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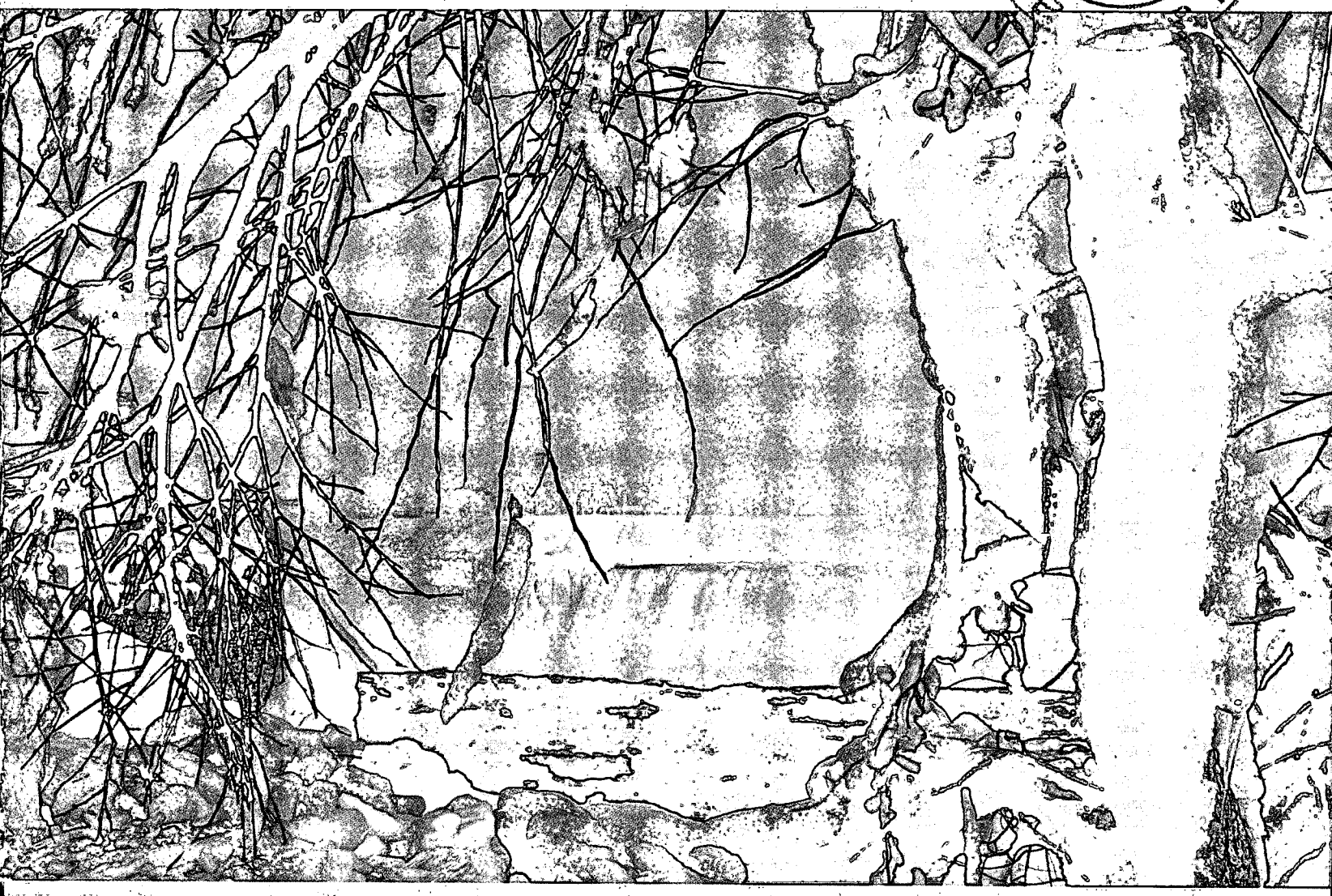
Transmissometer Measurements of the Great Lakes

K.P.B. Thomson and J. Jerome



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(Résumé en français)

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Abstract

Beginning in 1973 *in situ* measurements of the optical beam attenuance or transmittance have been obtained on the Great Lakes during the CCIW monitoring cruise program. The instrument used for these measurements and the operational procedure are described. Sample data from each cruise are presented for reference purposes. The transmittance or attenuance data for Lakes Superior, Erie and Ontario are described in terms of their relation to other limnological parameters. Relations observed in the analyses of the optical data show that the beam transmittance or attenuance is an important limnological parameter for the surveillance of the Great Lakes.

