AUTUMNAL MIXING IN MAHONEY LAKE, BRITISH COLUMBIA

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NWRI Contribution No. 89-33

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July 1989

Executive Summary

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Lake mixing is a very important process. Incomplete lake mixing in the fall can result in poor oxygenation and bad water quality. Low oxygen concentrations result in high metal concentrations and odour and taste problems. Winter fish kills occur commonly in lakes that mix poorly. Ideally a lake should mix slowly and completely in the fall. A rapid mixing of a lake by a storm can kill fish.

To interpret natural phenomenon in lakes we need to understand mixing processes. To guide induced lake mixing by lake aeration, simple coefficients of lake mixing should be developed for computer models. In this study we compared wind driven lake mixing to mixing generated by density currents created by temperature changes (penetrative convection). For a sheltered lake, penetrative convection was approximately three times more important than wind driven mixing. An efficiency factor of 0.20 for penetrative convection energy is larger than literature values; our value is probably more accurate than earlier studies.

ABSTRACT

Monthly measurements of salinity and hourly mesurements of wind speed and water temperatures at four depths were made at Mahoney Lake, British Columbia for a five month period during the summer and autumn. The measurements were made during a time when the lake had been well stratified by a much larger than average runoff the previous spring. The potential energy of stratification was calculated from water densities at the various levels in the lake, and a major reduction in the value of the potential energy of stratification of the top 8 m of the water column was found in the period mid August to mid October. Analysis of the energy available from wind shear on the water surface and from penetrative convection during the autumn cooling period was made. Winds were found to be weak at Mahoney Lake during the months of record, and their contribution to mixing during the majority of the time was small. Penetrative convection from thermals descending from the cool surface contributed to the majority of the mixing. An efficiency factor of 0.20 for the penetrative convection energy, larger than values previously reported in the literature, was found to fit the measured loss of potential energy of stratification during the period.

Perspectives-gestion

Le mélange de lac est un processus très important. S'il est incomplet à l'automne, l'oxygénation et la qualité de l'eau pourront être mauvaises. De basses concentrations d'oxygène entraînent des teneurs élevées en métaux et des problèmes d'odeur et de goût. Les mortalités hivernales de poissons se produisent souvent dans des lacs où le mélange s'est mal fait. Dans l'idéal, le mélange devrait s'effectuer lentement mais totalement, à l'automne. Un mélange trop rapide du lac à la suite d'une tempête peut tuer les poissons.

Pour interpréter ce phénomène naturel dans les lacs, nous devrons bien comprendre les processus de mélange. Pour induire le mélange de lac par aération, il faut que soient mis au point des coefficients simples de mélange de lac pour les modèles informatiques. Dans cette étude, nous avons comparé le mélange de lac causé par le vent avec celui causé par les courants de densité dus aux changements de température (pénétration convective). Dans un lac abrité, la pénétration convective était environ trois fois plus élevée que le mélange éolien. On a trouvé un facteur d'efficacité de 0.20 pour l'énergie de pénétration convective, ce qui est plus élevé que les valeurs données dans la documentation; la nôtre est probablement plus précise que celles des études antérieures.

RÉSUMÉ

On a effectué des mesures mensuelles de la salinité et des mesures horaires de la vitesse du vent et de la température de l'eau à quatre profondeurs, dans le lac Mahoney (Colombie-Britannique) pendant une période de cinq mois d'été et d'automne. Ces mesures ont été prises à un moment où le lac avait été bien stratifié par un écoulement de surface inhabituellement élevé le printemps précédent. L'énergie potentielle de stratification a été calculée à partir des densités de l'eau à différents niveaux dans le lac, et on a constaté une importante réduction de la valeur de l'énergie potentielle de stratification dans les 8 mètres du haut de la colonne d'eau entre la mi-août et la mi-octobre. On a procédé à l'analyse de l'énergie fournie par le cisaillement du vent à la surface de l'eau et par la pénétration convective pendant le refroidissement à l'automne. On a trouvé que les vents étaient faibles sur le lac Mahoney pendant les mois couverts par l'étude, et qu'ils contribuaient peu au mélange la majeure partie du temps. La pénétration convective due aux courants thermiques descendant de

la surface plus fraîche donnaient la plus grande partie du mélange. On a trouvé qu'un facteur d'efficacité de 0.20 pour l'énergie de pénétration convective, plus élevé que les valeurs indiquées précédemment dans la documentation, correspondait à la perte mesurée d'énergie potentielle de stratification.

INTRODUCTION

Mahoney Lake is a meromictic lake in southern British Columbia (lat. 40°17'N long. 119°35'W, altitude 471 m above sea level). The surface area and volume of the lake when full are 198,000 m^2 and 1.36 million m^3 respectively. The unusual nature of the physical, chemical and biological properties of the lake were first documented by Northcote & Halsey (1969). Mahoney lake receives a shallow ice cover for a period of 2 to 4 months every winter, and shows striking vertical variations in temperature due to the suppression of vertical mixing by the strong salinity gradient.

The interesting nature of the physics of meromictic lakes has been known for a long time, and calculations of the energy required for completely mixing some example lakes were made by Hutchinson (1957). Temperature and total dissolved solids data for several meromictic lakes in central Washington state (U.S.A.) have been published (Walker 1974). The dual control of density by both temperature and chemical (salinity) effects on the water are discussed.

Diurnal temperature changes measured near the surface of a shallow African salt pan, including data on total heat content and stability are reported by Ashton & Schoeman (1988). A good introduction to physical-chemical conditions and biological conditions in Mahoney Lake, and a neighbouring dimictic lake (Green Lake) has been published (Northcote & Hall 1983). The lakes were observed to be entirely different from one another and physical and geological reasons for the differences were postulated. The possibility that differences in wind climate caused significantly different conditions was discussed.

During the spring and early summer of 1983, unusually large amounts of run-off caused a large layer of relatively fresh water to be be introduced on the surface of Mahoney Lake. This layer was of lower salinity than the surface layer in preceeding or succeeding years (Northcote & Hall MS), and offered a good opportunity to study mixing mechanisms. Major changes in the potential energy of stratification in the upper 8 m of the lake were noted in the period August to November, and these changes are analyzed herein. Following Imberger (1979), we examine the effects of wind driven circulation and cooling induced penetrative convection on mixing in the upper several meters of the lake. These calculations show whether wind effects or cooling effects or both are the main cause of autumnal mixing in Mahoney Lake.

