant on the above procedure was adopted as follows:

We first introduce the quantity R defined by the relation

$$L\,E\,R = K \qquad (2)$$

This means that R is the ratio of sensible heat swept away by the wind to latent heat carried off by the vapor. It has been discussed by Anders Angstrom, the Swedish meteorologist,[4] who finds that R averaged less than .10 for the North Atlantic during the forepart of September 1905. Angstrom concludes that R is in general relatively small, but until now it has been extremely difficult to obtain extensive and reliable information with respect to this quantity. However Mr. Bowen,[5] a physicist in the Norman Bridge Laboratory, has recently given us an equation which makes it possible to compute R from ordinary atmospheric data, without knowing either the sensible heat or the latent heat separately. His equation is

$$R = .46\,\frac{t_1 - t_2}{p_1 - p_2} \qquad (3)$$

where $t_1 - t_2$ is the difference between the temperature of the air and that of the water surface, and $p_1 - p_2$ is the difference between the vapor pressure of the moisture in the air and the pressure this would have if the air were saturated. Equations (2) and (3) together serve to eliminate K from equation (1) and express the new quantity R in terms of easily measurable magnitudes.

Next after substituting L E R for K in (1) we solve for I - B, which will be denoted by H. This is really the difference between the

4. Geografiska Annaler H. 3 p 13 (1920)

5. I. S. Bowen. Phys. Rev. 27 p 779 (1926)

solar and sky radiation which penetrates the water surface and the energy which the water body radiates back to the sky. For convenience it will be called the heat budget per square centimeter of surface

$$H = I - B = S + LE(1 + R) + C \qquad (4)$$

Now I must be the same for all water surfaces exposed to the same external conditions whether the water bodies are shallow and heat up rapidly or deep and therefore change slowly in temperature. This equality does not necessarily hold for B, however, because if two bodies of water have different temperatures they must radiate energy at different rates. For two surfaces exposed to the same conditions we can evidently write from (4) on account of the equality of I_1 and I_2.

$$B_2 - B_1 + S_1 + C_1 + LE_1(1 + R_1) = S_2 + C_2 + LE_2(1 + R_2) \qquad (5)$$

Since Bowen has pointed out that water radiates practically like a black body because it almost completely absorbs low temperature radiation we may compute $B_2 - B_1$ by means of Stefan's law, thus

$$B = 49.5 \times 10^{-10}\, T^4 \text{ gram calories per sq. cm. per hour} \qquad (6)$$

(See also Abbot, Annals of the Astrophisical Observatory vol. IV p 291) Because $T_2 - T_1$ in our application does not exceed 15°C and T_2 and T_1 are always between 0°C and 35°C we may calculate $B_2 - B_1$ with sufficient accuracy if we differentiate (5) with respect to T, obtaining

$$\frac{dB}{dT} = 198 \times 10^{-10} \times (290)^3 = .5 \text{ calories per sq. cm. per hr. per degree} \qquad (7)$$

and then multiply by the difference in temperature of the two surfaces. These considerations make it possible to subject equation (5) to experimental test.

Experimental procedure

The bodies of water were contained in a tank and pan, the two vessels being copper lined, but so dissimilar in size and shape that on the basis of well known facts with respect to evaporation from tanks and pans, they could be expected to lose water at substantially different rates. The volume, and therefore the heat capacity of the former was about fifty times that of the latter, the actual dimensions being as follows:

	Tank	Pan
Length	4.96 ft.	2.00 ft.
Width	4.96	2.00
Depth	5.06	.67
Depth of water below rim	0.10	0.05

The tank was insulated by two feet of wood shavings on all four sides and bottom. The pan had about eight inches of shavings and boards around all four sides and bottom. Before the shavings were put around the tank the heat leakage through the board walls which were 1.5 inches thick was found to be only 1.15 calories per degree per hour per square centimeter of open water surface, and independent experiments had shown that the shavings would reduce this to less than one tenth of this value. Such an amount is wholly negligible in comparison with the unavoidable errors of evaporation and temperature determinations in the present experiments, for an error of .1 millimeter in measuring evaporation would cause an error of 6 calories in the heat budget--at least six times as large as any that could possibly have resulted from leakage since the temperature drop never exceeded 10°C.

