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A Simple Colour Meter for Limnological Studies

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Abstract

A simple *in situ* irradiance meter for objective measurement of water colour has been designed and built by the Remote Sensing Section at CCIW. The principle of the instrument is to measure the upwelling natural irradiance close to the surface at two selected wavelengths and express these as a ratio or colour index. Experiments carried out with this instrumentation in Lake Superior have shown that the colour indices can be used as water-mass tracers with midlake and near-shore regions being clearly identified. Results also show that the colour indices provide a useful measurement of the relative turbidity characteristics of large lakes.

Résumé

Un appareil simple servant à mesurer de façon objective et à l'endroit même le rayonnement de la couleur de l'eau a été conçu et fabriqué par la Section de la télédétection du Centre canadien des eaux intérieures. Le principe de cet instrument est de mesurer les rayonnements naturels en soulèvement près de la surface de l'eau à deux longueurs d'onde différentes et de les exprimer sous forme de rapport ou d'indice de la couleur. Les expériences qui ont été faites avec cet appareil au lac Supérieur ont montré que les indices de la couleur peuvent servir de traceurs de masse d'eau permettant d'identifier clairement les régions du milieu du lac et près de la rive. Les résultats montrent aussi que les indices de la couleur sont utiles pour mesurer les caractéristiques de turbidité relative des grands lacs.

A Simple Colour Meter for Limnological Studies

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INTRODUCTION

It has been shown by a number of workers (e.g., Clarke, Ewing and Lorenzen, 1970) that variations in the blue/green radiance ratio of back-scattered light from the sea are related to chlorophyll content and hence primary productivity. Owing to the selective absorption of particles and yellow substance, the natural trend of colour changes in oceans and lakes is a shift from blue to green to red as one goes from clear to more turbid waters.

A simplified technique for characterizing the colour of the water is to measure, *in situ,* the upwelling radiance at two wavelengths and express these as a ratio or colour index. Systematic measurements in ocean waters with a simple meter based on this concept, have been carried out by Lundgren and Højerslev (1971). At a recent symposium "Optical Aspects of Oceanography" held in Copenhagen, in June 1972, Jerlov described a series of measurements in the Mediterranean with this same meter. Some important properties of the colour index reported by Jerlov (1972) and others are:

(1) for sun elevations greater than 15° the effect of solar elevation is not important,
(2) the index is measured best at depths of between 0 and 2 metres, and
(3) the effects of clouds on the colour index are usually small with observed changes in the index being less than 10%.

During a series of optical experiments in Lake Ontario in 1972 (Thomson and Jerome, 1974), some preliminary measurements of the colour index were obtained by measuring the upwelling light field with an *in situ* spectrograph (Incentives AB quanta spectrometer). These measurements verified the basic properties of the index previously outlined in points 1, 2 and 3.

As a result of these measurements, a simple colour index meter was designed and constructed during the winter of 1972-73 and a series of measurements was carried out using this instrument during the 1973 Lake Superior surveillance program.

This report describes the colour index meter and discusses in detail the interpretation of the data obtained during the field program.

COLOUR INDEX METER

The colour index meter is composed of three separate channels, each sensitive to a different portion of the visible spectrum. Each channel has its own aperture, collimating tube, filter and detector. An amplifier for each channel has been built into the instrument head to amplify the outputs of the detectors before they are transmitted to the deck unit. The watertight head has a depth capability of 10 metres and is weighted so that when lowered into the water the apertures face directly downward. A detailed drawing of the instrument head and one channel is shown in Figure 1.

Light enters each channel through a clear plexiglass cover and passes down the collimating tube. At the end of the tube an interference filter and photocell are mounted. The interference filter, selected for its wavelength of peak transmission, transmits the incident radiation within a 10 nm band of the chosen wavelength to the photocell. The collimating tube limits the angle of incidence of the radiation reaching the filter to less than 15°. This minimizes the shift in the peak transmission wavelength of the filter resulting from oblique incident radiation. The specifications of the filters used in the colour meter are given in Table 1. The radiation passing through the filter is detected by a selenium photocell. The output of the photocell is amplified and transmitted to the surface through the connecting cable. Preamplification reduces the effect of noise introduced to the signal during transmission.

Table 1. Filters Used in Colour Meter

Wavelength at peak transmission	Peak transmission
458 nm	41%
508 nm	37%
553 nm	36%

The instrument is calibrated by placing, sequentially, the aperture of each channel at a 1-metre distance from a quartz iodine standard lamp. The calibration enables the output of each channel to be expressed in $\mu W/cm^2$. During calibration a check of the linearity of the instrument was carried out by varying the distance from the standard source. The response of the meter was found to be linear over the expected range of operation (Fig. 2).

The principal component of the electronics (Fig. 3) is a Burr-Brown chopper amplifier, Type 3480K, chosen for its

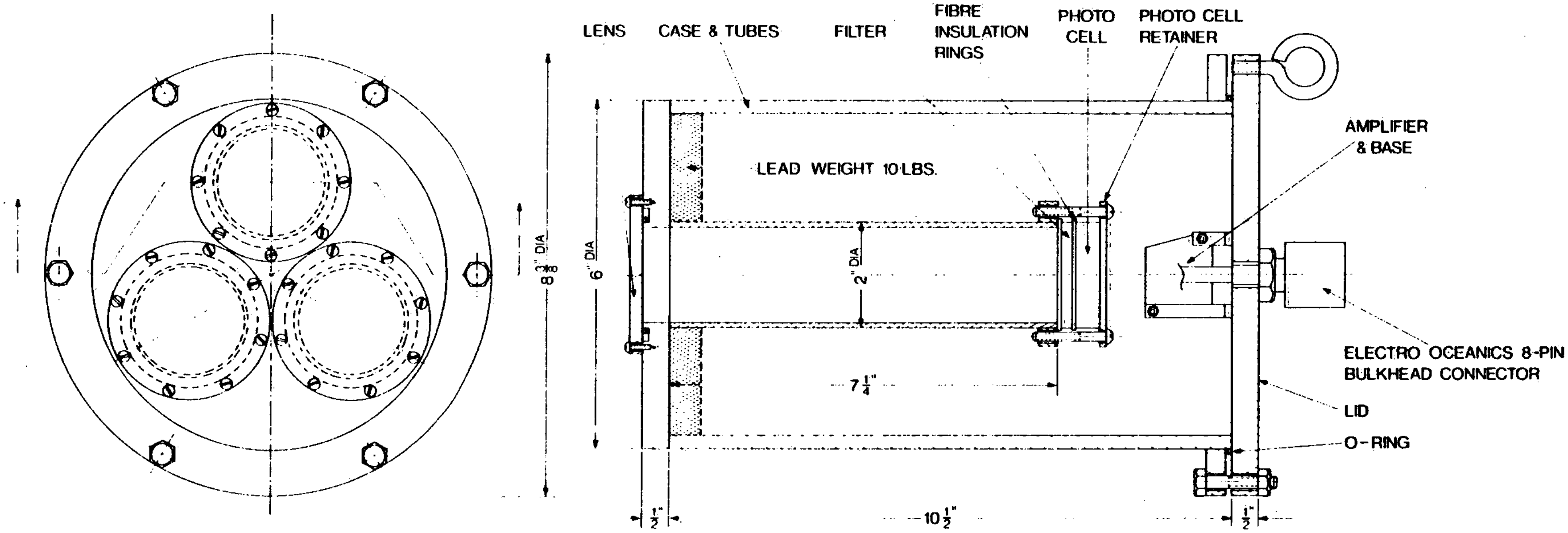


Figure 1. A detailed drawing of the colour index meter.

