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MASS-TRANSFER EVAPORATION ESTIMATES FOR BABINE LAKE, BRITISH COLUMBIA

by

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ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
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ABSTRACT

A modified form of the Lake Hefner mass-transfer equation was developed, tested and utilized to obtain daily estimates of evaporation from Babine Lake in northern British Columbia. The data used and the estimates obtained are presented here. Daily evaporation estimates ranged from 6.22 mm to -0.69 mm with a mean value of 1.83 mm. The greatest monthly total (81 mm) occurred in August. The total for the open water season was estimated to be near 380 mm. The work was a contribution to the Babine Watershed Change Study organized by Environment Canada.

*The work was undertaken while Mr. Spring was employed as a student assistant during the summer 1973.

ENVIRONNEMENT CANADA
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VALEUR ESTIMATIVE DE L'EVAPORATION PAR TRANSFERT DE MASSE POUR LE LAC BABINE EN COLOMBIE-BRITANNIQUE

par

K. Spring et D.G. Schaefer

RESUME

Une forme modifiée de l'équation de transfert de masse pour le lac Hefner a été mise au point, essayée et employée pour obtenir des valeurs estimatives journalières de l'évaporation du lac Babine dans le nord de la Colombie-Britannique. Les données dont on s'est servi et les valeurs estimatives obtenues sont présentées dans cette étude. Les valeurs estimatives journalières de l'évaporation sont comprises entre 6.22 mm et -0.69 mm, la valeur moyenne étant de 1.83 mm. C'est en août que l'évaporation totale mensuelle était la plus importante (81 mm) et le total pour toute la saison d'évaporation à ciel ouvert fut estimé à près de 380 mm. Ce travail est une contribution à l'Etude des modifications du bassin hydrographique de Babine faite par Environnement Canada.

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*Ce travail a été entrepris alors que Monsieur Spring était assistant-étudiant pendant l'été 1973.

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(Manuscript received November 5, 1973)

1. Introduction

Babine Lake, in northern British Columbia (Figure 1), is the rearing area for about 90 per cent of the sockeye salmon produced in the Skeena River system (Canada Department of Environment, 1973a). Over $8,000,000 have been spent there for the creation of artificial spawning channels at Topley Landing and Pinkut Creek. The expectation is one of adding 1,000,000 fish to the annual catch from about 1976 and early indications of success are encouraging (Canada Department of Environment, 1973b).

The lake has been little affected by man's activities until the recent past; however, mining, logging and human settlement have now reached a scale that require that a watch be kept for any significant change in the quality of the fish-rearing environment. Out of this context the multi-agency Babine Watershed Change Study coordinated by Environment Canada was initiated.

The current lake-evaporation estimates, for the 1972 season, were provided as one input to the larger study. In particular they will be incorporated into water and energy budget computations, which are in turn relevant to the development of lake-circulation models. An expanded series of measurements taken in 1973 is expected to lead to further evaporation estimates as well as computation of other energy budget components in future work.

2. Theory

Data availability dictated that a mass-transfer approach be used to obtain the required evaporation estimates. The Lake Hefner equation (Marciano and Harbeck, 1954) was selected. Ideally, an empirical equation of this type should be used under the same conditions as those upon which it was based. Possible error caused by the transposition of the Lake Hefner equation to the distinctly different geographic and climatic region of northern B.C. was beyond the scope of investigations at Babine Lake, thus creating some uncertainty in the absolute value of the estimates obtained. Other investigators have found the Lake Hefner coefficient to produce reasonable estimates for lakes much removed from Hefner (Richards and Irbe, 1969) and in any case there is less uncertainty in seasonal trends and in relative day-to-day fluctuations.

Quite apart from the question of the transferability of the mass-transfer coefficient is that of the specific nature of the available observational data base. Differences in this area led to the development of the so called "mini-max" once-per-day computation used to obtain the current estimates for Babine Lake.

In its original form the empirical equation found to produce the best linear fit to the Lake Hefner water budget data (Marciano and Harbeck, 1954) is given by

$$E = 6.25 \times 10^{-4} \, u_8 \, (e_o - e_8) \tag{1}$$

where E = evaporation in cm/3 hours,

u_8 = the wind speed at the 9 metre level in knots

e_o = the vapour pressure of saturated air at the surface water temperature in millibars, and

e_8 = the vapour pressure of the ambient air at 8 metres in millibars.

In the Lake Hefner study each of the parameters - air temperature, water temperature, relative humidity and wind velocity - were measured each half-hour throughout the day. Six consecutive half-hour readings were used to compute 3-hour averages of the individual parameters. These averages were then used to calculate the mass-transfer product, $u_8 . (e_o - e_8)$, over successive 3-hour periods. The sum of eight such computed values gave a daily total for comparison with the once-per-day evaporation estimates obtained using water budget methods. The empirical constant, 6.25×10^{-4}, was found to provide the best linear fit to the above data over a period of 493 days.

The data base at Babine Lake was not such as to permit a straightforward application of the computational scheme used on Lake Hefner. During the 1972 season data were gathered from a number of established climatological stations on the shores of the lake and from several special buoy installations operated by the Fisheries and Marine Service, DOE, as part of the Watershed Change Study. Locations of the station, heights of sensors and frequency of observations did not in general conform to the specifications of the Lake Hefner network.

In more specific terms, with respect to the parameters required for the computation of mass-transfer evaporation estimates, the following data were available:

a. Air Temperature and Relative Humidity - measured at sites on the lakeshore using Lambrecht thermo-hygrographs exposed in standard AES Stevenson screens at a height of 2 metres. During the 1972 season thermo-hygrographs were operated at Halifax Camp, Topley Landing and Pinkut Creek (see Figure 1). Daily maximum temperatures and minimum relative humidities were abstracted from the charts and rounded to the nearest degree Fahrenheit or whole per cent respectively.

b. Water Surface Temperature - measured at various locations by boat surveys which covered the lake at approximately 3-day intervals. Boat survey data corresponding to the locations of buoy stations 40 and 70 (see Figure 1) were plotted and smooth curves were obtained from these curves.

c. Wind Speed - measured using Lambrecht wind recorders mounted on buoys at various locations on the lake at a height of 4 metres. Data from stations 40 and 60 (see Figure 1) were utilized in the current study. Mean hourly wind speeds were digitized from the recorder charts. An average wind speed was computed for each day from the hourly records made available on punched cards by the Fisheries and Marine Service, DOE.

Consideration of the above led to the conclusion that the finest practicable time resolution involves once-per-day computations. Only wind data were available on an hour-by-hour basis. Shoreline thermo-hygrographs produced continuous temperature and relative humidity traces however, in practice, time resolution on a 31-day chart is insufficient to be confident in hourly values. Daily maximum and minimum values could be easily abstracted.

Water temperatures were measured only once every 3-5 days. According to the theory of sampling of a time series one can not specify oscillations with periods shorter than twice the sampling interval (and perferably four times the sampling interval). From this point of view fluctuations from one observation to the next have little meaning and the best that can be done is to establish the seasonal curves based upon a smoothing of the available data. Best estimates of the mean-daily values were taken from such seasonal curves.

The method selected for carrying out once-per-day computations, termed the "mini-max" method, was based on the following equation:

$$E = .0269\,(e_w - e_a) \cdot V$$

where E = evaporation in millimetres/day,

e_w = the saturation vapour pressure of air at the water temperature in millibars,

e_a = the "mini-max" vapour pressure of the ambient air in millibars computed using the maximum temperature and minimum relative humidity each day,

V = the daily average wind velocity in kilometres/hour using the 24 hourly values to compute the average, and

.0269 = the Lake Hefner empirical constant incorporating the units of measurement mentioned above.