MIXING IN LAKES

Figure 1 shows the well mixed upper layer with falling plumes of cool water eroding the stably stratified layers below. In meromictic lakes with small inflows this well mixed upper layer, the mixolimnion, is in the range 2 to approximately 8 m deep. In very sheltered meromictic lakes, such as crater bottom pans, the mixolimnion may be as shallow as 0.5 m (Ashton & Schoeman, 1988). During the autumn months, the water adjacent to the surface is cooled by several processes (mainly evaporative losses and long wave radiation) and the cooling causes plumes of water to descend. The process is similar to an inverted form of the convective currents that form in a saucepan when water is heated on a stove. In addition, mixing is caused by water motions from wind induced surface stresses. These wind induced water motions take many forms, but for light winds in heavily stratified lakes we are concerned with turbulent motions in the mixolimnion, which progressively erode the underlying layers. An energy calculation may be carried out using the following equations (Imberger 1979).

Velocity u_f of falling plumes:

$$u_f = \left[\frac{\alpha g h \widetilde{H}}{\rho_w C_p} \right]^{1/3} \qquad \text{................[1]}$$

in which
$\widetilde{H}$ = rate of cooling at the water-air surface, W m^{-2}
h = depth of mixed upper layer, m
g = gravitational acceleration, m s^{-2}
C_p = specific heat of water, J kg^{-1} $°C^{-1}$
ρ_w = density of water, kg m^{-3}
α = thermal coefficient of expansion of water, $°C^{-1}$

The power per unit area available for stirring from cooling equals an efficiency C_k times the water density times the falling plume velocity cubed. C_k was found to be about 0.13 by Imberger (1979) in studies on Wellington Reservoir, Australia, and this value was found to be in reasonable agreement with work by Sherman *et al* (1978).

The power per unit area available for mixing from wind induced motions is proportional to the cube of the shear velocity u^*. This is because the shear stresses at the surface (τ) are proportional to u^{*2}, and the mean drift speed is proportional to u^*, so that the associated power availability at the surface is proportional to u^{*3}. The total rate of working of the wind on the water is much larger than u^{*3}, and is more nearly equal to the product of the group velocity of the waves times the shear stress (τ), Turner (1973). However use of the shear velocity cubed as a reference for the energy used in mixing is a useful approach, and is extensively used in the literature. We will use the product $\rho_w u^{*3}$ herein for calculating an efficiency of wind energy utilization.

The shear velocity u^* is determined from a coefficient of drag C_d for the air-water interface. For a medium range of wind velocity (4 to 11 m s^{-1}), C_d equals 0.0012 for winds measured at 10 m above the ground surface (Large &Pond 1981). On this basis the shear velocity u^* is given by:

$$u^* = [\, 0.0012\, u^2 \rho_a / \rho_w \,]^{1/2} \qquad \text{....................[2]}$$

in which ρ_a = density of air, kg m^{-3}
ρ_w = density of water, kg m^{-3}
u = wind velocity at 10 m, m s^{-1}

Using C^* as the efficiency of wind energy utilization, the wind power per unit area available for mixing is proportional to C^* times u^{*3}. Values for C^* are still being researched, and a wide range of published values has appeared. Wind stress experiments by Wu (1973) yielded a value of C^* of 0.23, and values reported by Imberger (1979) ranged from 0.03 to 0.23, when a remote station was used for wind data, depending on the amount of sheltering allowed for from surrounding hills. A value of 0.26 was used in studies on wind mixing in Babine Lake (Farmer & Carmack 1981). Values used for modelling with the US Army Corps of Engineers model CE-QUAL-RI are $C^* = 0.12$ and larger, dependent on the value of the Richardson number, Johnson & Ford (1981).

Assuming that the power available from penetrative convection and from wind energy are additive, then the time rate of change of potential energy of stratification per unit area is:

$$\begin{array}{c}\text{Time rate of change of potential}\\ \text{energy per unit area}\end{array} = \underset{\substack{\text{convective}\\ \text{current}\\ \text{induced}}}{C_k \rho_w u_f^3} + \underset{\substack{\text{wind}\\ \text{induced}\\ \text{mixing}}}{C^* \rho_w u^{*3}} \qquad \text{..............[3]}$$

The potential energy of a horizontally layered lake is obtained by integrating the sum of the masses times the densities times the elevations of the individual layers. The potential energy is measured from a datum, usually the lowest point in the lake. Changes in potential energy of meromictic lakes are due to changes in temperature and redistributions of salinity in the water column.

The potential energy of stratification is the difference between the potential energy of the stratified lake, and the potential energy of a hypothetical totally mixed lake of the same average temperature and the same average salinity. This difference in potential energy may be reduced to a small difference in height by dividing by the product total water mass times gravitational acceleration (Ward 1980). The centre of gravity of the mixed lake is at a slightly greater elevation than that of the stratified lake. Change in the potential energy of stratification is equal to the amount of mixing energy that has been utilized. For lakes that show negligible changes in water surface level during the period of analysis, the calculations may be carried out from the surface downwards (using the water surface as datum). The integrations do not need to go for the full depth, and may be terminated at a depth deemed to show no change during the measuring period. The potential energy of stratification, Ps, in joules, is given by:

$$Ps = \int_0^{z_m} (\rho - \bar{\rho})\, g\, z_m\, A \, dz \qquad \text{............[4]}$$

in which z = the depth measured from the surface downwards, m
z_m = the depth of the level of no change (or bottom of the lake)
$A(z)$ = is the area of layer at depth z, m^2
$\rho(z)$ = is density of layer at depth z, kg m^{-3}
$\bar{\rho}$ = is mean density of layers above level of no change, kg m^{-3}
g = is gravitational acceleration, m s^{-2}.

The change in potential energy of stratification per unit area over a period of time Δt equals the power per unit area available for mixing from equation [3].

$$\Delta Ps/(A\Delta t) = \rho_w(C_k u_f^3 + C^* u^{*3}) \quad \text{......................} [5]$$

The following constants are used:

Coefficient of thermal expansion of water, α,	$= 1.8 \times 10^{-4}$ per °C
Depth of mixed layer, h,	= 8 m
Gravitational acceleration, g,	$= 9.8$ m s^{-2}
Density of water	$= 1000$ kg m^{-3}
Specific heat of water, Cp,	$= 4182$ J kg^{-1} $°C^{-1}$

FIELD MEASUREMENTS AND METHODOLOGY

Vertical temperature, conductivity and salinity readings were made with a YSI Model 33 meter at a sampling frequency of once per month, using depth intervals of 0.5 to 1.0 m. Care was taken to clean the probe after each immersion in the monimolimnion, with an acidic isopropanol solution (10 parts distilled water to 10 parts isopropanol to 1 part concentrated HCl). The accuracy of temperature measurements was checked against a calibrating mercury thermometer (Fischer No. 822-793) and an appropriate adjustment made. The precision of temperature measurements was estimated at ± 0.2 °C and depended upon manual interpolation on the meter scale. The accuracy of conductivity measurements was checked against 0.01 M KCl solution and compared to a Radiometer conductivity meter (CDM 3) fitted with a Radiometer CDC 304 conductivity probe. The precision of conductivity measurements on the high range scale was estimated at ± 200 $\mu S\ cm^{-1}$.