By a careful determination, the leakage coefficient of the pan was found to be .3 calorie per square centimeter per hour per degree[6]. The

6. The pan was taken into the laboratory, filled with water and covered with paraffined boards. On this cover was placed a galvanized iron pan having a standpipe in the center. A thermometer, stirring rod and the leads to a heating coil passed down through this standpipe and through holes drilled in the boards and then into the water. The amount of heat needed to maintain the water at a definite temperature several degrees above that of the room for a period of several hours was measured with a watt-hour meter. After the steady state was reached, the only way heat could be disposed of was by leakage through the walls since the water in the galvanized iron pan was kept at the same temperature as that in the insulated pan. As a mean of several runs .3 calorie per hour per square centimeter of open surface was adopted.

evaporation loss was determined in the usual way by observing the amount of makeup water required to bring the level back to a predetermined height defined by a wire projecting upward from below the surface. The error of this measurement lay between one tenth and two hundredths of a millimeter, depending on how badly the surface was disturbed by wind.

The surface temperature of each body of water was measured by means of a mercury in glass thermometer graduated in tenths, but for the change in temperature a Beckmann instrument was used, the water being stirred just before the volume temperature was read. The air temperature and absolute humidity were determined with an Assmann psychrometer.

Since equation (3) was derived from instantaneous values of the variables, we should, strictly speaking have continuous records for the entire time interval. Hourly readings are a good substitute, however. The first run was made on October 6 extending from 8:00 A. M. to 5:00 P.M.; the second on October 24, from 9:45 A. M. to 4:45 P. M. In this case the pan was maintained at 30°C by a measured amount of electric energy, and proper allowance was made in computing H. The third run extended from 5:20 A. M. January 24 to 2:20 A. M. January 25 while the fourth was from 2:10 A. M. February 7 to 2:10 A. M. February 8.[7]

7. For the first two runs the shavings were not used, but the walls of the tank were carefully shaded and the heat leakage computed by multiplying the coefficient 1.15 by the temperature drop through the walls. This procedure was legitimate for the part of the day covered by each of these runs, but when a complete twenty-hour run was attempted the greater temperature gradients through the tank walls which occurred during the night apparently caused bending with the consequent change of volume. At any rate a systematic error was found which was eliminated by using the insulation.

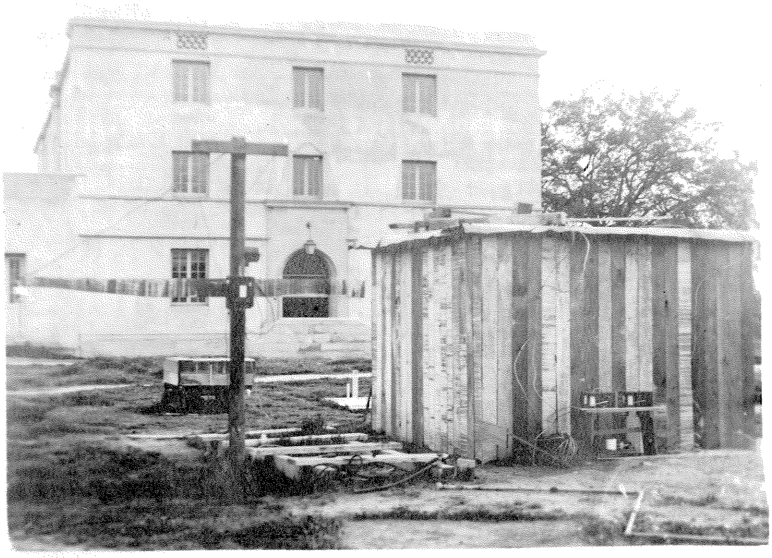

Fig 1. Pan and tank with auxiliary apparatus. Tank with recording thermometers is in the right foreground Pan is behind post. Psychrometer hangs from left end of lower crossarm.