low noise and low temperature drift specifications (specifications are listed in Burr-Brown applications note no. PDS-251A). The amplifier gain is 2000 for each channel and is linear over the range 10 µv to 5 mv RTI. The frequency compensation capacitor value, chosen to have a bandwidth of 0.5 Hz, gives an input noise figure of 0.4 µv P-P. To minimize the ±5 µv/v offset because of battery voltage, a simple Zener regulator circuit is used to regulate both the positive and negative voltage rails to 10 volts. The maximum offset owing to all causes is in the order of 1.5 µv RTI, and the minimum detectable signal is in the order of one µv. The results of a typical temperature check are shown in Table 2.

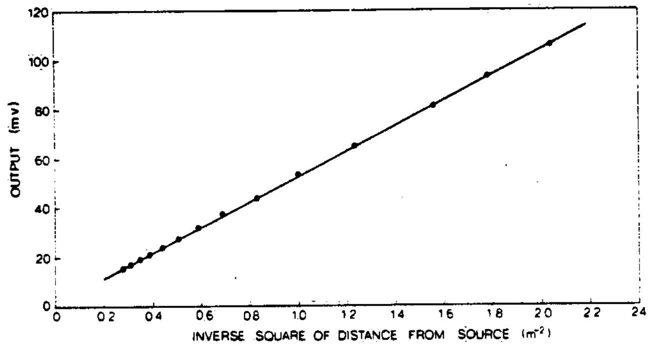


Figure 2. Linearity check of colour meter over standard output range.

The instrument is basically self-contained, light and easy to operate. Since it is battery-operated, it can be used from a small launch. A photograph of the complete prototype instrument is shown in Figure 4.

DISCUSSION OF RESULTS

Lake Ontario, 1972

As stated in the Introduction, the preliminary measurements carried out in 1972 were made using a spectrograph (Incentives AB quanta meter) as the means of measuring the upwelling light field.

In this series of measurements two indices were investigated:

$$K1 = \frac{I\ (450\ \text{nm})}{I\ (520\ \text{nm})} \qquad (1)$$

$$K2 = \frac{I\ (560\ \text{nm})}{I\ (520\ \text{nm})} \qquad (2)$$

where I is the upwelling irradiance at a specific wavelength.

Figure 5 shows the variation of K1 and K2 as a function of time of day and verifies observations made by other workers (Jerlov, 1972).

Figures 6a and 6b show the monthly values of K1 and K2, respectively, from July to October where the following trends were observed. For K1:

(1) decreasing from July to September,
(2) increasing from September to October, and
(3) a general increase from July to October.

For K2:

(1) no change from July to September and
(2) decreasing from September to October.

The highest values of K1 were found at midlake stations in July and at near-shore stations in September. For K2 the highest values occurred at near-shore stations for all of the months.

These preliminary assessments of the colour index data indicated clearly that the measurements could make an important contribution to a Great Lakes water quality monitoring program.

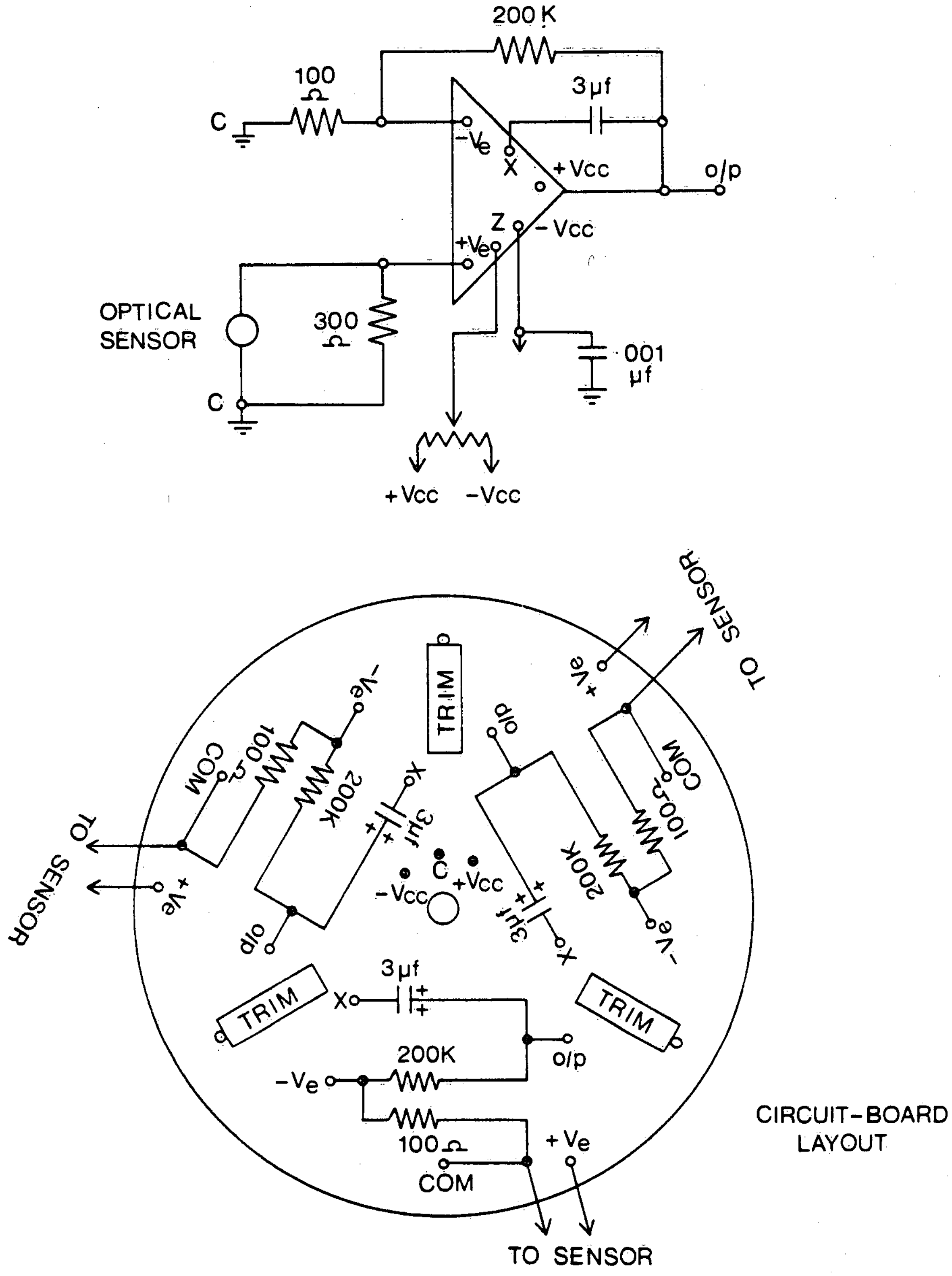
It was also evident that errors inherent in calculating the indices from the spectrometer traces were larger than desirable (in the order 10-20%). Unless these errors were reduced, it would be possible only to consider trends in these parameters.