Density was determined from the salinity readings from the YSI meter, using an oceanographic table which related density to salinity and temperature, Riley & Skirrow (1965). Calculations of density based on chemical composition and partial molal volumes, (MacIntyre & Melack 1982), showed very little difference between calculated density values and values estimated from seawater salinity tables. Thus the simpler approach, using the seawater density tables, was adopted.

During the summer and autumn of 1983, a data logger was operated at Mahoney Lake. Hourly measurements of wind velocity, water temperature at 4 depths (0,2,6,12 m) and air temperature were recorded by a Hymet package (Plassey recorder), positioned on a raft at mid-lake. Data collection commenced on 19th June, and terminated on 6th November. Water temperature measurements had an accuracy of ± 0.1 °C within the range 0 to 35 °C.

The data were downloaded onto a floppy disk at the National Water Research Institute, Burlington, Ontario, Canada. Daily averages of the data were calculated using a Fortran based computer programme, and the information was then transferred to a Lotus-123 spreadsheet for further processing. Wind measurements were made at 3 m above the water surface. Meteorological data for the complete study period were obtained from Penticton Airport station, 19 km north of Mahoney Lake, and were used to check on precipitation amounts during the study.

Bathymetric information for Mahoney Lake was taken from a contour map of the lake bed of scale 1:3000, with depth contours at intervals of 1 m. Areas were taken from the map with a Placom KP-90 digital planimeter. The area versus depth relationship is shown in Figure 2. Water surface levels relative to a bench mark on the lake shore were measured monthly.

The programme of field measurements enabled all the terms in equation 5 to be evaluated except the efficiencies. Data from the monthly field visits allowed the rate of change of potential energy of stratification to be found (left hand side of equation 5), and daily data on wind strengths and water temperatures were available from the data logger output and were used to determine the right hand side of equation 5, with assumed values for the efficiencies.

RESULTS

In order to obtain an average wind speed representative of the wind power, the sums of the cubes of the hourly wind speeds were computed, and divided by 24 to determine the daily average values of the wind speed cubed. Results are plotted in Figure 3. The difference in power between the windiest day (62 $m^3 s^{-3}$, $u = 3.96 m s^{-1}$) and the least windy day (0.3 $m^3 s^{-3}$, $u = 0.67 m s^{-1}$) is a very large factor (200 times). The average wind speed cubed for the whole period of record was 10.1 $m^3 s^{-3}$, that is $u =$ 2.17 $m s^{-1}$. This is a low value, indicating the winds are light at Mahoney Lake.

Hourly temperatures at depths of 0 and 2 m were noted to increase each afternoon with heat input from the sun by about ± 0.5 °C from the daily average temperature during the summer months. Daily averages of temperature of depths 0, 2, 6 and 12 m were calculated for the whole data set. Daily average temperature values of 0 and 2 m were found to be equal to one another within the measuring accuracy, and are plotted together (see Figure 4). The temperatures in the well-mixed 0 to 2 m layer are seen to maximize in early August. Temperature fluctuations of period about 4 to 5 days, corresponding with synoptic meteorological weather pattern time scales are seen in the surface layer data. Temperatures from 6 m depth are seen to maximize much later (about mid October), and temperatures from 12 m depth are shown to display no change.

Heat changes in the upper 8 m of the water column were calculated in order to determine the heat loss for the penetrative convection calculations. A temperature versus time profile for 4 m depth was first synthesized from the monthly temperature readings. Using the water volumes in each 2 m thick layer, the weighted average water temperature for the top 8 m of the water column was calculated for each day, and the daily change in temperature from the previous day listed. These temperature changes were converted to heat changes by multiplying by the depth times the specific heat of water, giving heat changes in J m^{-2} d^{-1}. The results were converted to units of W m^{-2} and are plotted in Figure 5. Note that only cooling changes are plotted. Changes associated with warming of the water column are shown as zero in Figure 5. The number of days when cooling occurred is small up to mid August, after which the number of days of cooling is large. The bursts of cooling during 4 to 5 day synoptic cycles show up well in Figure 5. Several days when the cooling was at least 150 W m^{-2} are shown. This value, equal to 3.6 kWh m^{-2} d^{-1} is significant when compared to the incoming energy from solar radiation on a bright, sunny day (7 kWh m^{-2} d^{-1}). During mid August to mid September, the time of maximum cooling, the average daily value was 55 W m^{-2}.

Using the monthly data from the manual (YSI meter) readings, values of density were computed from the readings of temperature and salinity. Field data were collected at approximately mid-month, and results for June 18, July 17, August 11, September 16, October 16 and November 18 are plotted (see Figure 6). As the depth of peak water temperatures works its way downwards in the water column, the destabilizating effects of warmer water underlying cooler water causes significant mixing of relatively fresh surface water into the relatively saline water in the 2.5 to 8 m range. This is the period of the main annual mixing events in the lake. The reduction in the size of the density step at 2.5 m between August 11 and October 18 is readily seen in Figure 6.

This reduction in the density step is equivalent to a major reduction in potential energy of stratification.

No significant changes in temperature or salinity were observed during the duration of the study below 8 m depth. the integration of equation 4 was thus evaluated for the range 0 to 8 m depth, for each of the 6 monthly data sets. Values for density were first computed from the temperature and salinity. The integral given in equation 4 was determined by step-wise integration, using 0.5 meter deep layers, and an area versus depth curve (Figure 2) for Mahoney Lake.

During the period of the study, the water surface height decreased between June 18 and October 18 by a negligile amount (0.11 m) and thus corrections for changing water surface levels were unnecessary. Values for the potential energy of stratification for the 0 to 8 m layer, in megajoules (MJ) are plotted, see Figure 7. An overall decrease of 37 MJ of potential energy of stratification during a four month period is noted, with the most significant decrease occurring between August 11 and October 18.

EFFICIENCY CALCULATIONS

For the analysis of the efficiency of utilization of energy for mixing, weekly averages of the daily wind speeds cubed (Figure 3 data) and of the cooling (Figure 5 data) were calculated. Results are given in Table 1. Work by previous researchers on wind mixing is normally referenced to the wind speed at 10 m above the ground. Logarithmic relationships (Large & Pond 1981) and power relationships (Canadian National Research Council, 1977) have been used to describe wind speed profiles. Judgement is involved in deciding on representative roughness conditions.

The ratio of the wind speed at 3 m above ground surface to the wind speed at 10 m was calculated using a). the power law distribution for open conditions and b). the logarithmic distribution for roughness height of 0.02 m. Results for the wind speed ratio were 0.84 and 0.80 respectively. An average value of 0.82 was assumed for the wind speed ratio, so that the wind measurements at Mahoney Lake must be divided by the factor 0.82 cubed (=0.55) for wind energy utilization comparisons. This is done in Table 1. The contribution of wind mixing to total mixing, listed in the final column of Table 1, is in the range 10% to about 60%. The 19-week average values of the wind and convective cooling data listed at the bottom of Table 1 show that the overall contribution of wind mixing to total mixing is small (about one quarter). The results of balancing equation 5 using trial and error values for the efficiency factors C^* (wind) and C_k (penetrative convection) are insensitive to the assumed values for C^*, but sensitive to the assumed values of C_k.