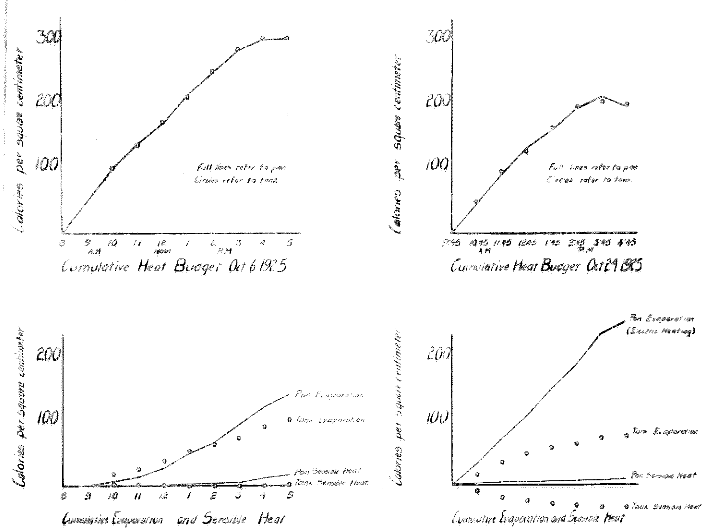

Fig 2. Cumulative heat budget, evaporation and sensible heat curves for October 6 and October 24 1925.

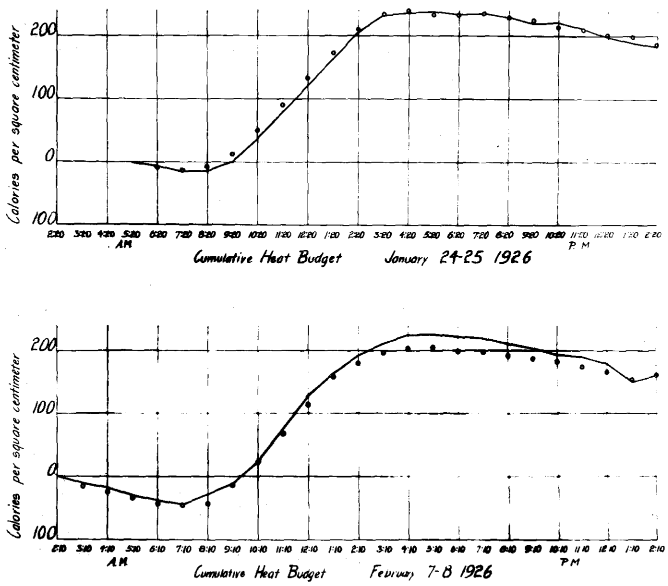

Fig 3. Cumulative heat budget curves for January 24-25 and February 7-8 1926

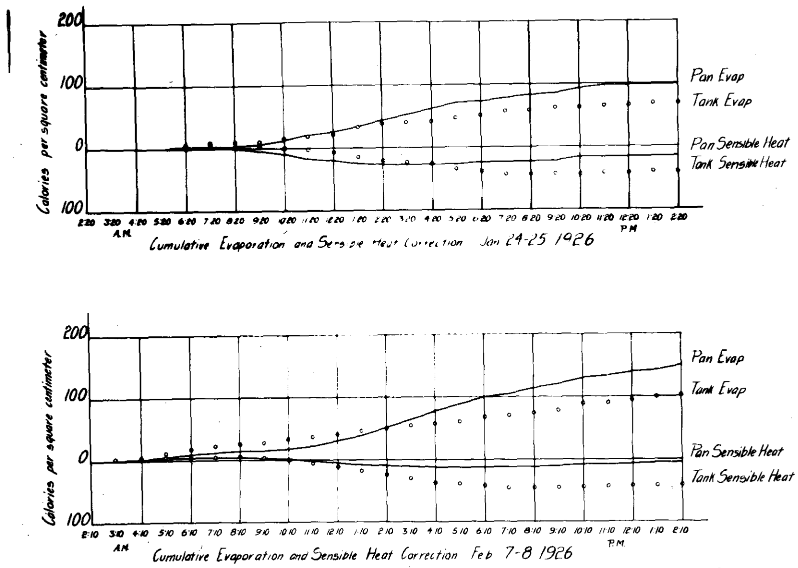

Fig 4. Cumulative evaporation and sensible heat curves for January 24-25 and February 7-8 1926

Results and comparison with theory

Equation (4) was used to compute H, the heat budget per square centimeter or resultant radiation for each body of water and for each time interval, i.e. the interval between successive readings which in most cases was one hour. The correction $B_2 - B_1$ was calculated by means of equation (7) and applied to the budget for the pan, in order to reduce H for the pan to the temperature of the tank, as indicated by equation (5). This process should then have brought the two budgets into agreement.