In most instances the daily minimum relative himidity is recorded at or near the time of occurrence of the maximum temperature. Since water vapour in the atmosphere experiences only slight diurnal variation the once-per-day "mini-max" vapour pressure was considered to be representative of ambient atmospheric moisture. It was therefore deemed acceptable for use in the mass-transfer equation when utilizing other mean daily data.

With regard to the empirical constant, it should be noted that the Lake Hefner constant was developed from atmospheric data measured at the 8-metre level. Data from Babine Lake were obtained from sensors at various lower levels as noted above. Although modifications to the 8-metre Hefner equation have been made to allow the use of data measured at other levels (Bruce and Clark, 1966), none was directly applicable to the data base available. Thus a decision was made to use the unmodified 8-metre Lake Hefner equation.

The use of data collected closer to the surface than 8 metres would tend to produce an underestimate of evaporation. A compensating factor is found in the fact that the mass-transfer coefficient is dependent on lake-surface area (Harbeck, 1961) in such a way that larger lakes require a smaller coefficient. Hence use of the coefficient developed at Lake Hefner would lead to an overestimate on Babine Lake, which has an area more than ten times as large.

Due to the compensating nature of the above factors and the inherent degree of uncertainty in the transposition of the mass-transfer coefficient to northern B. C. it appeared justifiable to use the existing Lake Hefner equation, recognizing that there would be some uncertainty in the absolute value of the results but that day-to-day trends and the seasonal distribution would be realistic. Introduction of the daily "mini-max" vapour pressure would then permit a once-per-day computation of the mass-transfer evaporation estimate.

3. Testing the Method

The evaporation process as modelled by the mass-transfer equation involves a non-linear combination of the variables air temperature, water temperature, relative humidity and wind speed. Such non-linear interactions could be expected to introduce variations in computed evaporation as a function of averaging time for the individual variables. In general one might expect use of the shortest possible averaging time to produce the best result when integrated over the period of interest. Development of the Lake Hefner equation was based upon 3-hour averages of the input variables and therefore, in the current case, this time period should serve as the base for comparison.

The proposed "mini-max" method utilizes daily mean values of the input variables. It was therefore necessary to determine the effects, if any, on the daily and monthly evaporation estimates resulting from an increase in the averaging interval from three to twenty-four hours. At the same time the representativeness of the "mini-max" vapour pressure had to be determined. It was also considered desirable to compare results with those obtained from hourly computations as well as once-per-month computations. Hourly observations are often the most frequent available. At the other end of the spectrum, use of monthly mean data would significantly reduce the number of computations required in the production of seasonal estimates and it was therefore of interest. Such a method has been applied in studies on the Great Lakes (Richards and Rodgers, 1964; Richards and Irbe, 1969) using monthly mean air temperatures and relative humidities obtained from observations spaced at 3-hour intervals, monthly mean wind speeds and monthly mean lake surface temperatures.

At locations off-shore on large bodies of water one intuitively expects water surface temperatures to vary rather slowly with a dominant seasonal cycle. An examination of Figure 2 reveals that most measurements fall within fractions of a degree Centigrade of the smoothed seasonal curves. This lends credence to the suggestion that water surface temperatures do not fluctuate over a very wide range on a short-term basis. The few measurements that fall more than 1 ^{o}C from the curves may well be affected by local eddies and be less significant than values obtained from the seasonal curves when considered as being representative of some finite area surrounding the point of measurement.

In light of the apparent stability of water surface temperatures it remained for fluctuations in meteorological conditions to account for non-linear interactions of potential significance over 1-hour to 1-day averaging periods. An appropriate test could then be performed utilizing hourly meteorological data from a weather station experiencing the same range of fluctuations in weather conditions as those experienced at Babine Lake. The nearest first order weather station with a complete record of hourly observations is Smithers Airport which is located about 65 kilometres to the west. Hourly meteorological data from that station were utilized. Although any arbitrary lake temperature curve would have enabled one to determine the significance of meteorological variability to the mass-transfer estimates, the Babine Lake curve for station 40 was used since it was a measured distribution from the lake being studied.

Evaporation calculations were performed using data for each hour, each three hours (using 3-hour means as at Lake Hefner) and each day (using the "mini-max" method). In carrying out the Hefner computation it was necessary to ignore the small discrepancy between an average of six observations spaced one-half hour apart and three observations spaced one hour apart. In addition, once-per-month estimates were computed as described above. The daily evaporation estimates for the lake "envisioned" at Smithers Airport for the months June to November, 1972, are listed in Tables 1.a to 1.f.

Monthly totals, including those resulting from the once-per-month computations, are summarized in Table 2.

An optimum result would be one in which daily evaporation values computed using the proposed technique ("mini-max" method) were identical to those using the established technique (Hefner method), i.e. seasonal totals would be identical and the correlation coefficient between daily values would be 1.00. In the current case the once-per-day "mini-max" computations produced values which totalled just 2 per cent less than the 3-hourly Hefner values over the June to November season. The correlation coefficient between the two sets of daily values was 0.964 (see Table 3 and Figure 3). It should be noted that the values correlated are not strictly independent, since the saturation vapour pressure at the water surface enters into both computations. However, the degree of relationship between evaporation estimates and one of the variables e_w, e_a and V (as previously defined) is relatively weak. The significant fact is that introduction of the "mini-max" daily vapour pressure and 24-hour average wind speed produced an acceptably small change in the computed results. Hourly values were similarly in close agreement (see Table 3 and Figure 3).

Values resulting from once-per-month computations using mean parameters, when totalled over the season, fell 16.7 per cent below those obtained using the Hefner method. The method was therefore not considered to be acceptable in this case.

As a result of the above testing it was decided to apply the Lake Hefner equation on a once-per-day basis using a daily air mass vapour pressure computed from the maximum temperature and minimum relative humidity, a daily water surface temperature and a daily mean wind speed.

4. Results

For the period from early June through October, 1972, daily evaporation values were computed using air vapour pressure data from Topley Landing and wind and water temperature data from the location of buoy station 40 (see Figure 1). The data used and the results obtained are listed in Tables 4.a. to 4.e. November results (Table 4.f.) were produced by combining air vapour pressure data from Pinkut Creek with water temperature data from the location of buoy station 70 and wind data from buoy station 60 in an effort to extend results to cover a more complete segment of the open water season (mid-May through December).

The frequency distribution of daily values is depicted in Figure 4. The mean daily value over the season was 1.83 mm. Due to the evident positive skew the median value (by linear interpolation) was 1.73 mm/day. Peak evaporation rates of over 6 mm. day were recorded on August 9 and September 18. In the first case the lake temperature was at its seasonal peak of almost 19°C. A strong northerly flow of relatively dry air combined with a high vapour pressure at the water surface to produce strong evaporation. On September 18 both the lake and air were much cooler. In this case a markedly stronger northerly flow of air contributed significantly to the computed evaporation.

Small amounts of condensation were indicated on five days during which the vapour pressure of the air exceeded that at the water surface. Three of these were in June and one in October, at times when the lake was relatively cool. On June 9 and 10 a weak cyclonic circulation pattern prevailed. Very warm temperatures on the 9th and higher humidities on the 10th were responsible for high air vapour pressures. On June 12 the air was cooler but nearly saturated. On October 6 a well developed warm sector brought warm and relatively humid air over the cool lake. The final case of condensation occurred on July 12 at an intermediate lake temperature. In this case a southerly air flow was followed by rain and a frontal passage. Relative humidities remained high throughout the day.

Monthly totals of evaporation from Babine Lake are presented in Table 5 and Figure 5 along with available small lake evaporation estimates based on data from the Topley Landing class A pan (computed by the method of Kohler, Nordenson and Fox, 1955). Estimates have been entered for the open water periods at the beginning and end of the evaporation season (May 15-31 and December 1-31). Peak evaporation was 81.0 mm (3.19 inches) in August as opposed to the small-lake estimate of 89.4 mm in July. This time lag is the expected pattern in a large, deep lake with its considerable heat storage capacity. The seasonal evaporation was estimated to be close to 380 mm (15 inches). By comparison, Ferguson, O'Neill and Cork (1970) estimated the mean small lake evaporation to be near 500 mm (20 inches) in the region of Babine Lake. However, there is inusfficient evidence upon which to base a conclusion regarding the relative magnitudes of evaporation from large, as opposed to small, lakes.