To measure the indices more directly it was decided that the simple meter described previously be constructed and used during the 1973 Lake Superior study.

Table 2. Water-Bath Temperature Check

	Channel			
Temperature °C	Blue	Green	Red	
20°C	1.1 mv	0.2 mv	1.6 mv	*RTO
	0.55 µv	0.1 µv	0.8 µv	*RTI
8°C	2.0 mv	3.8 mv	2.2 mv	RTO
	1.0 µv	1.9 µv	1.1 µv	RTI

*RTO = referred to output
*RTI = referred to input
The temperature specifications listed by Burr-Brown are 0.1 µv/°C RTI.



ALL RESISTORS 0.01 %
5 PPM/°C

Figure 3. Circuit diagram for the colour index meter.

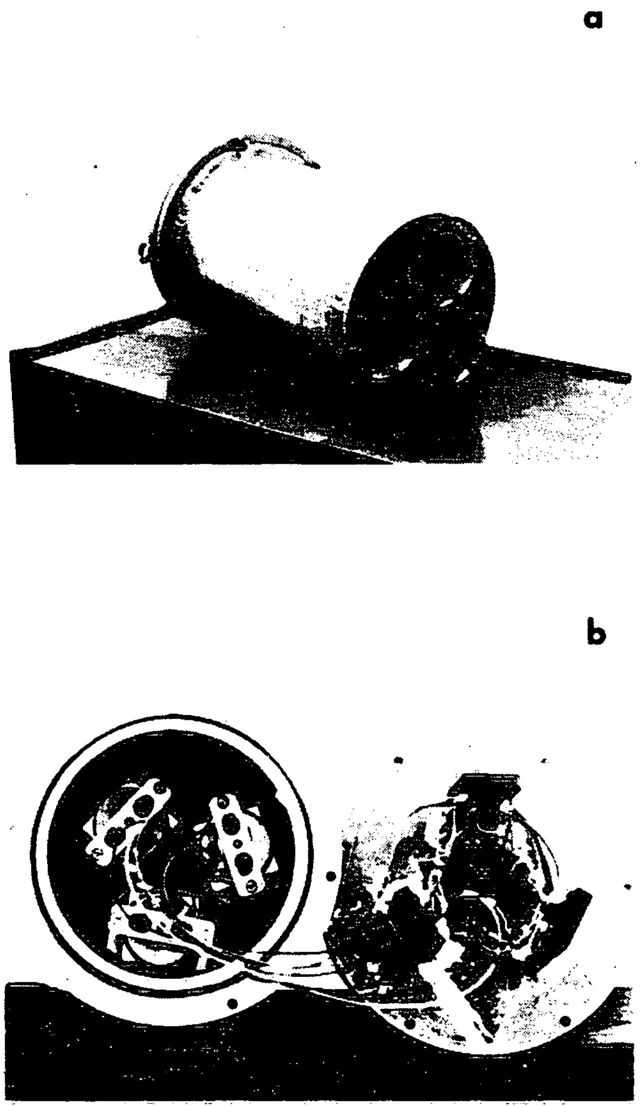


Figure 4. Colour index meter (a) view showing apertures in watertight casing and (b) interior view of photocell and filter mountings.

Lake Superior, 1973

Colour indices K1 and K2, taken at Lake Superior stations during June, July and September, are shown in Figures 7-9 (Table 1 indicates wavelengths used to determine K1 and K2). Transmissometer data from each cruise were also used as a check on the continuity of the individual data points. All the colour index data points shown in Figures 7, 8 and 9 are for solar elevations greater than 15 degrees. The colour index values for the June cruise were obtained using the quanta spectrometer and are shown here for continuity. The data for July and September were obtained with the colour index meter.

The general variations in both indices for any one month show clearly the change from the more turbid coastal regions to the clearer midlake waters. The main turbid areas of the Lake are clearly identified by both indices. For example, the largest gradients for both K1 and K2 are observed in the Duluth, Thunder Bay, and Whitefish Bay areas (Fig. 10). At specific times, turbidity gradients can be identified at other locations such as Marathon in July and September, and Nipigon Bay in September.

The values of K1 at 1-metre depths, range from 0.1-0.3 in very turbid water to 0.7-0.9 in midlake water. The highest values of K1 were observed during the June cruise (Fig. 7) at midlake stations.

The values of K2 cover the range from 3.0 in extremely turbid water to 0.7-0.8 in clear midlake water. In general, the values of K2 in the Duluth area cover the range 1.5-2.5. Consistent with the behaviour of K1 the lowest observed values of K2 also occurred in June at midlake stations.

The behaviour of both K1 and K2 shows clearly the changes in the water masses that occur over the period June – September. During June there is a narrow band of turbid water around the shore of the Lake. The main water body of the Lake is relatively clear with optical transmittance in the order of 70-80% (referred to a clear air path). The values of K1 are 0.6-0.9 and K2, 0.9-0.8, in this water mass. The large area of clear water, evident on the June charts, gradually decreases through the period June to September. The values of K1 and K2 are of course dependent on the back-scattering properties of the water mass in question. In water with very little suspended and/or dissolved substances the back-scattering is low and the blue region of the spectrum has a high penetration. Thus the upwelling light has a strong blue component. Hence we would expect high values of the index K1 and low values of the index K2 in clear midlake areas. Two areas that remain relatively low in back-scattering throughout the observation period are the north-east midlake areas and the eastern basin outside of Whitefish Bay.

Variations of Colour Index with Chlorophyll and Suspended Sediment

One of the principal objectives in undertaking this investigation was to examine how the indices relate to the chlorophyll content, and productivity in general. On examination, the correlation between the chlorophyll values for Lake Superior and K1 and K2 was low for all months with the possible exception of June (Fig. 11).