For the purpose of comparison, cumulative heat budgets were used, which were obtained by a process of continued summation as follows:

For each vessel the budget for the first hour was added to that for the second hour, then the budget for the third hour was added, then for the fourth and so on. Each series of these continued summations was plotted against time, full lines representing pan budgets, with the $B_2 - B_1$ corrections, and circles referring to the tank. See figures 2, 3 and 4. According to equation (5) the circles should fall on the lines. The discrepancy is within experimental error.

It will be observed that in all cases the maximum slope comes at noon which is consistent with measurements of incoming solar radiation made simultaneously. Also the integrated value of H begins to decrease after sundown as it should. The data are too voluminous to be presented in full, but the following abridgment (TableI), together with the curves showing cumulative heat budgets and sensible heat corrections will show how effectively Bowen's equation does actually take account of sensible heat. The table will also give a general indication of the magnitudes of R and of $B_2 - B_1$.

Table I

Oct. 6	Pan	Time	Tank	Time	Air	Time
Max. temp.	23.0	3p	19.1	4p	20.4	1p
Min. temp.	13.3	8a	17.7	8a	15.0	8a
Max vap. pres.					9.6mm	8a
Min vap. pres.					8.6mm	12n
Max R	+.21	5p	+ .15	5p		
Min R	+.03	12n	-.09	12n		
Av for run	+.10		+.01			
Max $B_2 - B_1$	2.4	3p				
Min $B_2 - B_1$	-1.0	8a				
Total for run	8.6					
Max H	307		306			

Oct 24	Pan	Time	Tank	Time	Air	Time
Max temp.	30.8	4p	19.3	4p	29.8	1p
Min temp.	30.2	11a	17.9	9a	21.7	9a
Max vap. pres.					8.8mm	10a
Min vap. pres.					5.2mm	2p
Max R	+.11	10a	-.51	10a		
Min. R	+.01	1p	-.25	4p		
Av for run	+.05		-.40			
Max $B_2 - B_1$	7.1	10a				
Min $B_2 - B_1$	5.5	1p				
Total for run	43.0					
Max H	215		209			

Table L (Continued)

January 24-25	Pan	Time	Tank	Time	Air	Time
Max. temp.	15.7	3p	9.8	5p	16.1	2p
Min. temp.	4.3	7a	8.3	7a	4.8	6a
Max. vap. pres.					7.9mm	7p
Min. vap. pres.					3.9mm	6a
Max R	+.78	1a	+.58	1a		
Min R	-.87	9a	-1.57	5p		
Av. for run	-.01		-.26			
Max. $B_2 - B_1$	2.9	4p				
Min. $B_2 - B_1$	-2.0	8a				
Total for run	+14.9					
Max heat budget	238		241			

February 7-8	Pan	Time	Tank	Time	Air	Time
Max.temp.	20.1	2p	14.3	4p	23.0	2p
Min. temp.	10.4	7a	12.4	8a	7.6	5a
Max. vap. pres.					11.1mm	4p
Min. vap pres.					4.6mm	9a
Max. R	+.35	4a	+.38	5a		
Min. R	-.48	10a	-1.16	5p		
Av. for run	+.02		-.27			
Max $B_2 - B_1$	+3.0	3p				
Min $B_2 - B_1$	-.9	7a				
Total for run	+25.5					
Max H	226		204			

It will be readily understood that in working in the open air where practically every magnitude involved in the entire experiment is changing incessantly, various sources of error must occasionally converge to produce an exceptionally large discrepancy between the heat budget curves for a short part of their length. The only conspicuous cases, however, are those of the middle of the day on January 24 and the time of maximum cumulative heat budget of February 7. The first case is explained by a stiff breeze which lasted for several hours, and made accurate reading of the water level impossible. It is to be expected that such an error would ultimately cancel itself however, since if at any time after the first reading the proper amount of water is not poured in, the error must sooner or later be corrected.