5. Summary and Conclusions

a. A variation of the mass-transfer method developed for Lake Hefner was successfully tested. Termed the "mini-max" method, it involved a once-per-day computation of lake evaporation based upon maximum temperature, minimum relative humidity, mean wind speed and daily water surface temperature.

b. During testing it was determined that the "mini-max" method produced total seasonal evaporation values within about 2 per cent of those obtained using the Hefner method. Use of monthly mean parameters led to a seasonal value about 17 per cent lower than that obtained from the Hefner method.

c. Daily computations for the period from early June through November, 1972, were performed using wind speeds and water temperatures measured at buoy stations on the lake and air temperatures and humidities from shortline climatological stations.

d. Mean daily evaporation was 1.83 mm. with a range from 6.22 mm. to -0.69 mm.

e. Greatest monthly evaporation was 81.0 mm. in August. The seasonal total was estimated at close to 380 mm.

f. A more intensive data gathering effort undertaken in 1973 will allow computations of evaporation from several sub-basins of the lake in future studies.

6. Acknowledgements

The authors wish to thank Dr. D. Farmer, Marine Sciences Directorate, DOE, for his co-operation in the provision of lake buoy and boat survey data gathered in support of the lake circulation study.

APPROVED,

J.R.H. Noble,
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Atmospheric Environment Service.

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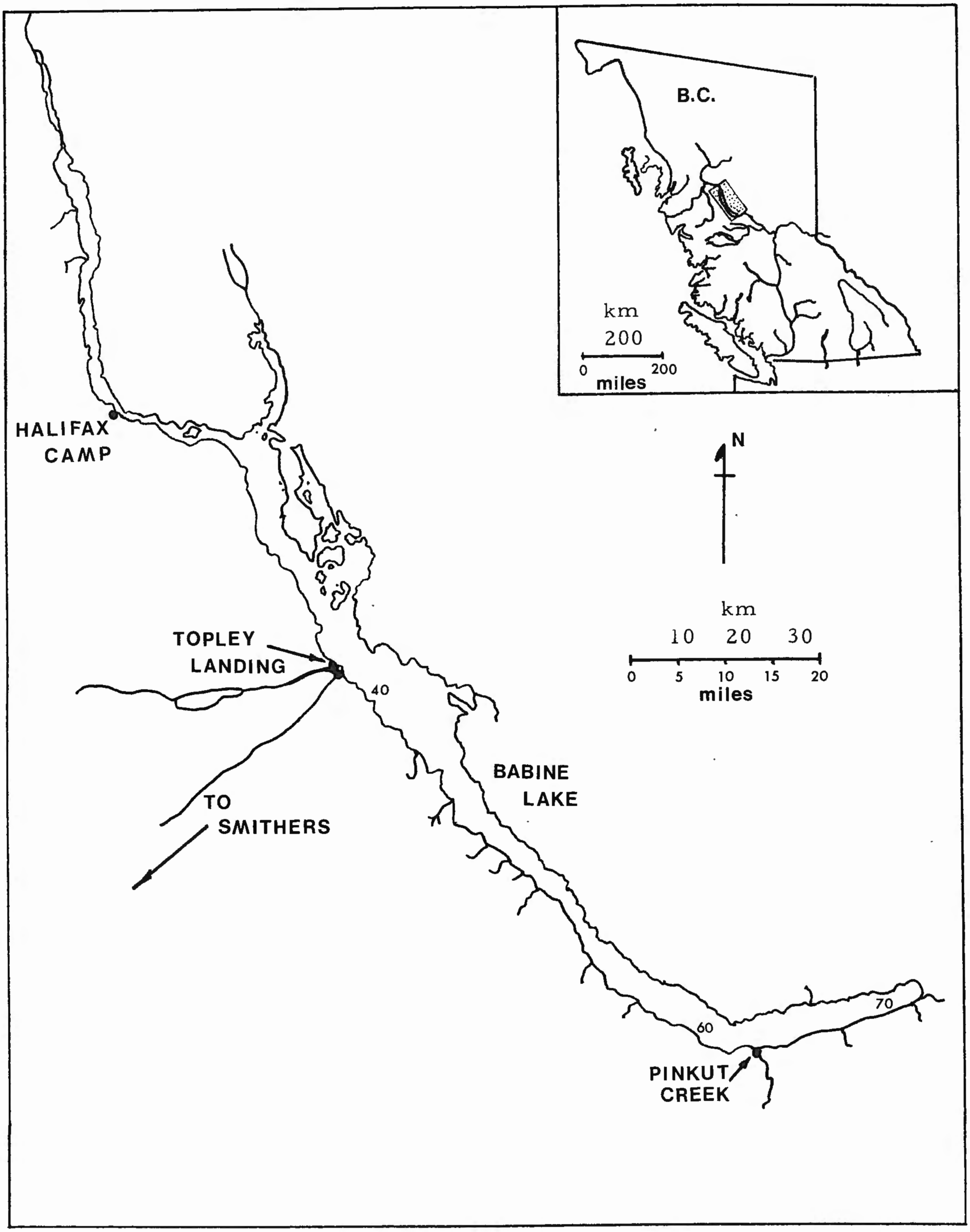