Résumé

On a commencé à effectuer en 1973 au cours de croisières de contrôle du Centre canadien des eaux intérieures, des mesures sur place de l'atténuation, ou de la transmittance, du faisceau optique dans les eaux des Grands lacs. Le rapport décrit l'instrument utilisé pour les mesures et la méthode employée. Il présente, à titre de référence, et décrit les données de transmittance, ou d'atténuation, des lacs Supérieur, Érié et Ontario, en relation avec d'autres paramètres limnologiques. Les relations observées dans les analyses des données optiques montrent que la transmittance, ou l'atténuation, du faisceau est un paramètre limnologique important pour la surveillance de l'eau des Grands lacs.

Transmissometer Measurements of the Great Lakes

K. P. B. Thomson and J. Jerome

INTRODUCTION

During 1973 an *in situ* transmissometer was incorporated into the Great Lakes monitoring program. This instrument, a Martek transmissometer (Model XMS), was used on Lakes Ontario, Erie and Superior to measure the optical beam attenuance or transmittance as a function of depth at various periods throughout the cruise season.

The basic instrument system used on the CCIW research vessels MARTIN KARLSEN and LIMNOS is briefly described. This is followed by a presentation of some of the data from each cruise as well as a detailed discussion on the limnological aspects of the transmittance measurements. Since the monitoring program, during 1973, was concentrated specifically on Lake Superior, most of the data discussed in this report relate to the Lake Superior study cruises.

INSTRUMENTATION

General Theory

The basic configuration of any transmissometer consists of a collimated light source, a detector and a defined optical path. A beam transmissometer ideally measures the fraction of light that is transmitted rectilinearly over a known path length. It is therefore a measure of the absorption and scattering in the medium in which it is immersed. The actual parameter measured can be expressed either as a percentage transmittance (T) relative to a free air or pure water path, or as a beam attenuation coefficient α, where:

$$\alpha = \frac{\ln (1/T)}{x}$$

and T is the fraction of the light beam transmitted through the medium relative to the reference path. When the optical x is normalized to one metre, T is called the transmissivity and α is expressed in units of m^{-1}.

The basic source of error in all transmissometers is due to the strong forward-scattering that occurs in water. These errors can be minimized by careful selection of field stops and detector apertures that minimize the detection of the forward-scattered light.

Since absorption in water varies with wavelength, some selection of optical filters is usually made. In some instruments a wide spectral interval may be scanned (Larsen, 1973); with others, a fixed optical band pass is used depending on the spectral region of interest.

The Transmissometer

The Martek XMS *in situ* transmissometer used in the study was developed at the Visibility Laboratory, University of California at San Diego. The instrument is equipped with a Martek DMS depth sensor which enables both signals to be fed into an X-Y plotter to obtain a transmission profile.

A quartz iodine bulb is used as the light source. Its current is continuously monitored to produce a constant intensity. A folded one-metre path length is used to make the instrument compact and more manageable in the field. The detector is a silicon photocell. The instrument is supplied with a number of Wratten filters. The filter selected for the Great Lakes monitoring work was a W45 filter, which has a peak transmission at 486 nm. The instrument is calibrated to 85.5% transmission in air to account for the decrease in the relative refractive index when immersed in water. When tested in distilled water the instrument gave readings within 5% of the experimental values (for the pass band of the W45 filter) obtained by Clarke and James (1939) for pure water.

Field Operation

During the first part of the field season both the depth sensor and the transmissometer were calibrated before every measurement. Difficulties in calibration were caused by fog forming on the glass faces of the transmissometer cooled from previous measurements. Since it was found that the calibration did not drift significantly over a 24-hour period, checks were made once or twice a day during the latter part of the season. For these calibrations the instrument was brought into the laboratory and allowed to warm up to prevent fogging of the glass faces.

Before each measurement the instrument was turned on for a short warm-up period to allow the light source to stabilize. The instrument was then lowered, in a horizontal mode, into the water either by hand or by winch. The transmissometer and depth sensor outputs were fed into an X-Y plotter and a continuous trace of transmission vs depth was obtained. The maximum depth reached was limited by a 30-metre cable until September when a 100-metre cable was obtained. The transmissometer was used mainly on a 0-100% scale except for some cases in very turbid water when either the 0-25% or 0-10% scale was selected.

ANALYSIS OF THE DATA

Data Storage

The transmittance vs depth profiles for all cruises have been digitized and stored on punch cards. For analysis of the data two systems can be considered. One system is to plot a contour map of the transmittance values at a particular depth; the other, a two dimensional approach, is to plot cross sections for a particular location in the lake. The most general presentation of the data is the transmittance values at one metre. The cross sections are only analysed for specific cases of interest.