With an efficiency of wind energy utilization taken from previous work ($C^*= 0.23$ was used), the efficiency of utilization of penetrative convection energy, C_k, may be determined using equation 5. Adjustments were made to the value of C_k, and the right hand side of equation 5 evaluated, until there was agreement with the rate of loss of potential energy of stratification (left hand side of equation 5). With a wind speed ratio u3/u10 of 0.82, a good match was determined with $C_k = 0.20$. The result of this matching is shown in Figure 7. A mean area of 110,000 m^2 was assumed for the part of the lake between 0 and 8 m below the surface. If the whole surface area of the lake were used for the calculation, then the value of C_k would be smaller and close to previously published results.

SUMMARY AND CONCLUSIONS

During the year selected for the intensive field work (1983), Mahoney Lake had received two years of above average spring run-off events (Northcote & Hall, MS). This caused the upper 2 m of the lake to be of much lower salinity than the rest of the lake, and of lower salinity than in preceding or succeeding years. The well developed stratification offered a good opportunity to observe mixing mechanisms.

Monthly data on salinities and hourly data on winds and temperatures were taken during the summer and autumn months. Winds were found to be light nearly all the time, with the variation in wind energy between the windiest and least windy days equal to several orders of magnitude. Values of the potential energy of stratification were calculated by integrating the density profile of the lake in one half meter thick increments. The loss of potential energy of stratification during the late summer and autumn was found to be mainly due to mixing from penetrative convection. Wind driven mixing during this period was minor. the efficiency factor for penetrative convection, C_k, based on the cube of the velocity of the falling thermals, was found to be equal to 0.20. This was larger then previously published values. No allowance was made for the input of sources of buoyancy (from ground water supplies to the lake, or bursts of occasional warming). If these were significant, then the value of C_k, would have been larger than calculated.

ACKNOWLEDGEMENTS

We would like to thank M. Mawhinney of the Tech. Operations Branch at the National Water Research Institute, Burlington for assistance in setting up the meteorological station.

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TABLE 1. Monthly Average Wind and Convective Cooling Data

Period	Wind Speed Cubed at 3 m	Wind Speed Cubed at 10 m	Shear Velocity Cubed[1]	Heat Loss by Cooling per Unit Area	Vel. of Falling Plumes[2]	Vel. Cubed of Falling Plumes	Rate of Change of Potential Energy[3]			Ratio of Wind mixing to Total
							Wind mixing	Conv. mixing	Total	
	$m^3\ s^{-3}$	$m^3\ s^{-3}$	$m^3\ s^{-3}$ $\times 10^{-6}$	$W\ m^{-2}$	$m\ s^{-1}$	$m^3\ s^{-3}$ $\times 10^{-6}$	$Jm^{-2}d^{-1}$	$Jm^{-2}d^{-1}$	$Jm^{-2}d^{-1}$	
June 20 – 26	6.73	12.2	0.0218	7.9	0.0030	0.027	0.43	0.46	0.89	0.49
27 – July 3	10.82	19.6	0.0350	44.9	0.0053	0.152	0.70	2.62	3.31	0.21
July 4 – 10	8.80	16.0	0.0284	28.6	0.0046	0.096	0.57	1.67	2.23	0.25
11 – 17	21.10	38.3	0.0682	11.1	0.0033	0.038	1.36	0.65	2.00	0.68
18 – 24	5.67	10.3	0.0183	12.1	0.0034	0.041	0.36	0.70	1.07	0.34
25 – 31	5.92	10.7	0.0191	38.1	0.0050	0.129	0.38	2.22	2.60	0.15
Aug. 1 – 7	11.56	21.0	0.0374	8.4	0.0031	0.028	0.74	0.49	1.23	0.60
8 – 14	8.82	16.0	0.0285	27.9	0.0046	0.094	0.57	1.63	2.19	0.26
15 – 21	16.95	30.7	0.0548	63.3	0.0060	0.214	1.09	3.69	4.78	0.23
22 – 28	11.03	20.0	0.0357	35.7	0.0049	0.120	0.71	2.08	2.79	0.25
29 – Sept. 4	5.60	10.2	0.0181	41.4	0.0052	0.140	0.36	2.41	2.77	0.13
Sept. 5 – 11	11.47	20.8	0.0371	99.2	0.0069	0.335	0.74	5.79	6.52	0.11
12 – 18	9.99	18.1	0.0323	44.5	0.0053	0.150	0.64	2.60	3.24	0.20
19 – 25	7.86	14.3	0.0254	38.5	0.0051	0.130	0.50	2.25	2.75	0.18
26 – Oct. 2	12.09	21.9	0.0391	91.5	0.0068	0.309	0.78	5.33	6.11	0.13
Oct. 3 – 9	13.23	24.0	0.0428	34.5	0.0049	0.116	0.85	2.01	2.86	0.30
10 – 16	3.34	6.1	0.0108	36.4	0.0050	0.123	0.21	2.13	2.34	0.09
17 – 23	10.78	19.6	0.0348	13.2	0.0035	0.044	0.69	0.77	1.46	0.47
24 – 30	10.98	19.9	0.0355	41.5	0.0052	0.140	0.71	2.42	3.13	0.23
19 WEEK AVERAGES	10.14	18.4	0.0328	37.8	0.0048	0.128	0.65	2.21	2.86	0.28

C* = 0.23
Ck = 0.20
Wind speed ratio 0.82 [u3/u10]

[1] calculated from equation 2
[2] calculated from equation 1
[3] calculated from equation 3

LIST OF FIGURES

Ward et al. "Autumnal Mixing in Mahoney Lake, British Columbia".