Figure 1 - Babine Lake Showing Station Locations

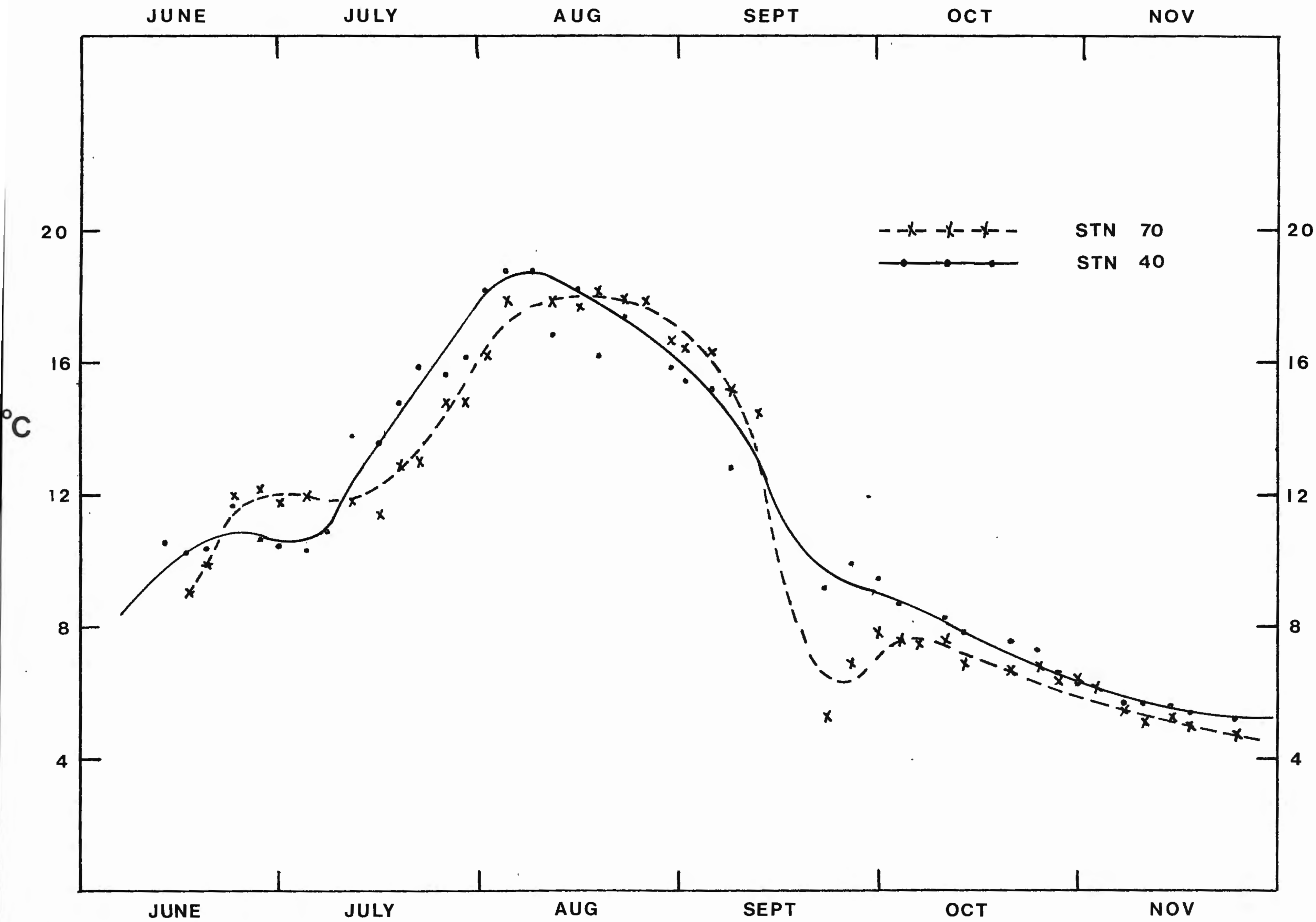

Figure 2 - Water Surface Temperatures at Stations 40 and 70

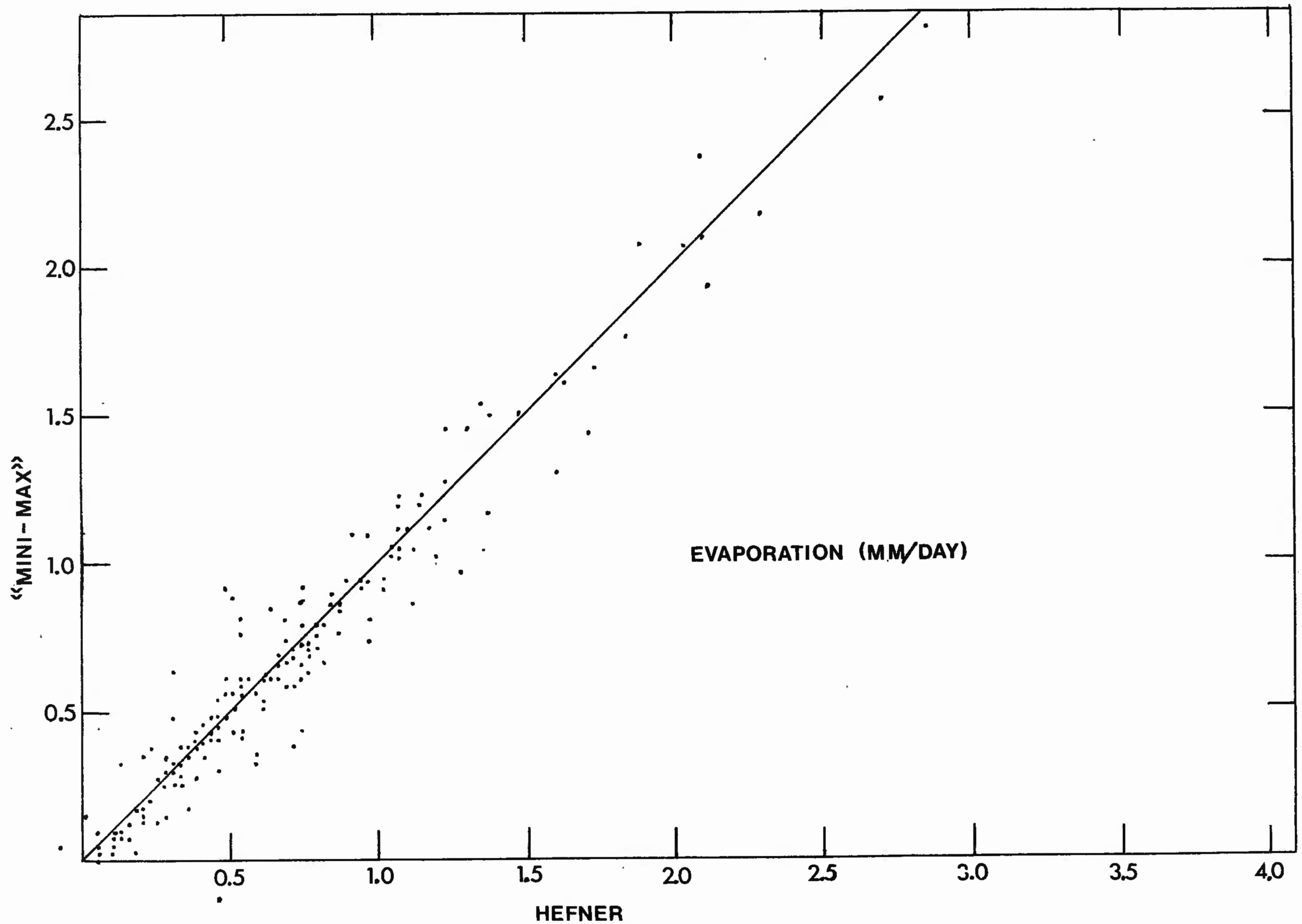

Figure 3 - Comparison of Daily Evaporation Estimates Using the Hefner and "Mini-Max" Methods