Lake Superior

Transmittance at One Metre (% per metre)

Contour maps of the transmittance at a depth of one metre for the time period from May to November are shown in Figures 1 to 6. These data give a descriptive record of the development of the principal water mass regimes throughout the season. Essentially, there are two significant regimes defined by the transmittance measurements, namely the midlake and the coastal areas.

In the midlake region sediment loading is very low. The biological activity present in this area is the significant factor in determining the transmittance values. In May, the biological activity is very low, and the major part of the lake has transmittance values over 70%. Even areas very close to the shoreline have high transmittance values. By June the region of over 70% transmittance has receded from the shore in most areas. This results from an increase in sediment loading in the near-shore areas as well as biological growth beginning in the warm near-shore waters. The temperature of the central lake is still less than 4°C and significant biological growth is not yet present. By July, the region of over 70% transmittance has decreased to three small regions, and midlake temperatures have increased sufficiently to influence biological growth in midlake areas. As a result, most of the midlake transmittance values have dropped into the 50-70% range. In September, when the biological growth cycle has reached or just passed its peak, all of the midlake area is in the 50-70% transmittance range. By October, the biological activity in the central lake area is declining. The resulting decrease in the organic particle content of the water is demonstrated by a region in the eastern section of the central lake that now has over 70% transmittance. As further clearing of the water occurs through November, the region of over 70% transmittance increases in both the western and eastern sections of the midlake area.

The behaviour of the transmittance values in coastal regions appears to be controlled by the dominant current patterns in the lake. The predominant flow is geostrophic with a westward-moving current along the north shore and an eastward-flowing current along the south shore (Bennett, 1974).

In May, June and July this western drift, from Thunder Bay to Duluth, draws clear water into the western Duluth basin. Turbid inputs such as those from the Nipigon River are directed westward. The effect of the Black Bay and the Nipigon River areas is most evident in the data of the September cruise (Fig. 7).

The water in the Duluth area had the highest turbidities found in the lake. River input, shoreline erosion, and urban and industrial effluents combine to produce this very turbid area. During the entire field season there is a current flow out of the Duluth area eastward along the south shore. The turbid waters carried out of the Duluth area produce a band of low transmittance through the Apostle Islands and along the south shore. In most months this effect can be noticed as far eastward as the Keweenaw Peninsula.

Several point sources of turbidity can be identified from the transmittance measurements. The principal areas are Silver Bay Harbour, Minnesota and Marathon, Ontario. The two urban regions, Duluth and Thunder Bay, produce waters having the lowest average transmittance. In all months, with the exception of July, the values at one metre were less than 20% in the Duluth area. The values in Thunder Bay remained between 30% and 50% from June to November. The relatively constant values indicated no significant variation in the input from these centres during the field season.

Vertical Profiles

By combining all of the transmissometer readings taken on one transect, a vertical profile of the transmittance across the lake can be produced which illustrates stratification and different water masses. A transmittance profile from Ontonagan, Michigan to Grand Marais,