The case of February 7 is perhaps not quite so simple. It will be observed that most of the points for the tank are too low, but there are none too high. This suggests an unfortunate beginning, for a single error in the initial setting of the water surface into supposed coincidence with the peg would tend to cause a systematic error throughout the entire run. An initial error in reading the water temperature would have the same effect. These two causes combined with errors which could occur during the run might very probably explain the difficulty since an error of .1 millimeter in one direction on the tank and the opposite direction on the pan would account for 12 calories, while an error of 0°.05C in reading the tank temperature would account for an additional seven calories, while the total departure is only 22 calories. Although we cannot say with certainty that this combination of errors actually occurred, nevertheless the mere fact that it is within the range of probability shows that such discrepancy as does exist is not beyond the limits of experimental error, particularly if we allow for certain additional inaccuracies, the magnitude of which cannot be estimated with certainty, For example, the wet and dry bulb thermometers would often fluctuate as much as half a degree while the instruments were being read; there must also have been slight fluctuations in the volumes of the containing vessels, and finally there was doubtless a small temporary absorption and subsequent release of heat by the insulating material.

A continuous run of several days' duration would cause such a large heat budget to accumulate that the combined errors due to all sources would become negligible in comparison. To avoid the possibility of disastrous interruption, such a program must be carried out during the summer when there is little or no danger of rain, because the two vessels cannot be depended on to catch the same depth of rain. If done successfully such an extended run might actually check the numerical value of the coefficient .46 in Bowen's equation.

Although in the two cases mentioned the error is approximately twenty calories or ten percent of the maximum budget, nevertheless it is not sufficiently large in any of the runs to obscure the validity of Bowen's theory. The run which confirms this theory best is that of October 24, when the pan was artificially heated. In this case the departure between the two cumulative sensible heat curves is several times as large as the departure between the heat budget curves. It is perfectly obvious that if Bowen's correction were not applied in this case, the two heat budget curves would diverge widely from each other.

While this run furnishes the most striking example of the necessity for applying equation(3), each of the other three shows it in some degree. Thus the difference between the cumulative sensible heat correction curves in the latter part of all the runs is large in comparison with any discrepancy in the cumulative heat budget curves. It is not fair to draw conclusions from the first part of the runs because at this time the quantities weare comparing had not become large in comparison with unavoidable errors.

From 4:20 to 5:20 P. M. on January 24 the ratio R has the remarkably high numerical value of 1.57 and the complete data show that it was numerically greater than .30 during a large part of each complete run, yet the discrepancy in the curves is nowhere greater than ten percent of the maximum heat budget, and is generally much less. The variation of R for the tank is far from being in phase with the variation for the pan, e. g. on January 24 the minimum R for the pan comes at 9:00 A. M. whereas for the tank it comes at 5:00 P. M. During a great deal of the time the ratios have opposite signs. These facts show that Bowen's correction is really significant. Without applying it we could not obtain an agreement so long as we are dealing with hourly changes.

The case may be quite different, however for longer periods, for although R for the tank is relatively large during the daytime run of October 24, while for the pan it is not, since the pan was artificially heated, the average value of R does not exceed .27 numerically for either pan or tank in either of the long runs. It doubtless would not have been as large as .27 if the tank water had not been stirred so as to keep cold water at the surface which ordinarily would have remained below. This inference is justified by the fact that the average R was in the direction from air to water. This suggests that although R takes on large values at times, nevertheless when averaged over long intervals of time, it may be a small fraction as Angstrom found for the conditions he investigated.

It is thus seen that by using Bowen's theory we bring into agreement the two heat budgets which we believe on the basis of the conservation of energy ought to agree. In other words, the theory works, and on this ground it is justified. The foregoing is therefore a correct method of computing H. It follows that we can take the pan to a lake, compute H as has been done here, and after making the $B_2 - B_1$ correction, apply this H to the lake. We may then determine S, R and C for the lake and compute E by the following equation

$$E = \frac{H - S - C}{L(1 + R)} \qquad (8)$$

which is obtained from (1) on substituting L E R for K and solving for E.