Fig 1

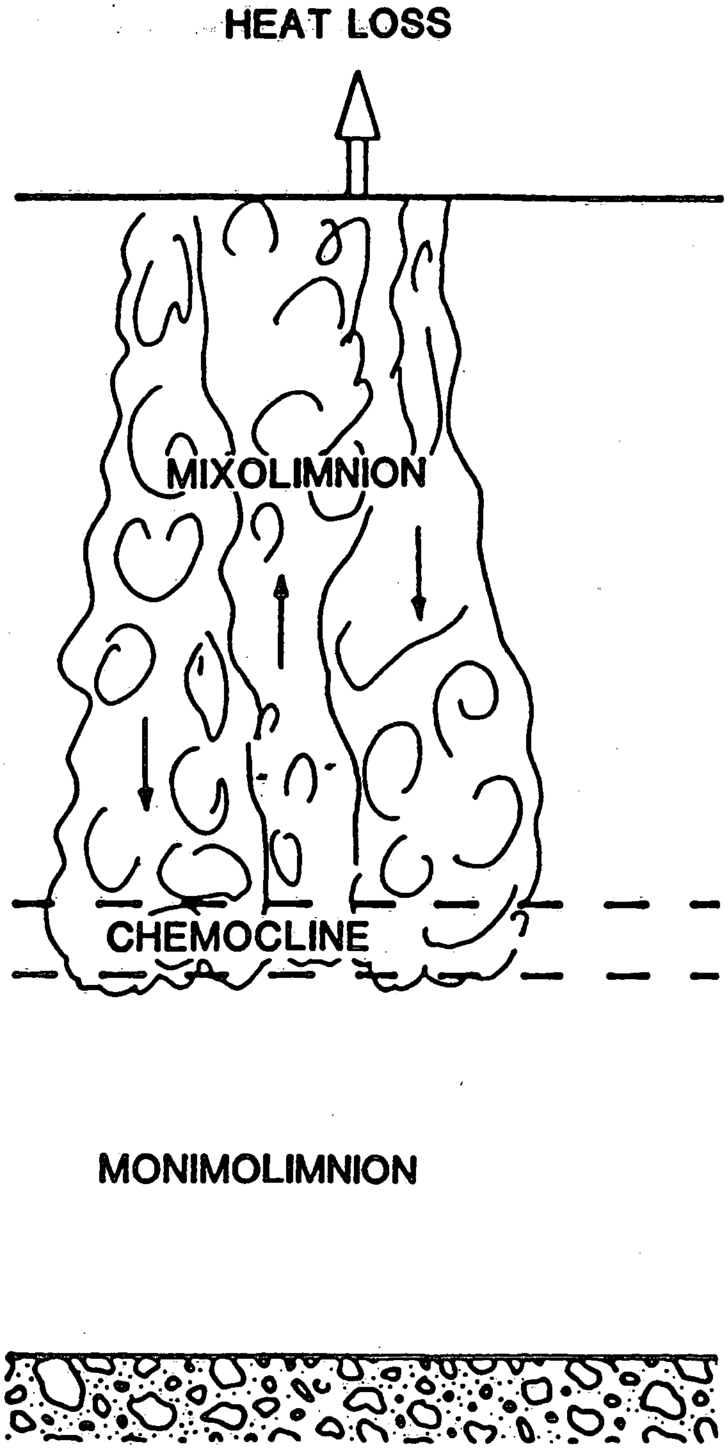

Fig 2

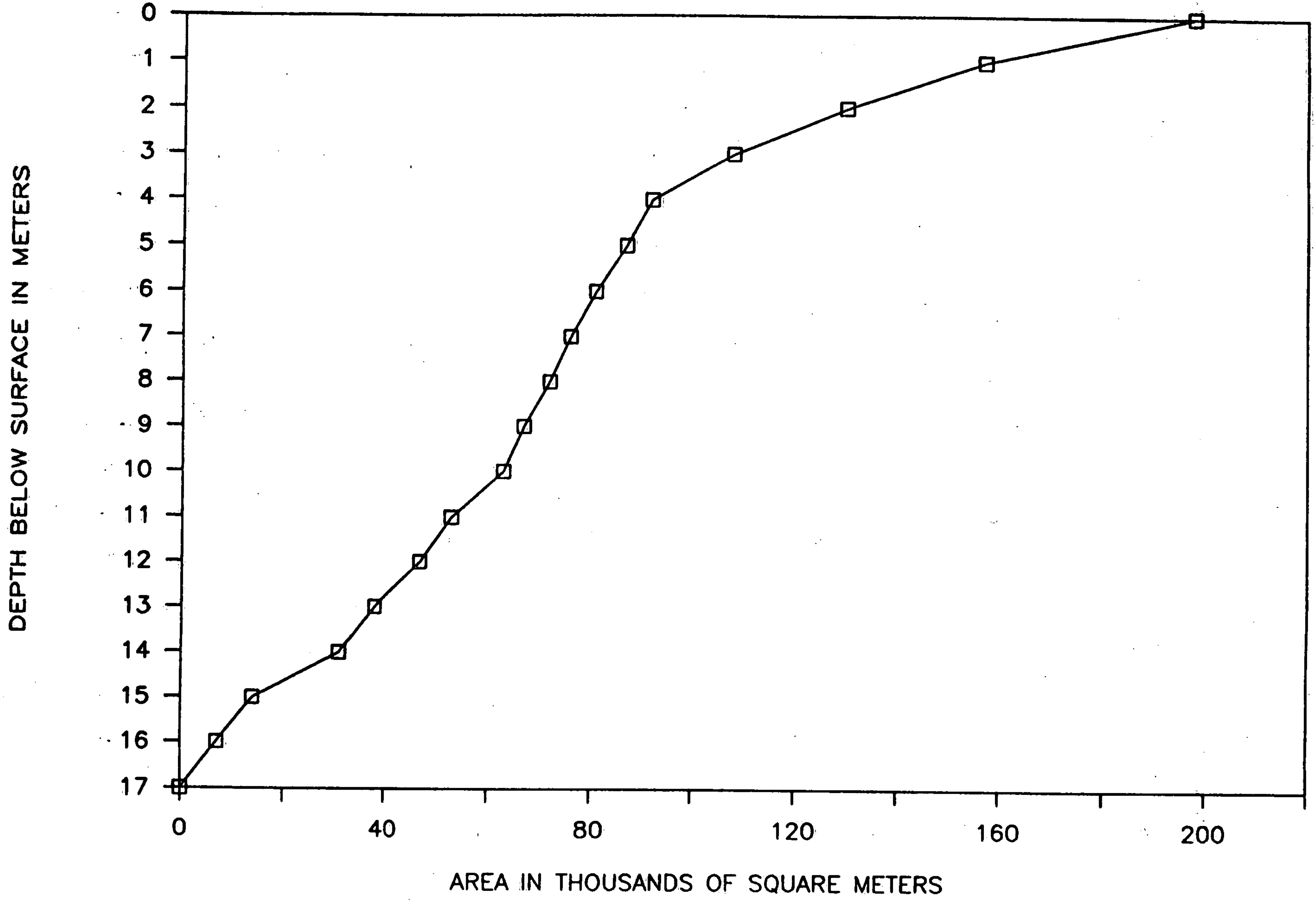
DEPTH BELOW SURFACE IN METERS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
0
40
80
120
160
200
AREA IN THOUSANDS OF SQUARE METERS