Although the correlations were poor, the K2 values appeared to have consistently stronger correlation than K1. This effect was expected since the observed shift in the peak transmission (Thomson and Jerome, 1974) tends to the wavelength range 550-560 nm as the chlorophyll content increases. Hence an increase in chlorophyll should

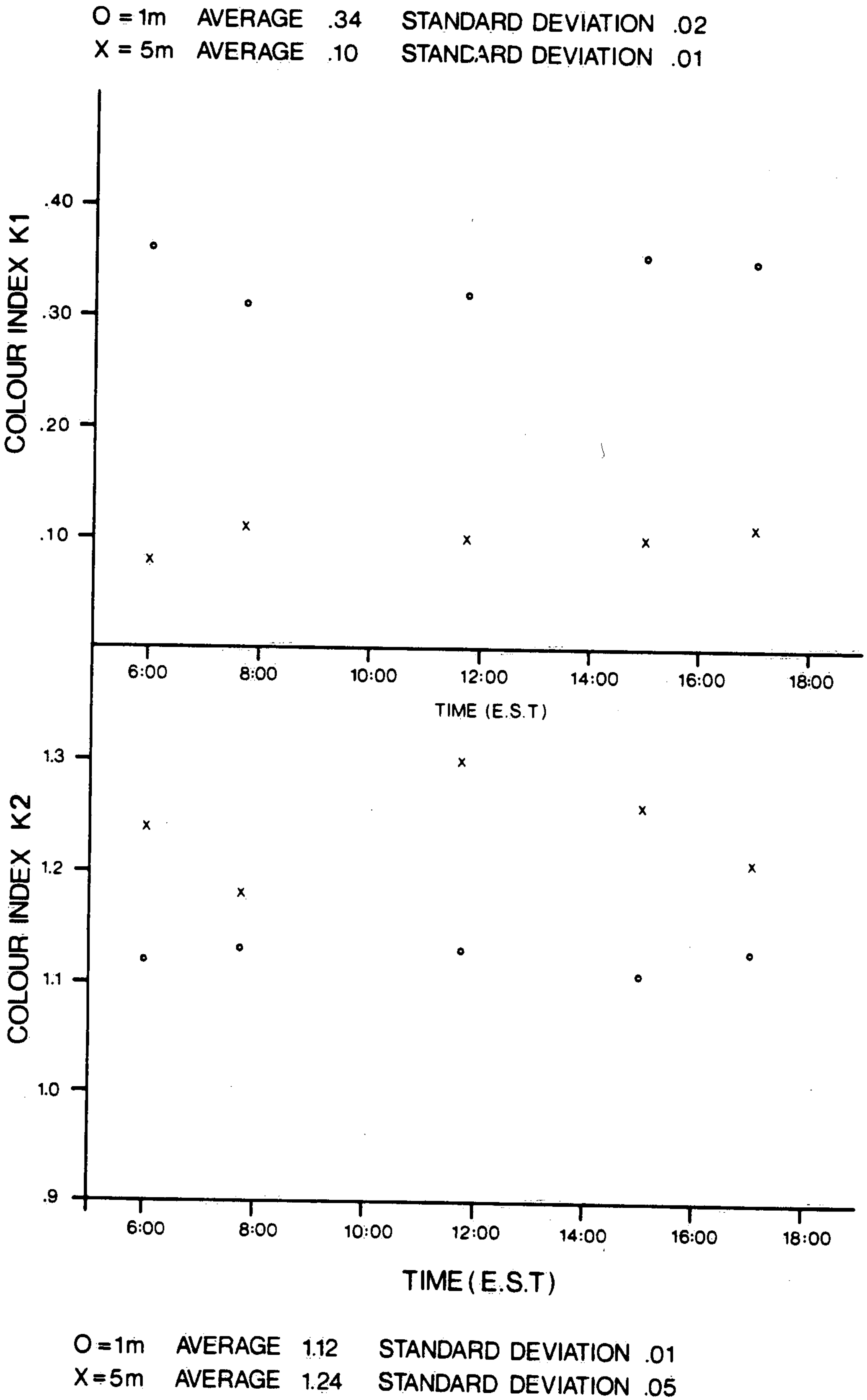


Figure 5. Variation of the colour indices K1 and K2 over one daylight period.

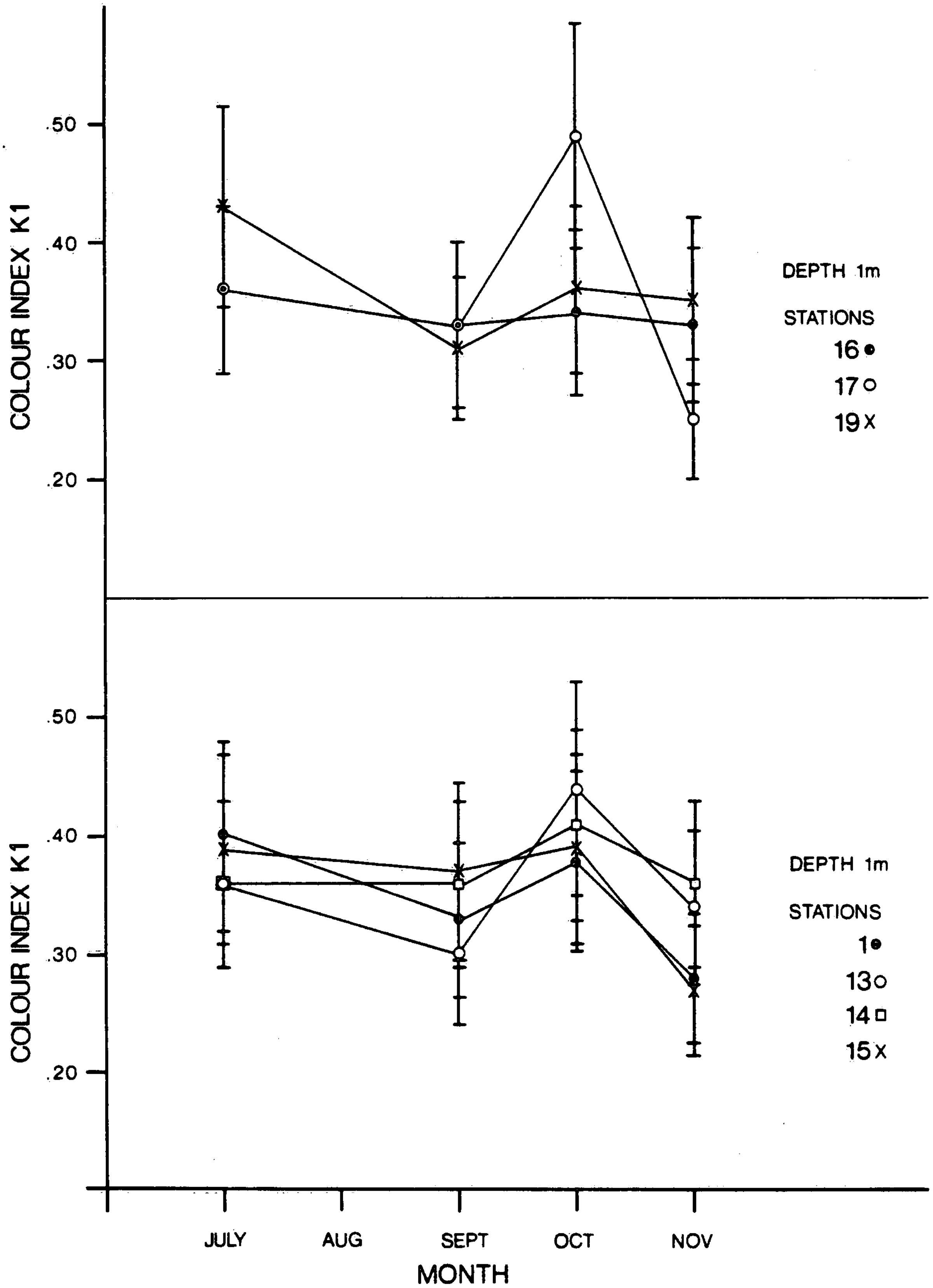


Figure 6a. Temporal variation of colour index K1 for Lake Ontario. The bars represent total estimated error.