This can be taken as the primary standard for calibrating all other methods of determining lake evaporation. Other equations such as the famous one that bears the name of Dalton contain certain empirical constants which can only be evaluated when a series of real lake evaporations are known. The procedure outlined herein furnishes the only method thus far devised for ascertaining these required lake evaporations with satisfactory precision and reliability. Like most primary standards, this is difficult to apply although under certain conditions it is possible to shorten the work considerably.

On superficial examination it might appear that this research is nothing but a comparison of evaporation from two vessels of different dimensions, with certain corrections applied. As a matter of fact it is more than that. While it is true that H has been determined by means of observations on the pan, nevertheless this was merely an expedient that had to be resorted to because as yet no technique has been developed for measuring B with satisfactory precision and convenience. If such a technique ever is developed, then lake evaporation can be found without using any pan and without making measurements on wind velocity. Moreover, if it turns out that the effect of the atmosphere in causing a transfer of sensible heat really is small under conditions that might be called normal--which is not unlikely--then air temperature and humidity need enter the calculations only as terms in a relatively small correction which for many purposes can be neglected entirely. Obviously then it is worth while to accumulate as much information as possible in regard to the value which R assumes at various places and various times of the year. This can easily be done by means of Bowen's equation, when the requisite wet and dry bulb and water temperatures become available.

Suggested Engineering Applications

The use that can be made of the foregoing facts and principles will depend on what particular kind of information is desired and also on what data and facilities are available. Two highly practical applications will be described.

One which it would be desirable to make in the near future is the testing of some of the most promising empirical equations that have been proposed for expressing evaporation in terms of various atmospheric elements. Such an investigation would be somewhat expensive, but it would certainly repay the cost, because if any of these equations are really capable of expressing the facts with sufficient precision, they will without doubt be extremely useful when once their validity has been established. The procedure would be as follows:

A representative body of water should be chosen for which the inflow and outflow are not sufficiently large to require any appreciable correction for heat carried to the lake or away from it with the water. The contours of the lake should be known. A well insulated pan such as has been used in this research should be installed near the lake and hourly readings continued for at least one month. The data should include:

Lake temperatures at all depths, once at the beginning and again at the end of the time interval chosen, and preferably once or twice between.[8]

Hourly lake surface temperatures.

Hourly surface and body temperatures for the water in the pan.

Hourly wet and dry bulb readings over both lake and pan.

Hourly wind movement.

8. A series of subsurface temperatures can easily be run in one hour.

The heat budget for the pan for each hour should be computed according to equation (4). The preci se method of doing this may be illustrated by the following numerical illustration taken from our run of February 7 and 8.

Table II

Time	9:10 A. M.		10:10 A. M.
Total volume of water poured in			12 cc
Pan surface temp. (centigrade)	12.7		14.7
Pan body temp	11.9		13.6
Dry bulb	19.4		19.9
Wet bulb	9.8		11.5
Av atmospheric vapor pressure		5.3 mm	
Change in body temp.		1.7	
Av surface temp for the hour		13.3	
Av air temp for the hour		19.7	
Pan temp - air temp = $t_1 - t_2$		-6.4	
Pressure of sat. vapor at water surf. temp.		11.4 mm	
$p_1 - p_2$		6.1 mm	
R (direction of flow from air to water)		-.48	
Area of surface = 3720 sq. cm.			
Evap. in calories = $\frac{12 \times 585}{3720}$ =		1.9 cal	
Correction for expansion of water		2.6 cal	
Corrected evaporation		4.5 cal	
Sensible heat (passing from air to water)		-2.2 cal	
Depth of pan = 19.5 cm			
S = 1.7 x 19.5 =		33.1 cal	
Heat budget = 33.1 + 4.5 - 2.2 =		35.4 cal	

The $B_2 - B_1$ correction should be found by the use of equation (7) as follows: (using our tank in place of the lake)

Average pan surface temperature	13.3
Average tank surface temperature	12.7
$T_2 - T_1$	.6
$B_2 - B_1 = .5\,(T_2 - T_1) =$	.3

Applying this correction to the pan heat budget gives the correct tank or lake heat budget.

Tank heat budget = 35.4 + .3 =	35.7

If the pan temperature is the higher, then the numerical quantity should be added, and vice versa.