FIG. 2

Fig 3

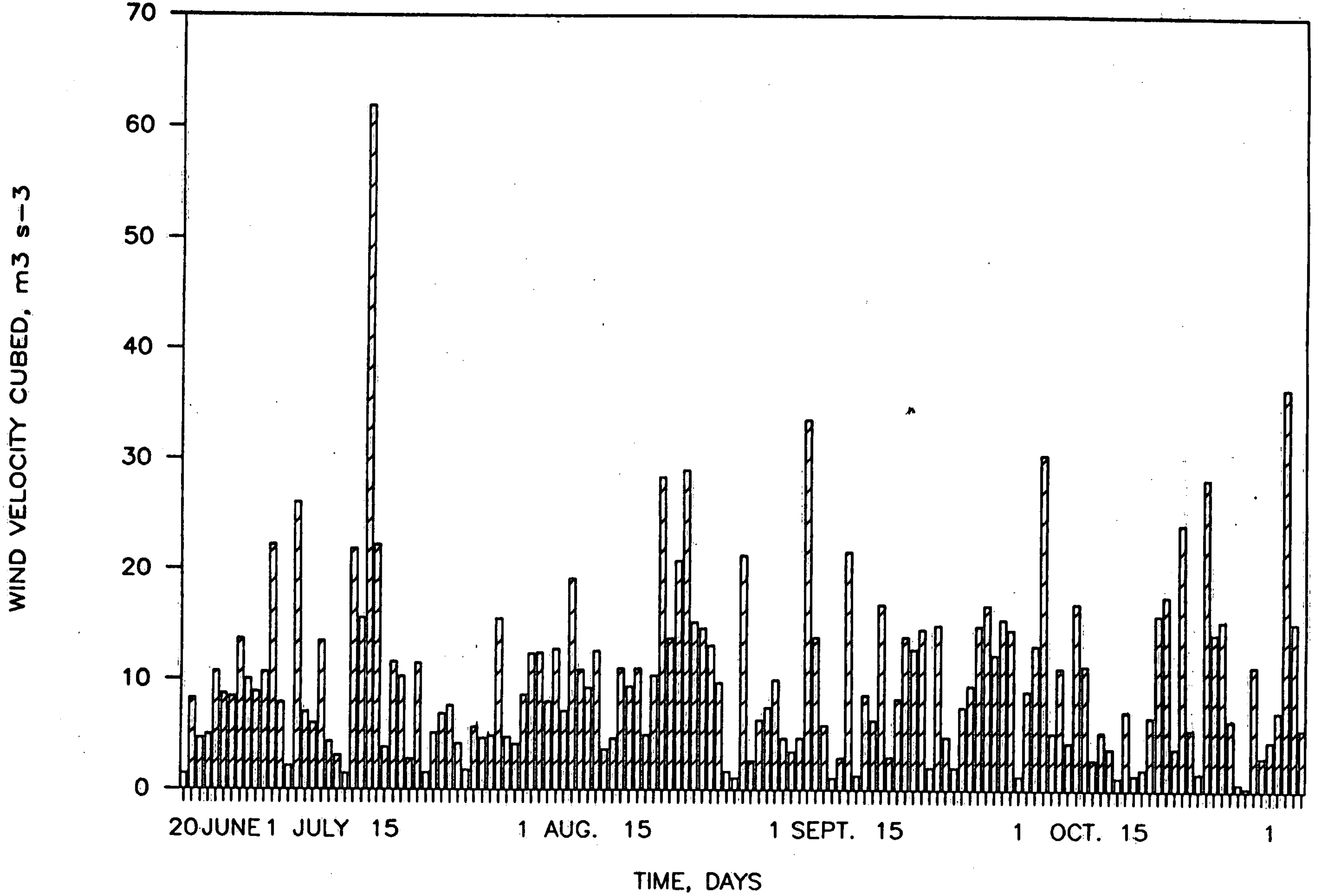
70
60
50
40
30
20
10
0
WIND VELOCITY CUBED, m3 s−3
20JUNE 1 JULY 15
1 AUG. 15
1 SEPT. 15
1 OCT. 15
1
TIME, DAYS

Fig. 3

Fig

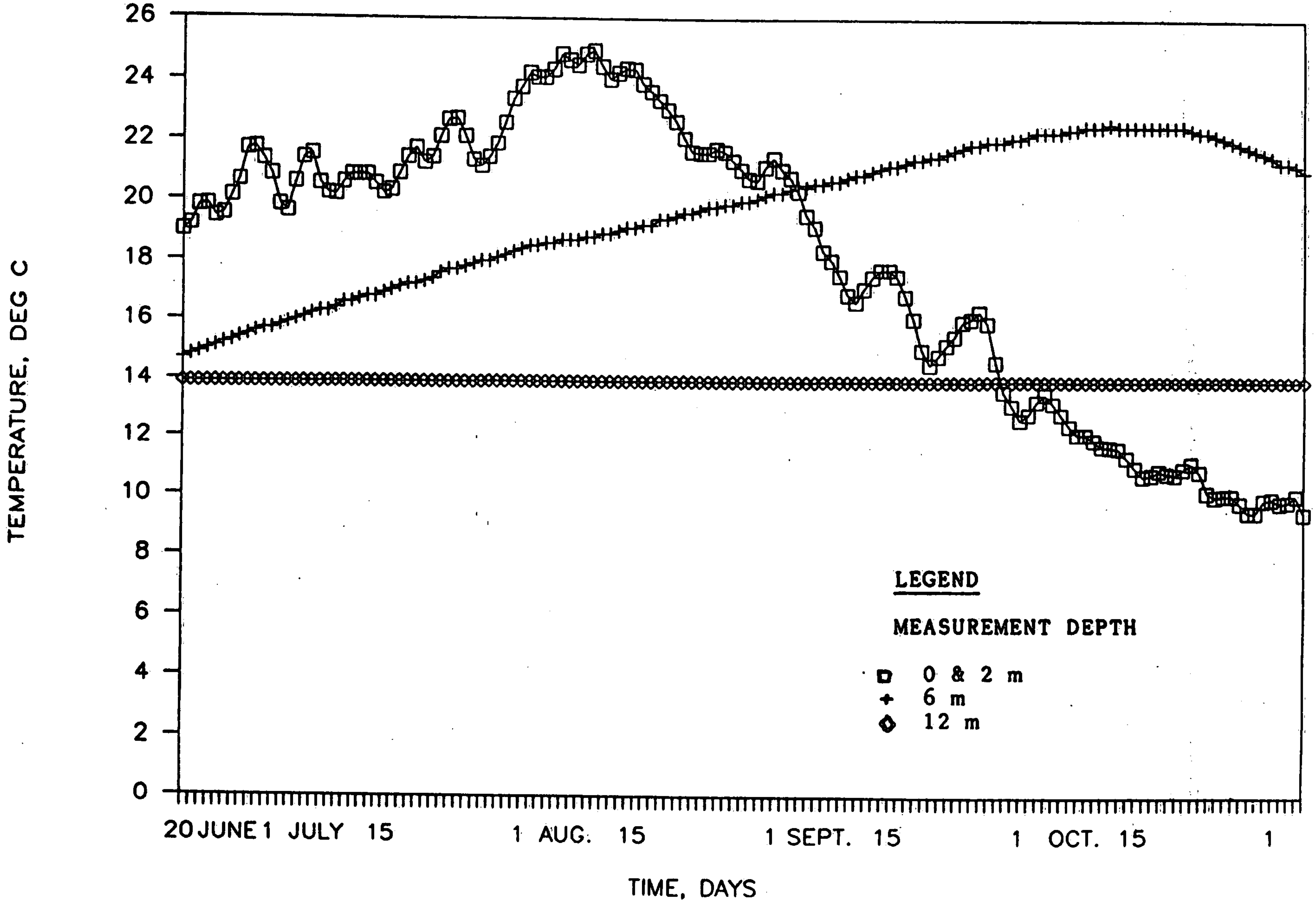
26
24
22
20
18
16
14
12
10
8
6
4
2
0
TEMPERATURE, DEG C
20 JUNE 1 JULY 15
1 AUG. 15
1 SEPT. 15
1 OCT. 15
1
TIME, DAYS
LEGEND
MEASUREMENT DEPTH
◻ 0 & 2 m
+ 6 m
◇ 12 m