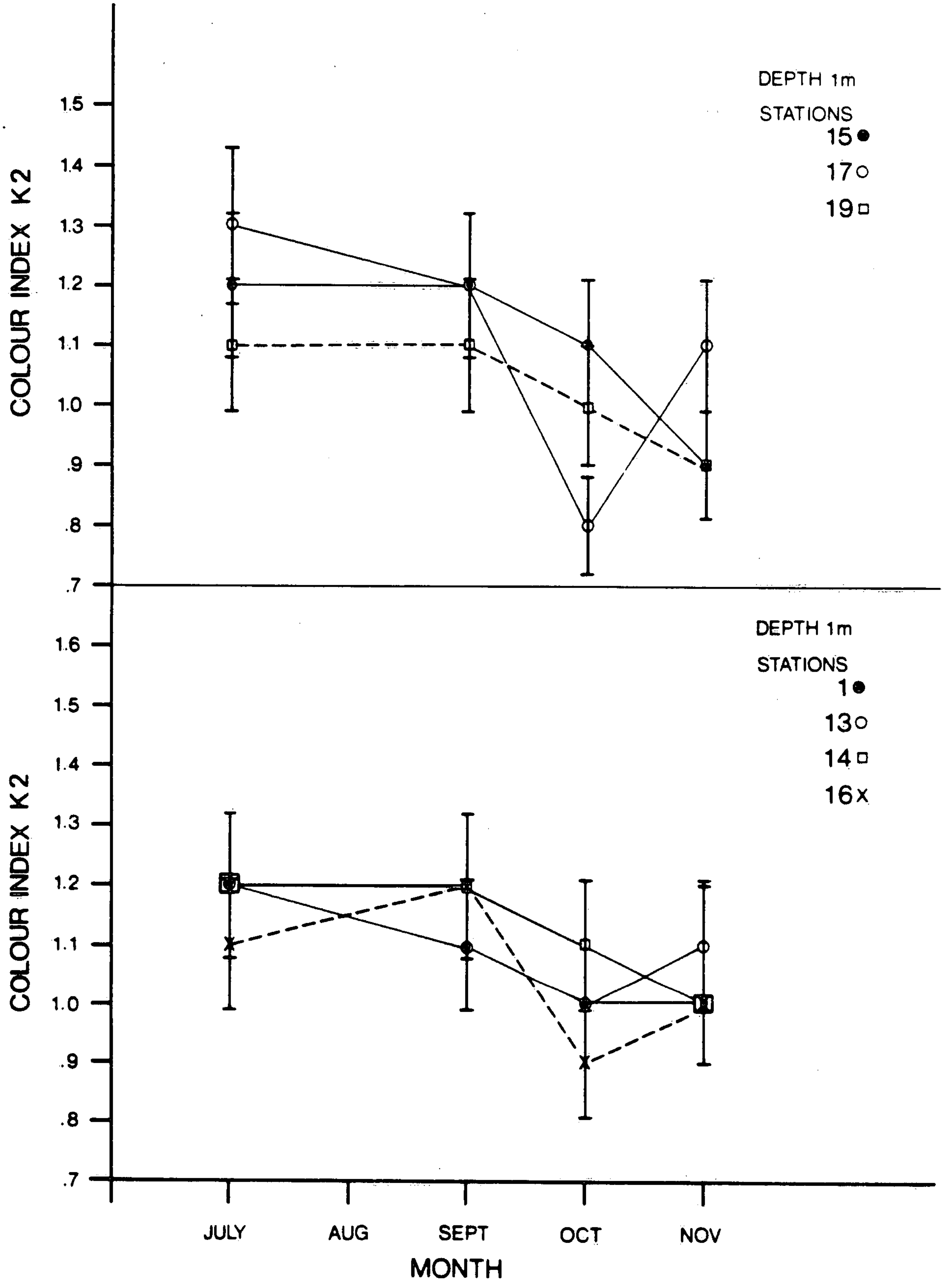


Figure 6b. Temporal variation of colour index K2 for Lake Ontario. The bars represent total estimated error.