All these hourly heat budgets should then be added, giving the total lake budget for the entire month, in case that is the interval selected. The change in heat content of the lake should be computed from the lake body temperatures as follows:

At the beginning of the month the temperature of each layer should be multiplied by the volume of that layer and all the products summed. This will give the total heat above the zero temperature datum at the beginning of the month. A similar summation should be made for the end of the month. The difference between these two will give S of equation (8). Under the conditions specified, C can be taken equal to zero.

A suitable average value of L should be chosen and the average of all the hourly determinations of R should be found.[9] The monthly evaporation can then be computed from equation (8). This will constitute a more reliable

9. In practice it may not be possible to use a single average value of R, but instead to break the main period up into smaller periods each with its proper R. There is, however, no apparent reason why this practical detail cannot be handled satisfactorily.

estimate of the real lake evaporation than it has ever been possible to make heretofore. Now having this reliable estimate of lake evaporation together with all the atmospheric data we need, including wind velocities, we can select any empirical equation, and determine its constants. This will put the empirical equation on a reliable basis, if it happens to be capable of expressing the facts consistently, so that thenceforward the equation can be used, and the pan with its hourly evaporations can be dispensed with. The following fact should be carefully borne in mind however.

Before any empirical equation is ever used for computing lake evaporation it should first be subjected to a severe test of this kind to make sure that it is actually capable of giving results that are in agreement with real lake evaporations.

A second application of the principles set forth in the first part of this paper may be described as follows:

In spite of the apparent fickleness of the atmosphere, there is nevertheless a certain constancy in it. For example, the average temperature for any one month does not vary more than a few degrees from year to year or from place to place over vast areas. By analogy we should expect certain regularities in the behavior of the ratio R, which, when they are definitely known, will make it possible to estimate R without all the detailed information needed for the experimental verification of the theory underlying this research. The same thing applies to the $B_2 - B_1$ correction. If we once become acquainted with the meteorological behavior of these quantities, then a pan placed in the vicinity of a lake can be corrected so as to give the lake evaporation, without having observations made more than once a day, or perhpas once a week. Great possibilities lie in the use of recording instruments when we know how to interpret the records.

The following data relative to R and $B_2 - B_1$ are now available in addition to what are contained in Table I but it is perfectly straightforward work to procure any further amount that may be desired.

On April 15, 1925 observations were made at Silver Lake in Los Angeles for the purpose of estimating the magnitude of R under representative conditions. The results are presented in the following table.

Table III

Time	Dry bulb	Wet bulb	Water temp	R	Location
8:20 A	20.8	15.6	20.0	-.06	High up on bank
8:25 A	19.6	14.6	20.0	+.02	Near edge of water
8:30 A	20.0	17.0	20.0	.00	Over water near edge
9:00 A	21.0	15.2	20.0	.00	Near boat landing
9:30 A	22.4	16.8	20.3	-.14	Alittle north of center of lake
9:45 A	22.5	16.8	20.4	-.15	Near center of lake
2:00 P	25.4	17.8	22.0	-.18	A little north of center of lake
2:15 P	29.0	19.0	22.0	-.39	1/4 mile to leeward of lake
5:00 P	21.4	16.0	21.1	-.02	Near boat landing

We must rule out those cases in which the wet and dry bulb temperatures were taken over land at an appreciable distance from the water's edge, because in these cases the air could become heated and give a value of the ratio that is much too high. This is illustrated by the case in which the wet and dry bulb temperatures were taken 1/4 mile from the lake. Selecting the acceptable data gives -.08 as the average daytime value of R. At night the sign would reverse but could not reach a very high positive value because for such a thing to happen the daily range of air temperature would have to be greater than it really is.

The general conclusion that we must draw, therefore is that for this day, which was certainly very representative, the value of R is so small as to make the air effect practically negligible. This fact does not detract in the least from the usefulness of Bowen's equation, however, because this equation gives us the only direct means we have of showing that the exchange of sensible heat is really small or perhaps negligible.

In conclusion the writer wishes to express his appreciation of the many helpful suggestions he has received from Dr. Millikan and other members of the faculty of the California Institute, and of the valuable suggestions and assistance given by Mr. Burt Richardson in carrying out the observations and computations.