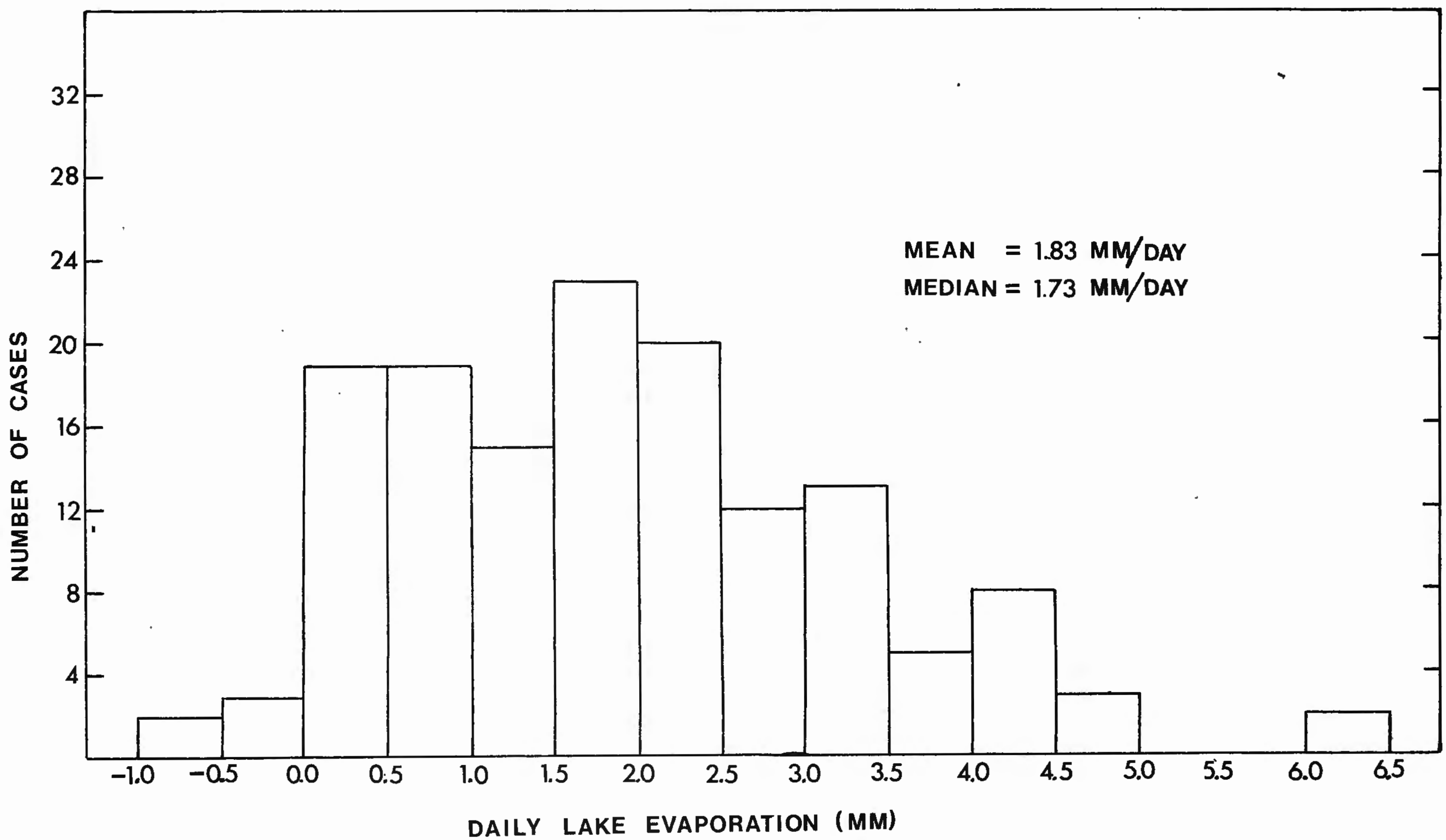

Figure 4 - Distribution of Daily Evaporation Estimates for Babine Lake for the 1972 Season

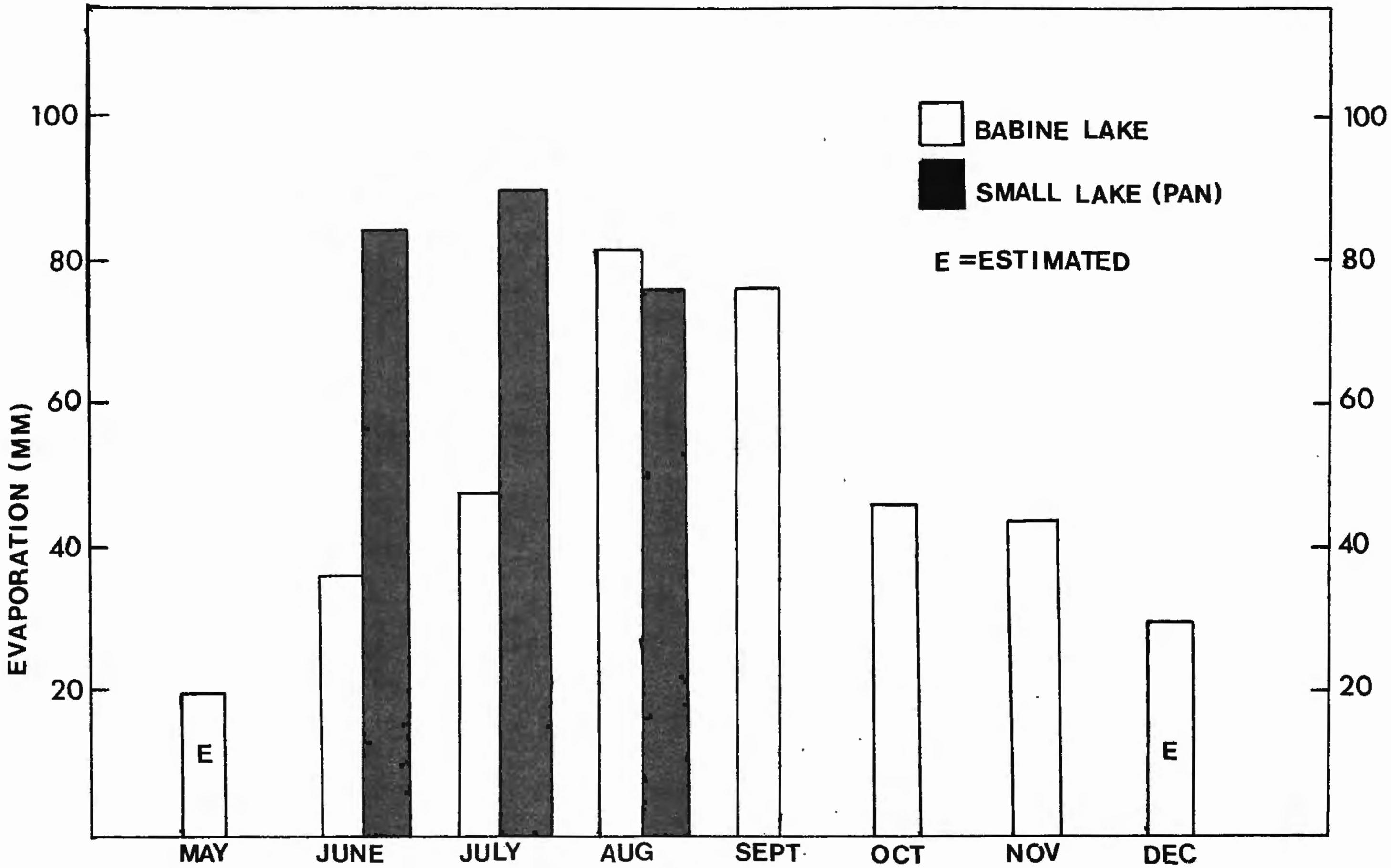

Figure 5 - Monthly Lake Evaporation Estimates for Babine Lake and the Topley Landing Class A Pan

TABLE 1.a

TEST COMPARISONS AT SMITHERS AIRPORT FOR JUNE

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.77	0.76	0.79
2	0.59	0.53	0.61
3	1.03	1.21	1.06
4	0.21	0.37	0.24
5	0.44	0.92	0.49
6	0.49	0.56	0.50
7	0.90	1.09	0.91
8	0.44	0.53	0.45
9	0.05	-.01	0.05
10	-.13	0.05	-.09
11	0.63	-.54	0.69
12	0.68	0.27	0.71
13	0.05	0.09	0.06
14	-.02	0.14	-.01
15	0.20	0.12	0.21
16	0.47	0.48	0.49
17	0.62	0.61	0.63
18	0.84	0.87	0.85
19	0.82	0.84	0.86
20	0.91	0.93	0.93
21	0.77	0.78	0.80
22	1.06	0.87	1.11
23	0.28	0.38	0.33
24	0.56	0.44	0.52
25	2.19	2.17	2.27
26	0.47	0.57	0.49
27	0.29	0.33	0.30
28	0.69	0.85	0.73
29	1.04	1.12	1.06
30	0.81	0.89	0.83
MONTHLY TOTALS	18.19	18.35	18.86

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MINI-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 1.b

TEST COMPARISONS AT SMITHERS AIRPORT FOR JULY

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.46	0.49	0.48
2	0.26	0.36	0.28
3	0.15	0.32	0.12
4	0.28	0.63	0.38
5	0.65	0.83	0.64
6	0.57	0.62	0.56
7	0.52	0.82	0.53
8	0.17	0.37	0.20
9	0.33	0.18	0.36
10	0.09	0.06	0.10
11	0.28	0.30	0.31
12	0.15	0.02	0.19
13	0.38	0.42	0.40
14	0.50	0.50	0.52
15	1.29	1.18	1.37
16	1.10	1.19	1.15
17	1.56	1.60	1.62
18	0.67	0.80	0.68
19	0.44	0.48	0.43
20	0.50	0.61	0.53
21	0.96	1.10	0.95
22	0.57	0.77	0.53
23	0.64	0.58	0.68
24	0.61	0.51	0.62
25	0.71	0.61	0.73
26	1.04	1.02	1.04
27	0.92	0.74	0.95
28	1.32	1.52	1.35
29	0.70	0.70	0.72
30	0.69	0.74	0.70
31	2.63	2.54	2.69
MONTHLY TOTALS	21.15	22.60	21.73