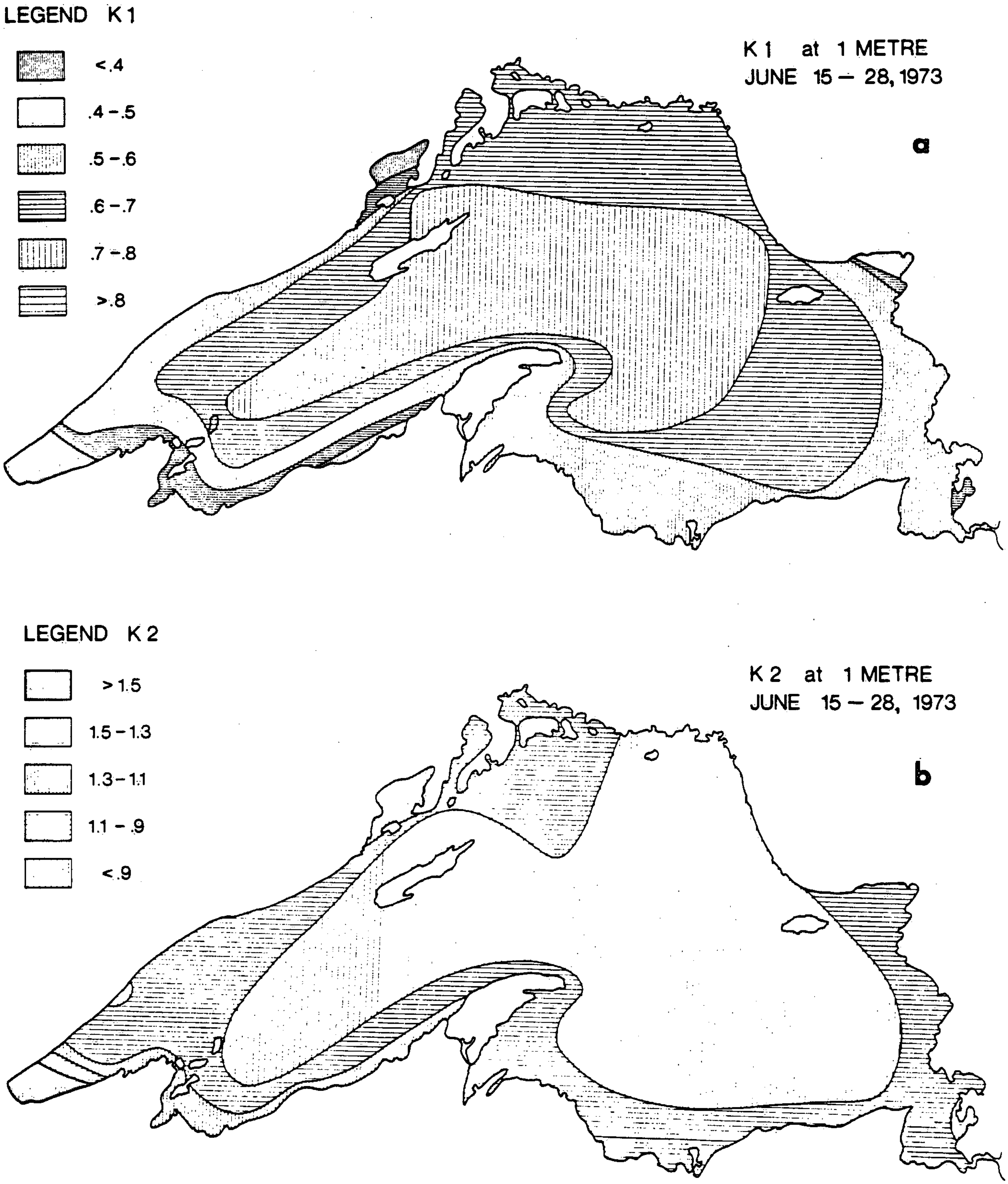


Figure 7. Colour indices for Lake Superior, June 1973 (a) K1 at 1 metre and (b) K2 at 1 metre.

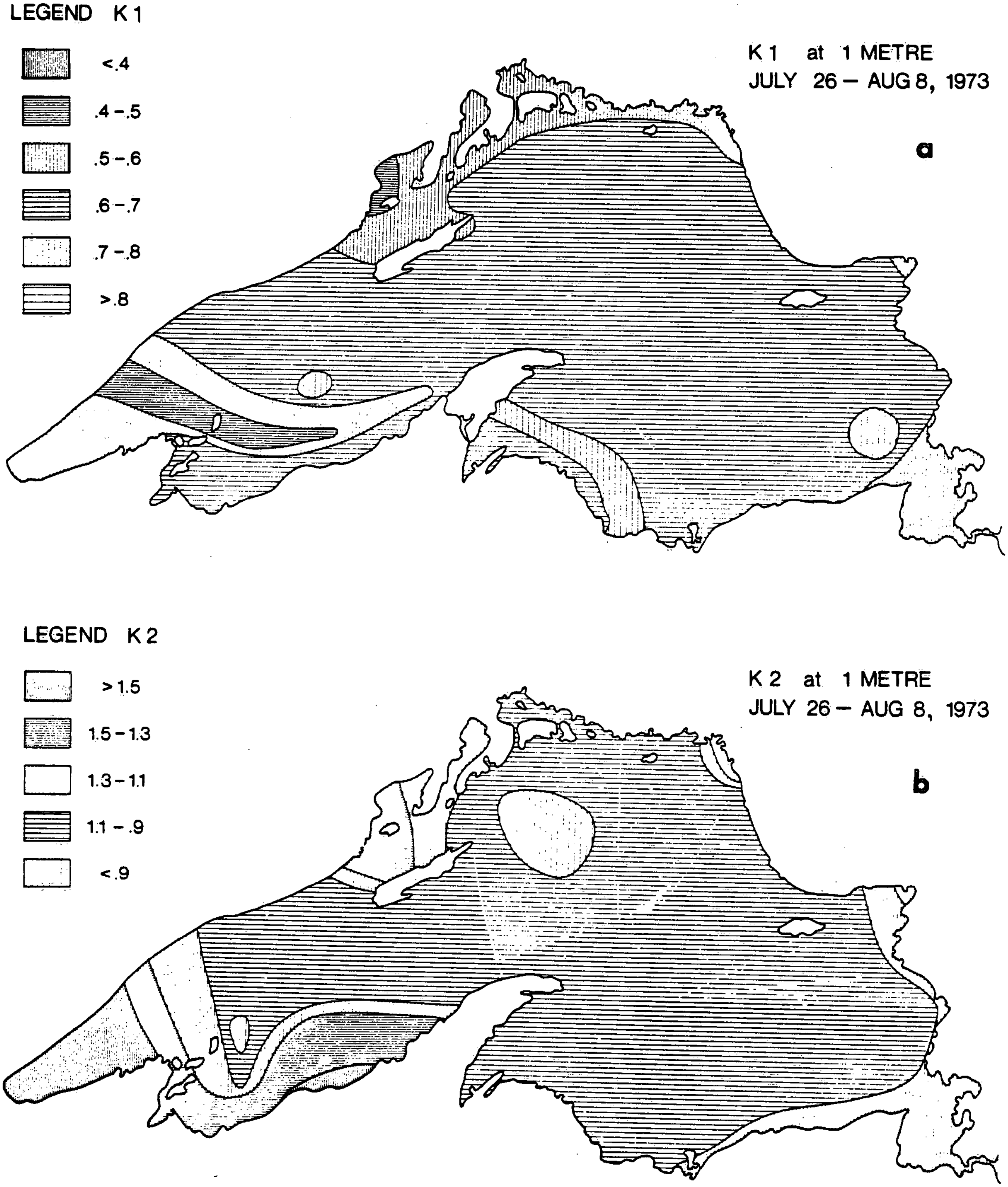


Figure 8. Colour indices for Lake Superior, July 1973 (a) K1 at 1 metre and (b) K2 at 1 metre.