Fig. 4

Fig

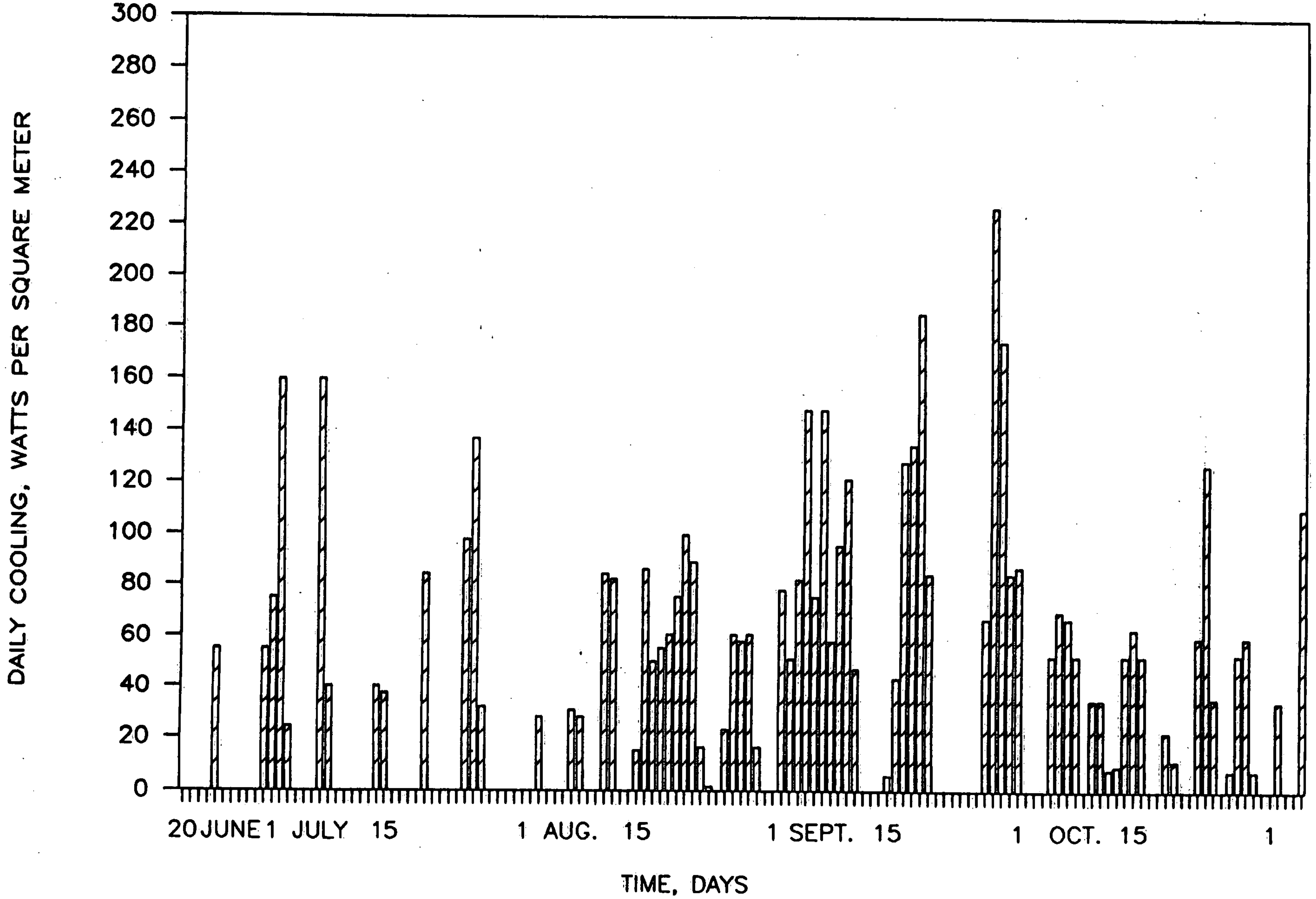
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
DAILY COOLING, WATTS PER SQUARE METER
20 JUNE 1 JULY 15
1 AUG. 15
1 SEPT. 15
1 OCT. 15
1
TIME, DAYS