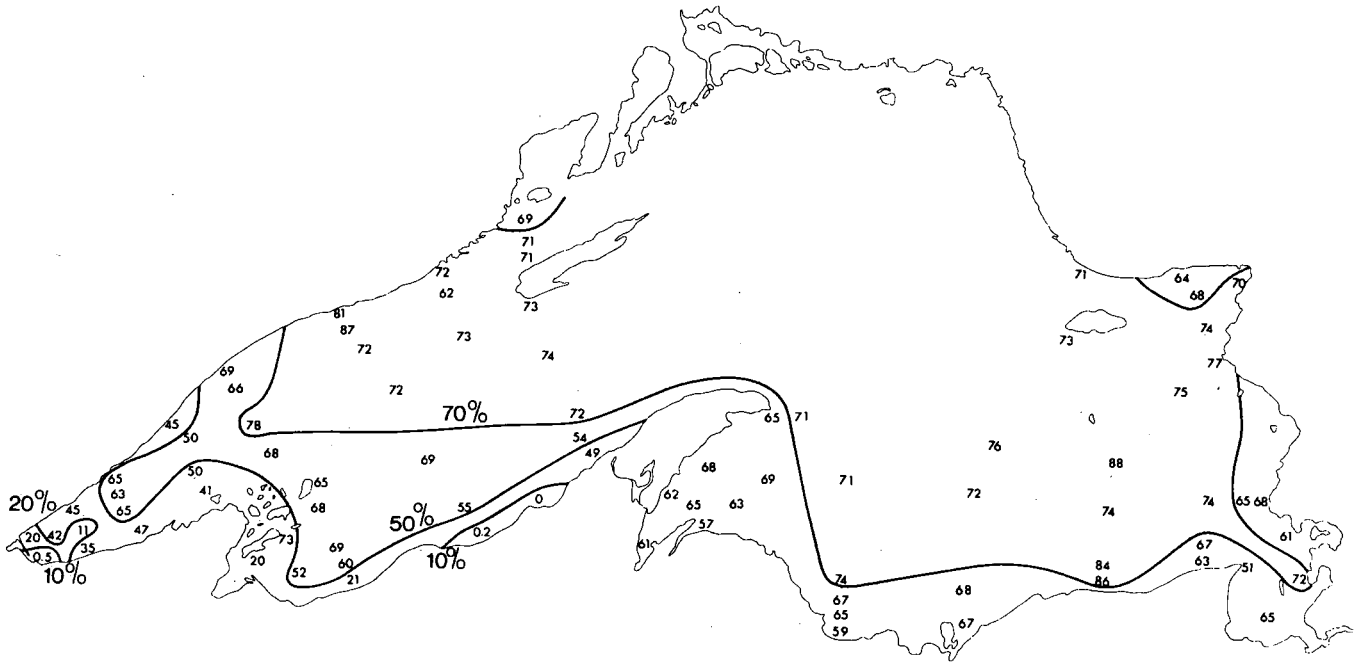

Figure 1. Transmittance values (%) at one-metre depth, Lake Superior, May 12-26, 1973.

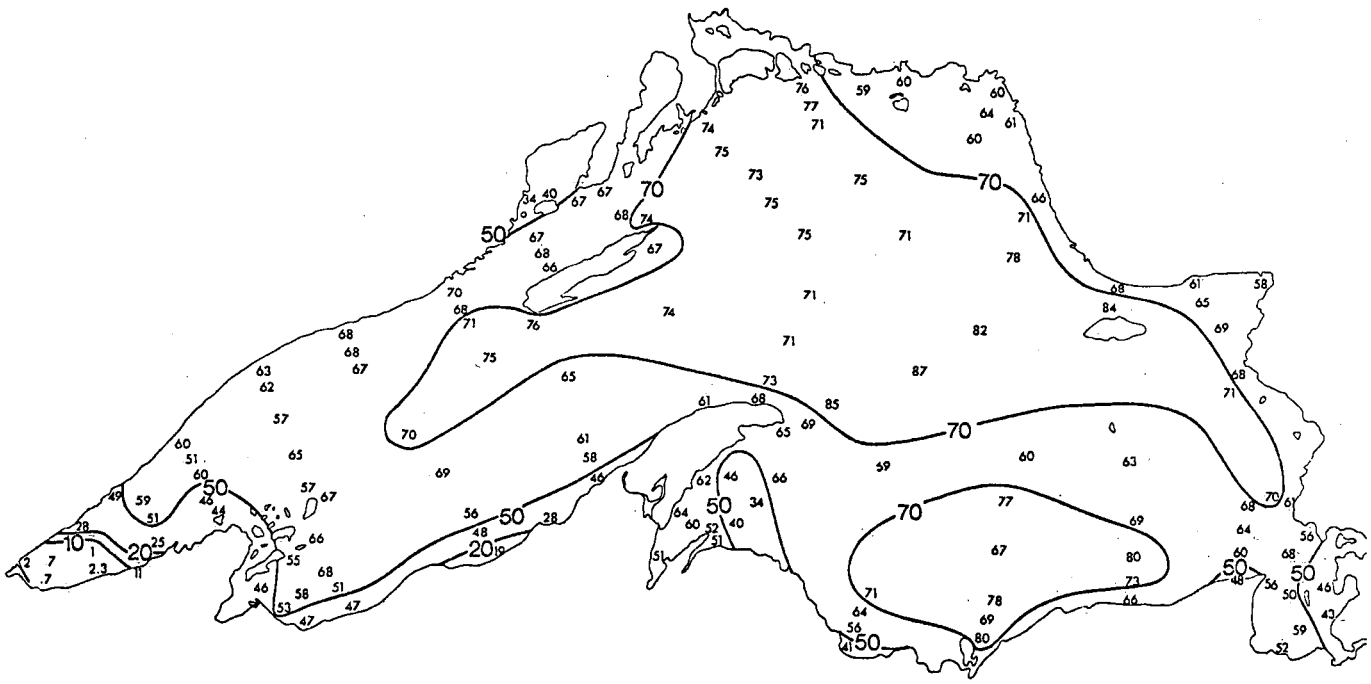

Figure 2. Transmittance values (%) at one-metre depth, Lake Superior, June 15-29, 1973.