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MINI-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 1.c

TEST COMPARISONS AT SMITHERS AIRPORT FOR AUGUST

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.44	0.47	0.46
2	0.49	0.43	0.50
3	0.36	0.35	0.36
4	1.29	1.45	1.28
5	0.28	0.26	0.30
6	1.04	1.20	1.05
7	0.30	0.29	0.32
8	3.52	4.14	3.56
9	2.01	2.04	2.02
10	1.10	1.05	1.12
11	1.18	1.14	1.21
12	0.75	0.74	0.76
13	0.46	0.40	0.47
14	0.93	0.81	0.96
15	1.07	1.11	1.08
16	0.29	0.26	0.31
17	0.72	0.64	0.77
18	0.35	0.37	0.37
19	0.70	0.68	0.70
20	0.51	0.57	0.53
21	0.50	0.40	0.54
22	0.67	0.59	0.70
23	1.32	1.49	1.37
24	0.57	0.37	0.59
25	1.25	0.97	1.27
26	1.42	1.50	1.46
27	0.27	0.31	0.29
28	1.22	1.46	1.22
29	0.80	0.79	0.81
30	0.98	0.93	1.01
31	0.77	0.77	0.79
MONTHLY TOTALS	27.54	27.99	28.18

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MIN-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 1.d

TEST COMPARISONS AT SMITHERS AIRPORT FOR SEPTEMBER

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.75	0.77	0.78
2	1.03	1.05	1.05
3	0.31	0.38	0.35
4	0.76	0.44	0.73
5	2.07	2.07	2.08
6	0.44	0.41	0.44
7	0.72	0.70	0.72
8	0.26	0.24	0.27
9	0.77	0.66	0.81
10	0.51	0.41	0.53
11	0.64	0.67	0.65
12	0.42	0.31	0.45
13	0.79	0.70	0.77
14	0.47	0.48	0.49
15	2.04	2.37	2.07
16	0.94	0.92	0.94
17	0.65	0.69	0.67
18	1.79	1.75	1.83
19	1.16	1.02	1.19
20	1.87	2.05	1.88
21	0.39	0.36	0.40
22	1.06	1.02	1.07
23	0.82	0.86	0.83
24	0.54	0.59	0.54
25	0.95	0.93	0.95
26	0.37	0.43	0.37
27	0.24	0.27	0.24
28	0.66	0.61	0.67
29	0.74	0.78	0.79
30	0.74	0.72	0.78
MONTHLY TOTALS	24.90	24.64	25.35

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MINI-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 1.e

TEST COMPARISONS AT SMITHERS AIRPORT FOR OCTOBER

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.46	0.55	0.49
2	2.80	2.80	2.84
3	2.07	1.92	2.11
4	0.43	0.41	0.43
5	0.52	0.44	0.52
6	0.22	0.31	0.28
7	0.16	0.17	0.19
8	0.58	0.34	0.59
9	0.88	0.94	0.88
10	0.21	0.21	0.21
11	0.22	0.21	0.22
12	0.40	0.36	0.41
13	0.16	0.12	0.16
14	0.37	0.28	0.37
15	0.10	0.08	0.10
16	0.21	0.16	0.21
17	0.12	0.10	0.12
18	0.12	0.08	0.13
19	0.23	0.12	0.26
20	0.05	0.04	0.05
21	0.07	0.03	0.07
22	0.69	0.66	0.74
23	0.18	0.18	0.19
24	0.41	-.15	0.46
25	0.27	0.15	0.29
26	0.67	0.81	0.69
27	0.41	0.46	0.42
28	1.12	1.21	1.13
29	0.44	0.42	0.44
30	0.32	0.26	0.33
31	0.06	0.01	0.06
MONTHLY TOTALS	14.95	13.67	15.40

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MINI-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 1.f

TEST COMPARISONS AT SMITHERS AIRPORT FOR NOVEMBER

DAY	HOURLY EVAP.	DAILY EVAP.	3-HOUR EVAP.
1	0.14	0.08	0.15
2	0.07	0.02	0.07
3	0.10	0.10	0.10
4	1.58	1.63	1.60
5	1.70	1.66	1.72
6	1.04	1.04	1.06
7	0.18	0.19	0.19
8	0.45	0.46	0.46
9	0.09	0.08	0.09
10	0.12	0.11	0.12
11	0.10	0.09	0.11
12	0.32	0.33	0.34
13	0.37	0.40	0.38
14	0.73	0.78	0.74
15	1.20	1.27	1.23
16	0.72	0.70	0.73
17	1.17	1.11	1.18
18	0.60	0.60	0.61
19	0.66	0.68	0.67
20	2.08	2.08	2.09
21	1.58	1.30	1.59
22	0.70	0.91	0.74
23	0.83	0.77	0.87
24	1.00	0.96	1.02
25	0.75	0.68	0.77
26	0.69	0.67	0.70
27	0.17	0.14	0.17
28	0.58	0.56	0.59
29	0.48	0.61	0.49
30	0.33	0.48	0.31
MONTHLY TOTALS	20.54	20.49	20.89

HOURLY EVAPORATION IS COMPUTED EACH HOUR AND ADDED.

DAILY EVAPORATION IS COMPUTED ONCE DAILY USING THE "MINI-MAX" METHOD.

THREE-HOUR EVAPORATION IS COMPUTED AS ON LAKE HEFNER.

EVAPORATIONS ARE IN MILLIMETERS/DAY.

TABLE 2

TEST COMPARISONS OF MONTHLY TOTALS (MILLIMETERS) AT SMITHERS AIRPORT

MONTH	HOURLY METHOD	DAILY "MINIMAX" METHOD	3-HOURLY METHOD	MONTHLY AVERAGE METHOD
JUNE	18.19	18.35	18.86	15.93
JULY	21.15	22.60	21.73	16.81
AUG.	27.54	27.99	28.18	21.69
SEPT.	24.90	24.64	25.35	23.42
OCT.	14.95	13.67	15.40	11.66
NOV.	20.54	20.49	20.89	19.08
TOTALS	127.27	127.74	130.41	108.59

TABLE 3

CORRELATION OF DAILY EVAPORATION ESTIMATES FROM THE TEST AT SMITHERS AIRPORT

	HOURLY COMPUTATIONS	DAILY COMPUTATIONS (MINIMAX)	3-HOURLY COMPUTATIONS (HEFNER)
HOURLY COMPUTATIONS	1.000	.966	1.000
DAILY COMPUTATIONS (MINIMAX)		1.000	.964
3-HOURLY COMPUTATIONS (HEFNER)			1.000