Fig. 5

Fig 6

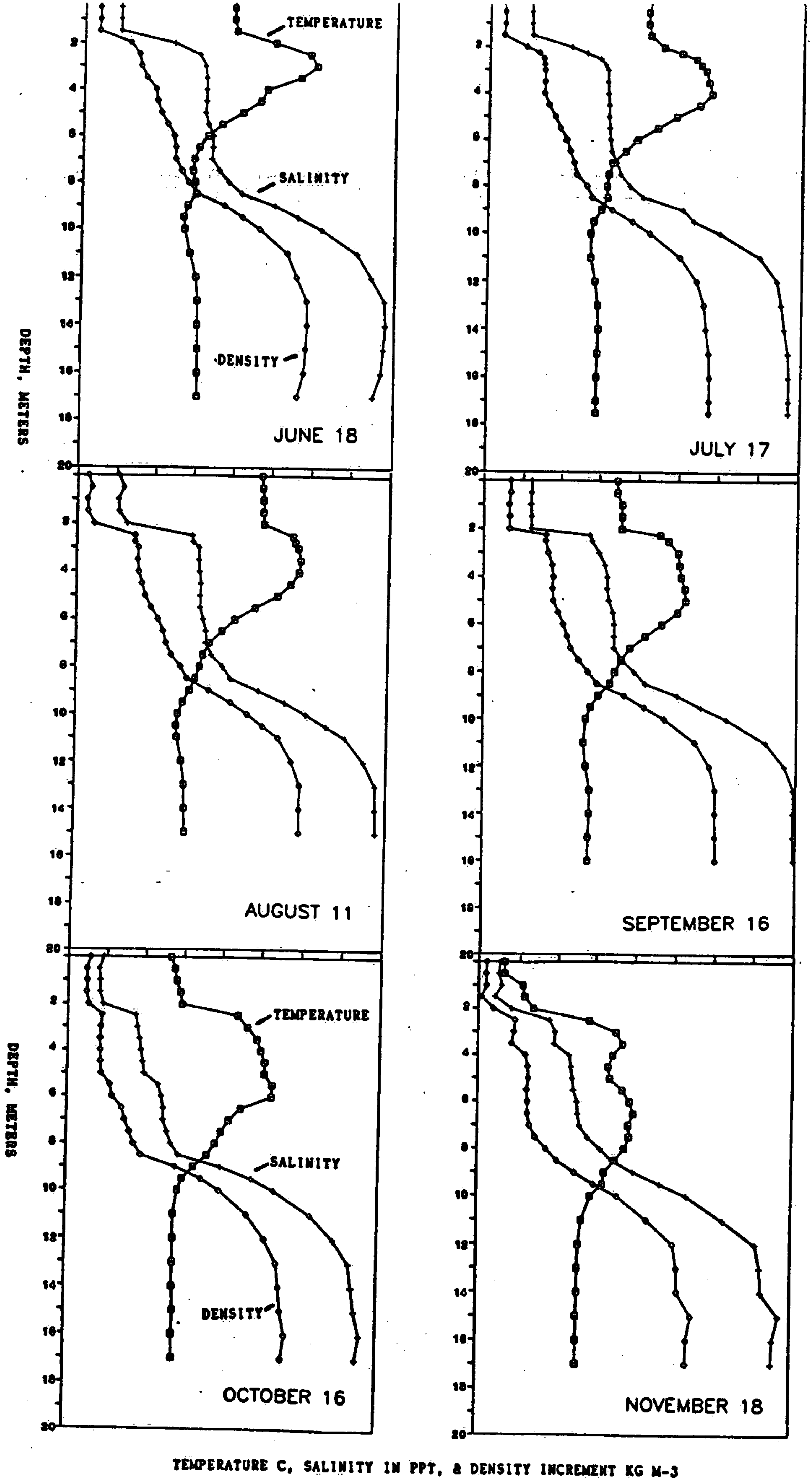
TEMPERATURE
SALINITY
DENSITY
DEPTH, METERS
2
4
6
8
10
12
14
16
18
20
JUNE 18
JULY 17
AUGUST 11
SEPTEMBER 16
OCTOBER 16
NOVEMBER 18
TEMPERATURE C, SALINITY IN PPT, & DENSITY INCREMENT KG M-3

Fig 7

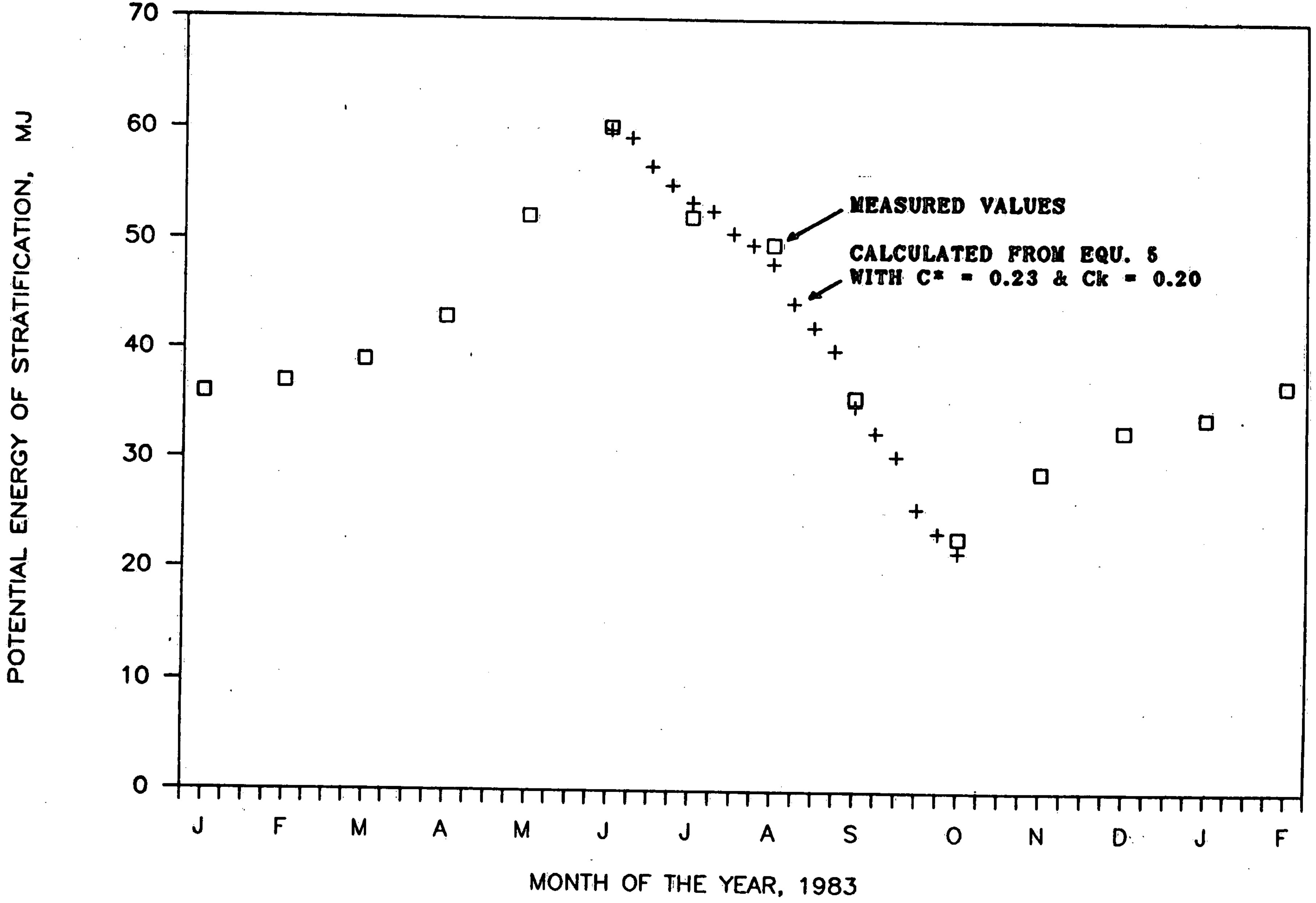
POTENTIAL ENERGY OF STRATIFICATION, MJ
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
J
F
MONTH OF THE YEAR, 1983
MEASURED VALUES
CALCULATED FROM EQU. 5
WITH C* = 0.23 & Ck = 0.20

Fig.7