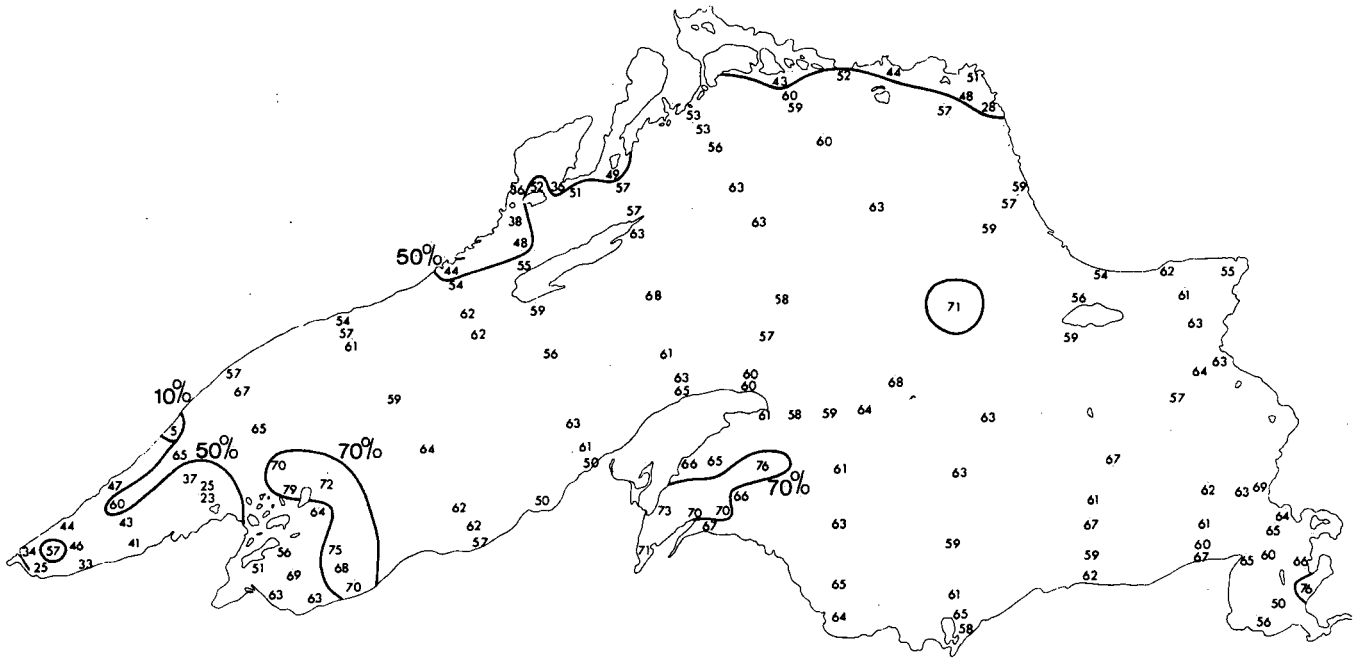

Figure 3. Transmittance values (%) at one-metre depth, Lake Superior, July 26-August 9, 1973.