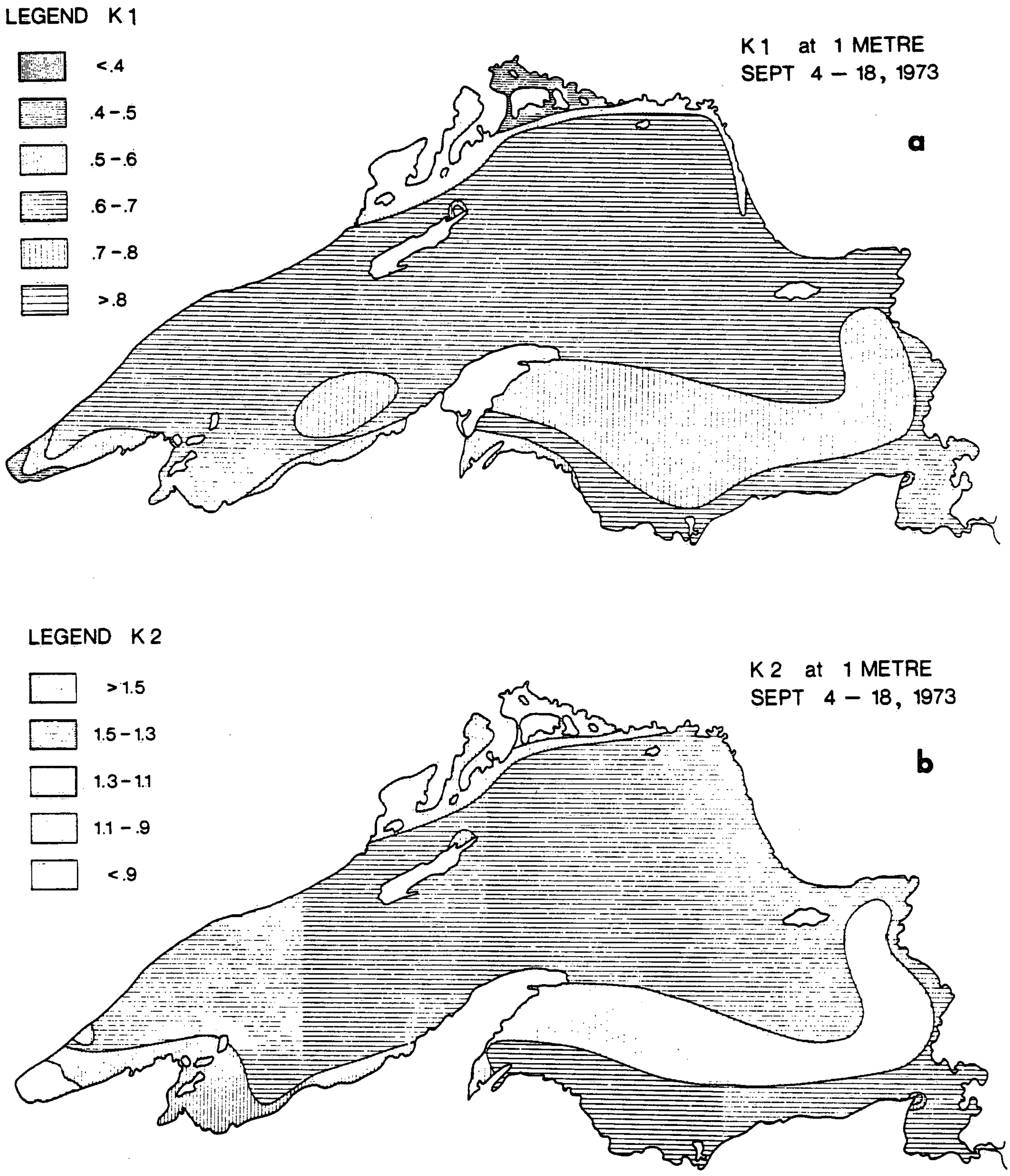


Figure 9. Colour indices for Lake Superior, September 1973 (a) K1 at 1 metre and (b) K2 at 1 metre.

have a greater effect on K2 than K1. The effect of suspended sediment will be similar for both K1 and K2 assuming that the suspended material is not selectively absorbing in the wavelength range 450-560 nm.

During a number of the Lake Superior cruises, spectral irradiance data were obtained using the *in situ* spectrometer. These data were used to calculate the dominant colour wavelength based on the CIE (Committee on Colorimetry, 1953) chromaticity system (Thomson and Jerome, 1974).

A comparison of the calculated dominant colour wavelengths and the indices K1 and K2 shows high correlation coefficients in all cases. A typical example is shown in Figure 12. Though this result is expected from the simple physical relations between these two colour systems, the implications are very important. In the case of the dominant colour wavelengths it has been observed that chlorophyll amounts in the order of 40 mg/m^2 are required before the colour wavelength shifts to the range 550-560 nm (Thomson and Jerome, 1974). In the case of Lake Superior it was apparent that this wavelength range was the exception rather than the rule; owing to the generally low chlorophyll values (typically 0.5-2.0 gm/l for a 0-20 metres integrated sample) the colour of Lake Superior is determined more by suspended and/or dissolved inorganic material than by biological activity. Hence it appears that the chlorophyll values observed in Lake Superior are too low to influence the indices K1 and K2 by any significant amount. In essence, the chlorophyll values are below a threshold limit for these particular indices.

CONCLUSIONS

Data from the Lake Superior and Lake Ontario cruises have shown that the colour indices are good indicators of the general turbidity features of the lake. They act as water-mass tracers with midlake and near-shore regimes being clearly identified. The experience gained in this experimental phase has indicated that a ratio which is more dependent on suspended load is highly desirable. In the future for this purpose, the addition of optical filters sensitive to the 600-630 nm range is planned.

As a biological indicator, there is sufficient evidence to believe that this type of measurement is an important contribution. Further research on the threshold sensitivity for chlorophyll for these parameters, however, is necessary.

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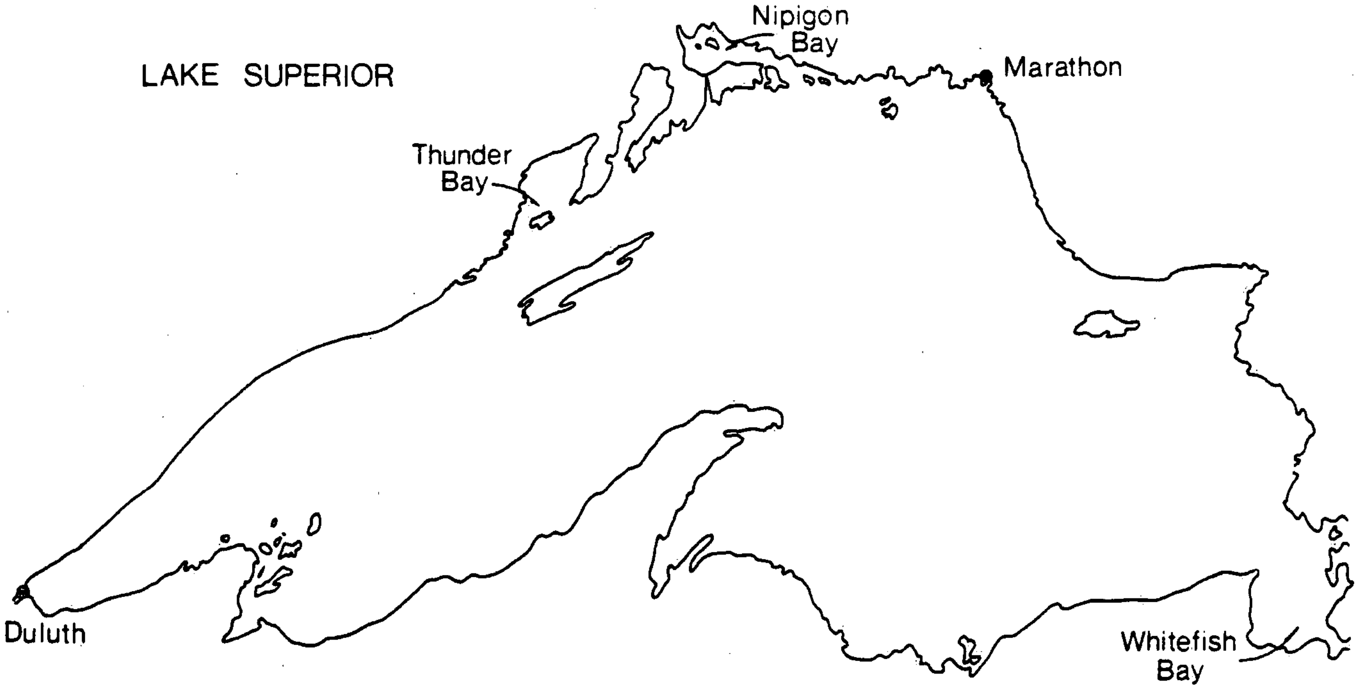

Figure 10. The main turbid areas of Lake Superior as indicated by the colour indices.