TABLE 4.a

BABINE LAKE EVAPORATION ESTIMATES FOR JUNE, 1972

AIRTEMP, MINRH FROM	1078209	TOPLEY LANDING
WATER TEMP FROM	40	TOPLEY AREA
WIND DATA FROM	40	TOPLEY AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	****	****	****	6.7	9.81	15.9	*****
2	****	****	****	6.7	9.81	8.5	*****
3	****	****	****	7.8	10.50	15.5	*****
4	15.0	51	8.69	7.8	10.50	10.9	0.53
5	14.4	43	7.05	7.8	10.50	13.5	1.25
6	15.6	33	5.84	7.8	10.50	9.2	1.16
7	22.8	25	6.94	8.9	11.32	7.5	0.88
8	23.9	22	6.49	8.9	11.32	11.9	1.54
9	25.6	39	12.80	8.9	11.32	5.0	-.20
10	18.3	63	13.24	8.9	11.32	13.0	-.67
11	10.0	95	11.66	10.0	12.27	22.0	0.36
12	11.7	90	12.37	10.0	12.27	25.9	-.07
13	15.6	68	12.04	10.6	12.78	11.5	0.23
14	17.2	55	10.79	10.0	12.27	6.1	0.24
15	15.6	60	10.63	10.0	12.27	5.1	0.23
16	12.8	51	7.53	10.0	12.27	14.3	1.81
17	15.0	40	6.82	10.6	12.78	9.9	1.59
18	18.9	30	6.92	10.6	12.78	11.8	1.85
19	17.8	36	7.33	10.0	12.27	11.5	1.53
20	17.8	40	8.15	10.6	12.78	14.0	1.74
21	16.1	54	9.81	10.6	12.78	9.8	0.78
22	17.2	47	9.22	10.6	12.78	14.5	1.38
23	21.7	44	11.42	11.7	13.74	13.1	0.82
24	23.3	36	10.30	11.7	13.74	4.7	0.44
25	16.7	40	7.60	10.6	12.78	20.3	2.83
26	14.4	46	7.54	10.6	12.78	17.3	2.42
27	16.7	46	8.74	10.6	12.78	12.7	1.37
28	16.1	35	6.36	10.0	12.27	11.8	1.87
29	13.9	41	6.47	10.0	12.27	20.8	3.25
30	12.8	41	6.06	10.0	12.27	17.8	2.98
MONTHLY AVERAGES	16.7	47	8.84	9.4	11.99	12.9	1.19

NET EVAPORATION FOR THE MONTH WAS 35.70 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 4.b

BABINE LAKE EVAPORATION ESTIMATES FOR JULY, 1972

AIRTEMP, MINRH FROM 1078209 TOPLEY LANDING
WATER TEMP FROM 40 TOPLEY AREA
WIND DATA FROM 40 TOPLEY AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	18.9	33	7.62	10.0	12.27	16.4	2.05
2	23.9	28	8.25	10.0	12.27	4.2	0.45
3	26.7	26	9.11	10.0	12.27	4.5	0.38
4	25.0	38	12.03	10.0	12.27	14.2	0.09
5	27.2	32	11.54	10.6	12.78	10.0	0.33
6	22.8	35	9.71	10.6	12.78	18.0	1.48
7	23.9	32	9.43	10.6	12.78	9.5	0.85
8	17.2	55	10.79	10.6	12.78	9.5	0.51
9	13.3	82	12.52	11.7	13.74	9.7	0.32
10	16.1	60	10.90	11.7	13.74	8.8	0.67
11	17.2	63	12.35	11.7	13.74	8.3	0.31
12	17.8	81	16.50	12.8	14.77	14.9	-.69
13	16.7	53	10.07	13.9	15.77	10.0	1.52
14	17.2	45	8.82	13.9	15.77	16.6	3.09
15	20.0	40	9.35	13.9	15.77	15.2	2.61
16	22.8	31	8.60	13.9	15.77	18.9	3.63
17	21.1	45	11.25	15.0	17.04	14.5	2.26
18	22.8	33	9.16	15.0	17.04	14.8	3.13
19	21.1	42	10.50	15.0	17.04	3.9	0.69
20	25.6	38	12.47	15.6	17.71	6.4	0.90
21	25.6	43	14.11	15.6	17.71	10.8	1.04
22	21.7	45	11.68	15.6	17.71	9.4	1.52
23	16.1	79	14.35	15.6	17.71	7.3	0.66
24	17.8	60	12.22	16.7	19.00	6.3	1.14
25	16.1	65	11.81	16.7	19.00	8.9	1.71
26	16.1	52	9.45	16.7	19.00	6.0	1.55
27	18.9	46	10.62	16.7	19.00	10.1	2.27
28	17.8	41	8.35	17.8	20.37	12.4	4.01
29	17.8	46	9.37	17.8	20.37	15.8	4.65
30	18.9	50	11.54	17.8	20.37	6.5	1.55
31	20.6	42	10.19	17.8	20.37	8.1	2.22
MONTHLY AVERAGES	20.0	47	10.80	13.9	16.09	10.6	1.51

NET EVAPORATION FOR THE MONTH WAS 46.90 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 4.c

BABINE LAKE EVAPORATION ESTIMATES FOR AUGUST, 1972

AIRTEMP, MINRH FROM	1078209	TOPLEY LANDING
WATER TEMP FROM	40	TOPLEY AREA
WIND DATA FROM	40	TOPLEY AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	21.7	34	8.82	17.8	20.37	10.4	3.21
2	23.3	42	12.01	17.8	20.37	5.3	1.20
3	23.3	48	13.73	17.8	20.37	8.8	1.57
4	21.1	38	9.50	17.8	20.37	8.5	2.47
5	20.0	58	13.55	17.8	20.37	13.3	2.43
6	23.9	40	11.79	18.9	23.08	7.5	2.26
7	25.6	38	12.47	18.9	23.08	9.0	2.55
8	25.0	30	9.50	18.9	23.08	9.1	3.33
9	18.9	42	9.69	18.9	23.08	17.3	6.21
10	14.4	75	12.30	18.9	23.08	11.5	3.33
11	15.6	65	11.51	18.9	23.08	14.3	4.45
12	18.3	46	9.67	17.8	20.37	10.0	2.88
13	20.0	42	9.82	17.8	20.37	8.0	2.28
14	21.7	38	9.86	17.8	20.37	4.1	1.15
15	23.3	32	9.15	17.8	20.37	6.7	2.20
16	24.4	41	12.53	17.8	20.37	11.0	2.31
17	22.2	45	12.04	17.8	20.37	9.2	2.06
18	13.3	72	10.99	16.7	19.00	12.6	2.71
19	24.4	52	15.89	16.7	19.00	8.0	0.67
20	24.4	35	10.70	16.7	19.00	9.5	2.12
21	22.8	50	13.88	16.7	19.00	3.9	0.53
22	21.7	43	11.16	16.7	19.00	12.4	2.61
23	18.9	52	12.00	16.7	19.00	13.6	2.55
24	21.1	36	9.00	15.6	17.71	8.5	1.99
25	17.2	50	9.80	15.6	17.71	14.9	3.16
26	18.3	40	8.41	15.6	17.71	9.0	2.26
27	18.3	43	9.04	15.6	17.71	10.6	2.46
28	17.2	41	8.04	15.0	17.04	8.9	2.14
29	15.6	46	8.15	15.0	17.04	17.3	4.12
30	17.2	36	7.06	15.0	17.04	18.2	4.87
31	20.6	41	9.95	15.0	17.04	16.3	3.11
MONTHLY AVERAGES	20.6	45	10.71	17.2	19.86	10.6	2.61

NET EVAPORATION FOR THE MONTH WAS 81.02 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 4.d