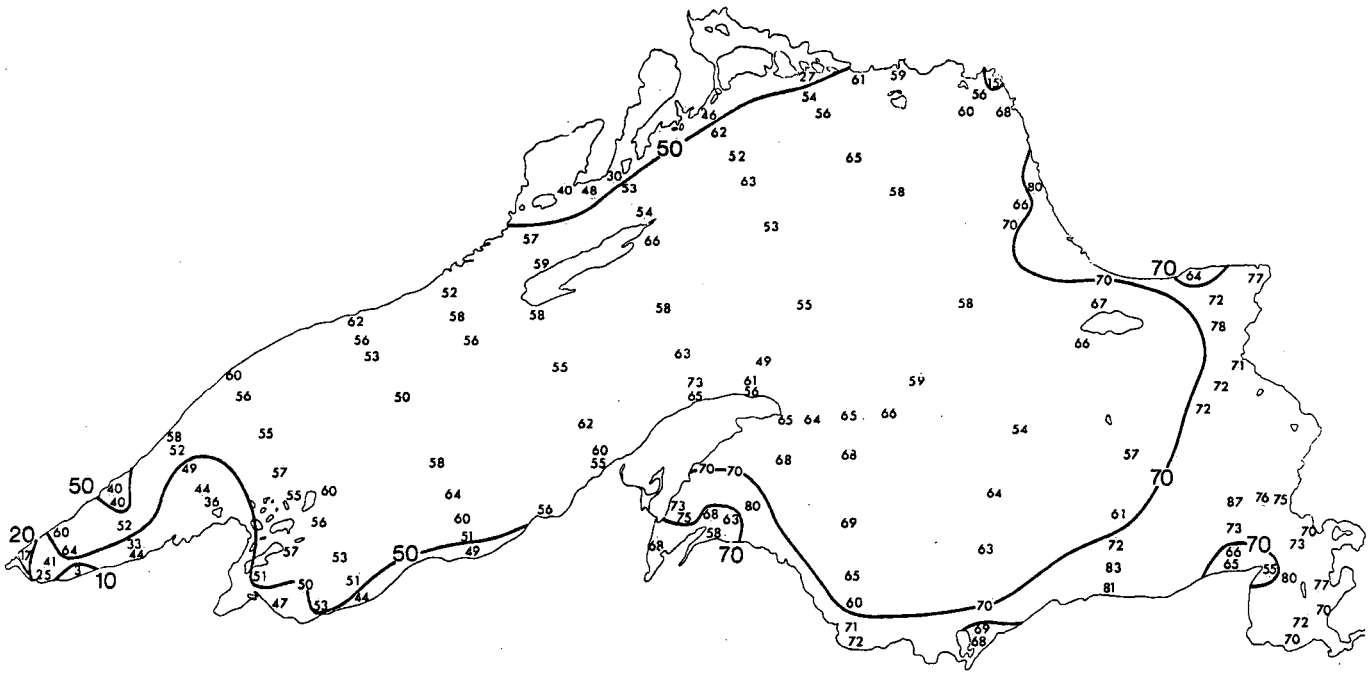

Figure 4. Transmittance values (%) at one-metre depth, Lake Superior, September 5-18, 1973.