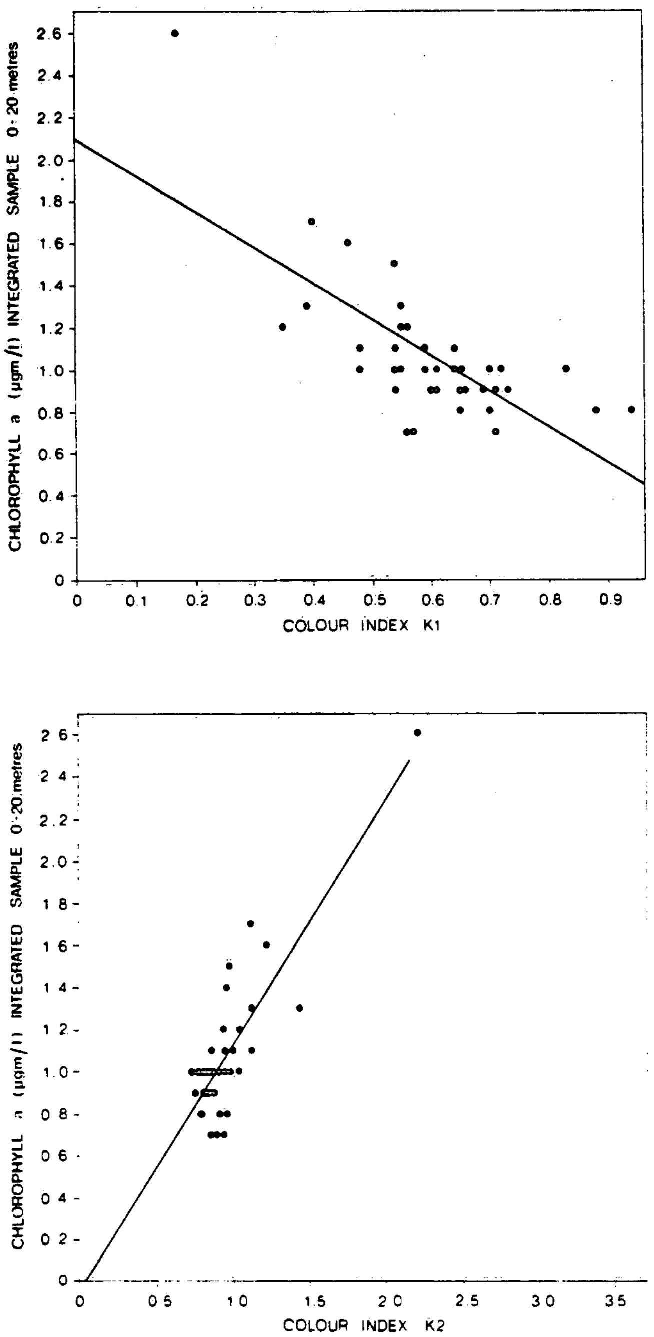

Figure 11. Chlorophyll *a* vs colour indices K1 and K2 for Lake Superior. The correlation cœfficients are 0.52 for K1 and 0.72 for K2.

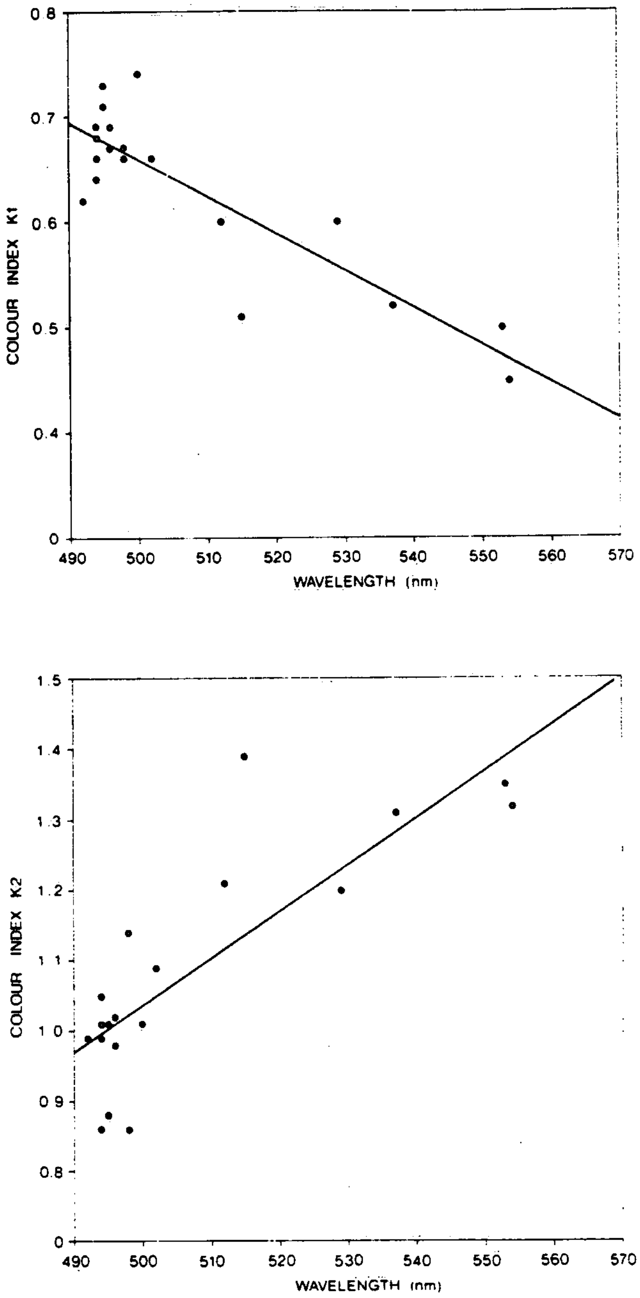

Figure 12. Colour indices K1 and K2 vs the dominant colour wavelength for Lake Superior. The correlation cœfficients are 0.75 for K1 and 0.67 for K2.

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