BABINE LAKE EVAPORATION ESTIMATES FOR SEPTEMBER, 1972

AIRTEMP, MINRH FROM	1078209	TOPLEY LANDING
WATER TEMP FROM	40	TOPLEY AREA
WIND DATA FROM	40	TOPLEY AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	22.8	32	8.88	15.0	17.04	11.8	2.58
2	22.8	32	8.88	15.0	17.04	13.8	3.01
3	23.3	45	12.87	13.9	15.77	10.0	0.78
4	21.1	52	13.01	13.9	15.77	3.4	0.25
5	17.2	39	7.65	13.9	15.77	18.5	4.04
6	8.9	80	9.06	13.9	15.77	20.9	3.77
7	11.7	59	8.11	13.9	15.77	11.5	2.36
8	11.1	70	9.25	12.8	14.77	12.0	1.79
9	15.6	44	7.79	12.8	14.77	17.2	3.22
10	17.2	46	9.02	12.8	14.77	16.4	2.53
11	18.3	40	8.41	12.8	14.77	13.8	2.36
12	20.0	43	10.05	12.8	14.77	13.7	1.73
13	21.7	35	9.08	12.8	14.77	7.0	1.06
14	20.0	57	13.32	11.7	13.74	20.9	0.23
15	16.1	45	8.18	11.7	13.74	20.4	3.04
16	12.2	48	6.82	11.7	13.74	21.5	3.99
17	7.2	64	6.50	11.7	13.74	13.2	2.56
18	6.1	61	5.74	11.7	13.74	28.3	6.08
19	2.8	68	5.08	10.6	12.78	17.9	3.70
20	4.4	77	6.44	10.6	12.78	25.8	4.39
21	4.4	83	6.94	10.6	12.78	26.8	4.20
22	1.7	80	5.49	10.6	12.78	22.9	4.49
23	1.1	56	3.70	10.6	12.78	14.9	3.64
24	1.1	60	3.97	10.6	12.78	5.8	1.37
25	6.1	51	4.80	10.0	12.27	2.2	0.44
26	3.9	40	3.21	10.0	12.27	7.2	1.74
27	5.0	66	5.76	10.0	12.27	10.8	1.89
28	10.0	72	8.83	10.0	12.27	11.0	1.01
29	16.1	45	8.18	10.0	12.27	14.5	1.59
30	17.2	46	9.02	10.0	12.27	21.4	1.86
MONTHLY AVERAGE	12.2	55	7.80	11.7	14.02	15.2	2.52

NET EVAPORATION FOR THE MONTH WAS 75.73 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 4.e

BABINE LAKE EVAPORATION ESTIMATES FOR OCTOBER, 1972

AIRTEMP, MINRH FROM	1078209	TOPLEY LANDING
WATER TEMP FROM	40	TOPLEY AREA
WIND DATA FROM	40	TOPLEY AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	15.0	41	6.99	10.0	12.27	14.3	2.02
2	15.0	32	5.45	8.9	11.32	27.9	4.40
3	7.8	45	4.72	8.9	11.32	26.2	4.64
4	8.9	43	4.87	8.9	11.32	18.7	3.24
5	11.1	40	5.28	8.9	11.32	11.3	1.84
6	18.9	54	12.46	8.9	11.32	15.4	-.47
7	12.8	70	10.34	8.9	11.32	9.3	0.24
8	5.6	90	8.18	8.9	11.32	15.0	1.26
9	-1.1	65	3.67	7.8	10.50	18.9	3.46
10	0.0	59	3.61	7.8	10.50	14.0	2.60
11	3.9	45	3.61	7.8	10.50	6.9	1.27
12	3.3	72	5.57	7.8	10.50	6.8	0.89
13	9.4	48	5.66	7.8	10.50	18.6	2.42
14	3.9	76	6.10	7.8	10.50	6.8	0.80
15	8.9	59	6.68	7.8	10.50	8.0	0.82
16	5.0	91	7.94	7.8	10.50	4.0	0.28
17	5.0	90	7.85	6.7	9.81	3.5	0.18
18	6.1	88	8.28	6.7	9.81	2.9	0.12
19	11.7	56	7.69	6.7	9.81	7.3	0.41
20	3.9	85	6.82	6.7	9.81	6.8	0.54
21	6.1	95	8.94	6.7	9.81	11.5	0.27
22	10.6	51	6.52	6.7	9.81	18.5	1.63
23	7.2	53	5.38	6.7	9.81	15.6	1.86
24	13.3	56	8.55	6.7	9.81	23.5	0.80
25	7.2	60	6.09	5.6	9.09	17.2	1.38
26	3.3	58	4.49	5.6	9.09	****	****
27	0.6	70	4.47	5.6	9.09	****	****
28	2.2	45	3.22	5.6	9.09	****	****
29	2.2	62	4.44	5.6	9.09	****	****
30	8.3	61	6.67	5.6	9.09	****	****
31	8.9	70	7.92	5.6	9.09	****	****
MONTHLY AVERAGES	7.2	62	6.40	7.2	10.25	13.2	1.48

NET EVAPORATION FOR THE MONTH WAS 45.77 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 4.f

BABINE LAKE EVAPORATION ESTIMATES FOR NOVEMBER, 1972

AIRTEMP, MINRH FROM	1070573	PINKUT CREEK
WATER TEMP FROM	70	PINKUT AREA
WIND DATA FROM	60	PINKUT AREA

DAY	MAX AIR TEMP	MIN RH	AIR MMVP	WATER TEMP	WATER VP	AVG DAILY WIND	EVAPORATION
1	3.3	91	7.04	5.6	9.09	****	***
2	6.7	66	6.47	5.6	9.09	****	***
3	3.3	92	7.12	5.6	9.09	5.5	0.29
4	1.1	78	5.16	5.6	9.09	19.9	2.10
5	-3.3	82	3.93	5.6	9.09	16.3	2.25
6	-2.7	82	4.26	5.6	9.09	12.0	1.56
7	-1.1	90	5.08	5.6	9.09	7.5	0.81
8	0.0	90	5.51	5.6	9.09	9.6	0.93
9	1.1	82	5.42	5.6	9.09	16.0	1.58
10	2.2	80	5.73	5.6	9.09	7.2	0.65
11	1.1	80	5.29	5.0	8.72	9.3	0.86
12	0.0	81	4.96	5.0	8.72	9.7	0.98
13	-0.6	82	4.83	5.0	8.72	11.9	1.24
14	-0.6	70	4.12	5.0	8.72	8.3	1.03
15	-1.1	66	3.72	5.0	8.72	11.0	1.48
16	-2.2	73	3.80	5.0	8.72	10.3	1.36
17	-3.3	73	3.50	5.0	8.72	14.0	1.96
18	-3.9	72	3.30	5.0	8.72	11.9	1.73
19	-3.3	74	3.54	5.0	8.72	8.1	1.13
20	-2.2	77	4.00	5.0	8.72	21.3	2.69
21	2.2	66	4.73	5.0	8.72	21.7	2.32
22	3.3	59	4.57	5.0	8.72	19.3	2.16
23	****	**	****	5.0	8.72	12.4	***
24	****	**	****	5.0	8.72	11.5	***
25	****	**	****	5.0	8.72	16.5	***
26	****	**	****	3.9	8.02	20.5	***
27	****	**	****	3.9	8.02	10.8	***
28	****	**	****	3.9	8.02	8.4	***
29	****	**	****	3.9	8.02	16.0	***
30	****	**	****	3.9	8.02	10.4	***
MONTHLY AVERAGES	0.0	78	4.82	5.0	8.73	12.8	1.46

NET EVAPORATION FOR THE MONTH WAS 43.66 MILLIMETERS IN THIS AREA.

TEMPERATURES ARE IN DEGREES CENTIGRADE.

RELATIVE HUMIDITIES ARE IN PER CENT. VAPOUR PRESSURES ARE IN MILLIBARS.

WINDS ARE IN KM/HOUR.

EVAPORATION VALUES ARE IN MILLIMETERS/DAY.

TABLE 5

MONTHLY EVAPORATION ESTIMATES FOR BABINE LAKE AND SMALL LAKE EVAPORATION FOR THE TOPLEY LANDING CLASS A PAN (MILLIMETERS)

	BABINE LAKE	TOPLEY LANDING
MAY	20.00*	-
JUNE	35.70	83.06
JULY	46.90	89.41
AUGUST	81.02	75.18
SEPTEMBER	75.73	-
OCTOBER	45.77	-
NOVEMBER++	43.66	-
DECEMBER	30.00*	-
SEASONAL TOTAL	378.78	

* VALUES FOR THE ICE-FREE PERIODS MAY 15-31 AND DECEMBER 1-31 ARE ESTIMATES USED TO COMPLETE THE EVAPORATION SEASON.

++ NOVEMBER RESULTS ARE FOR THE SOUTH ARM OF THE LAKE.