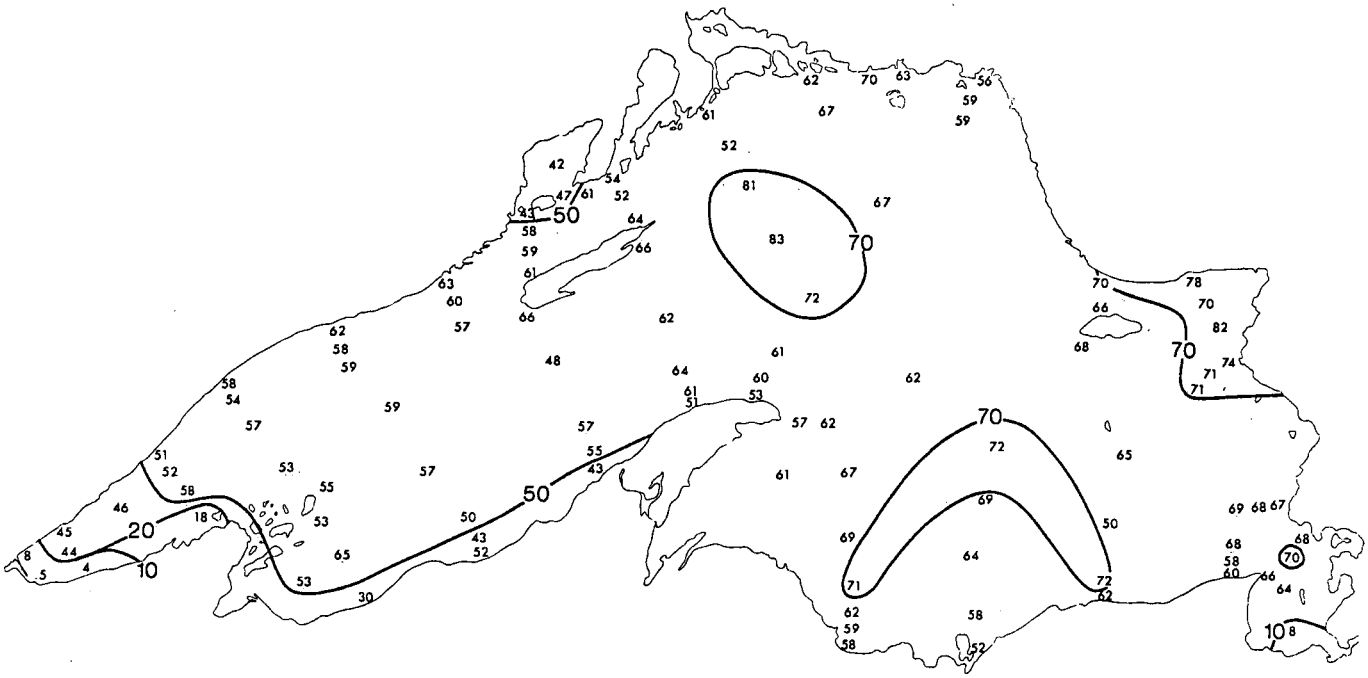

Figure 5. Transmittance values (%) at one-metre depth, Lake Superior, October 9-29, 1973.

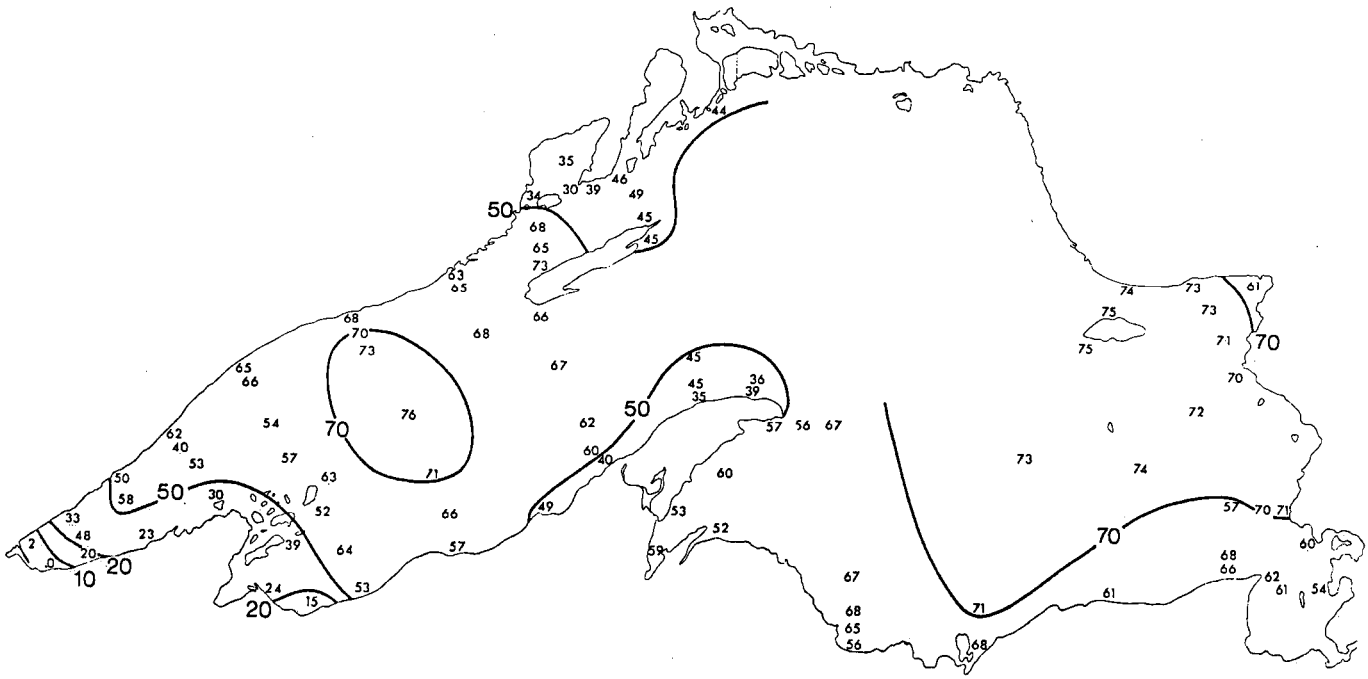

Figure 6. Transmittance values (%) at one-metre depth, Lake Superior, November 13-30, 1973.

Minnesota for the month of September is shown in Figure 8. This profile indicates some of the physical processes present in the lake at this time.

The band of low transmittance values lying near the south shore to a depth of 65 metres demonstrates the presence of an eastward current along the American shore. Another interesting feature is the presence of clear water ($T > 60\%$) at shallow depths along the north shore. Upwelling was present on the north shore off Grand Marais at this time (Bennett, 1974). During this September cruise period, the vertical profiles indicated a region of minimum transmittance in the area of the thermocline. Subsequent biological and chemical measurements (Watson, Thomson and Elder, 1974) show that this minimum at a depth of 20-25 metres is associated with biomass, representing a significant fraction of the total biomass in the epilimnion of Lake Superior. The significance of the optical measurements in this particular case is that normal biological (ship) sampling procedures would not have detected this important layer.

Lake Ontario and Lake Erie

Figures 9 to 13 show the values of transmittance at a one-metre depth for Lake Ontario and Lake Erie over a period of several months.

Lake Ontario

The Lake Ontario transmittance data clearly show the influence of the Niagara plume. On both of the October and December cruises there is a relatively steep gradient in the transmittance from the Niagara River eastward along the south shore of the lake. The December data also indicate the development of two distinct water masses. A relatively clear area with transmittance values greater than 50% is found in the midlake mass and a band of much lower transmittance values is observed along the shore. These midlake and coastal water masses have also been identified by other optical techniques (Thomson, Jerome and McNeil, 1974).

Lake Erie

During the April cruise on Lake Erie (Fig. 11) only one station showed transmittance values greater than 20%. The extremely low transmittance values over the whole lake occurred, since most of the winter suspended material was unable to settle out due to ice-free conditions and exposure to strong winds.

In July, the central basin and sections of the eastern basin show transmittance values greater than 50%. The transmittance values in the August period in these same areas are generally lower than those observed in July.

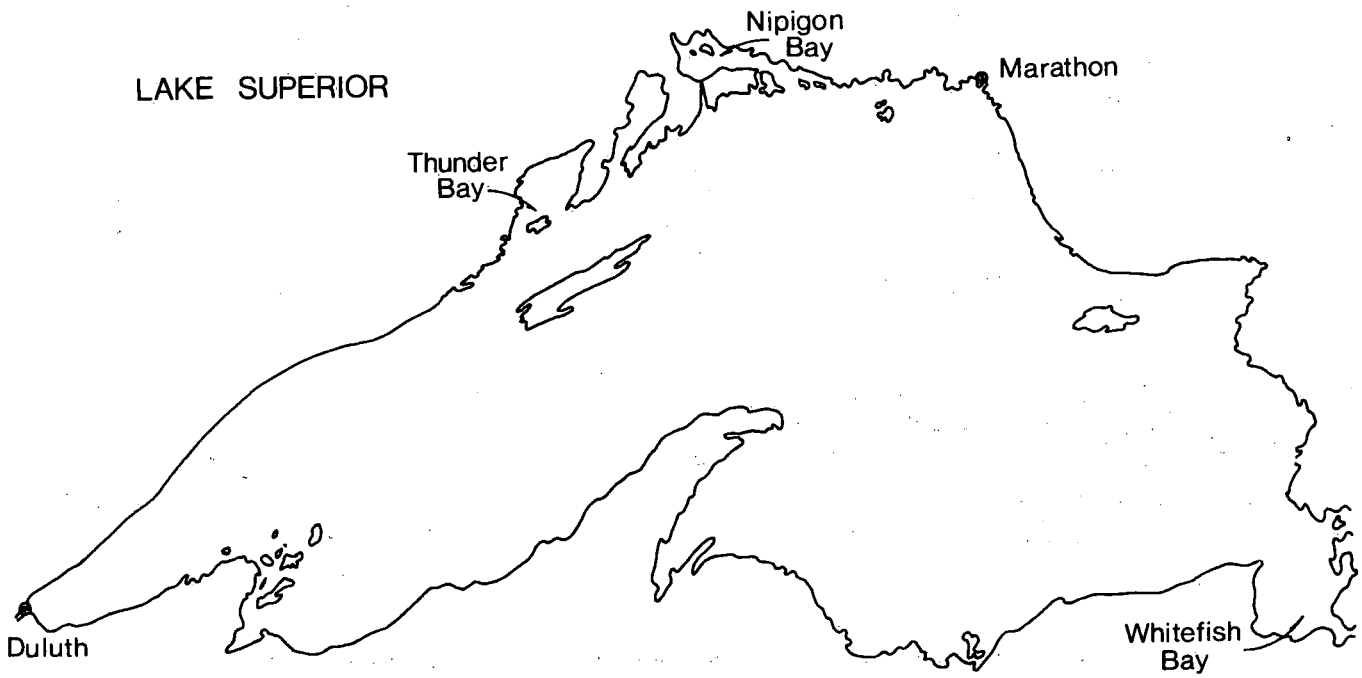

Figure 7. The main turbid areas of Lake Superior as indicated by the transmissometer data.

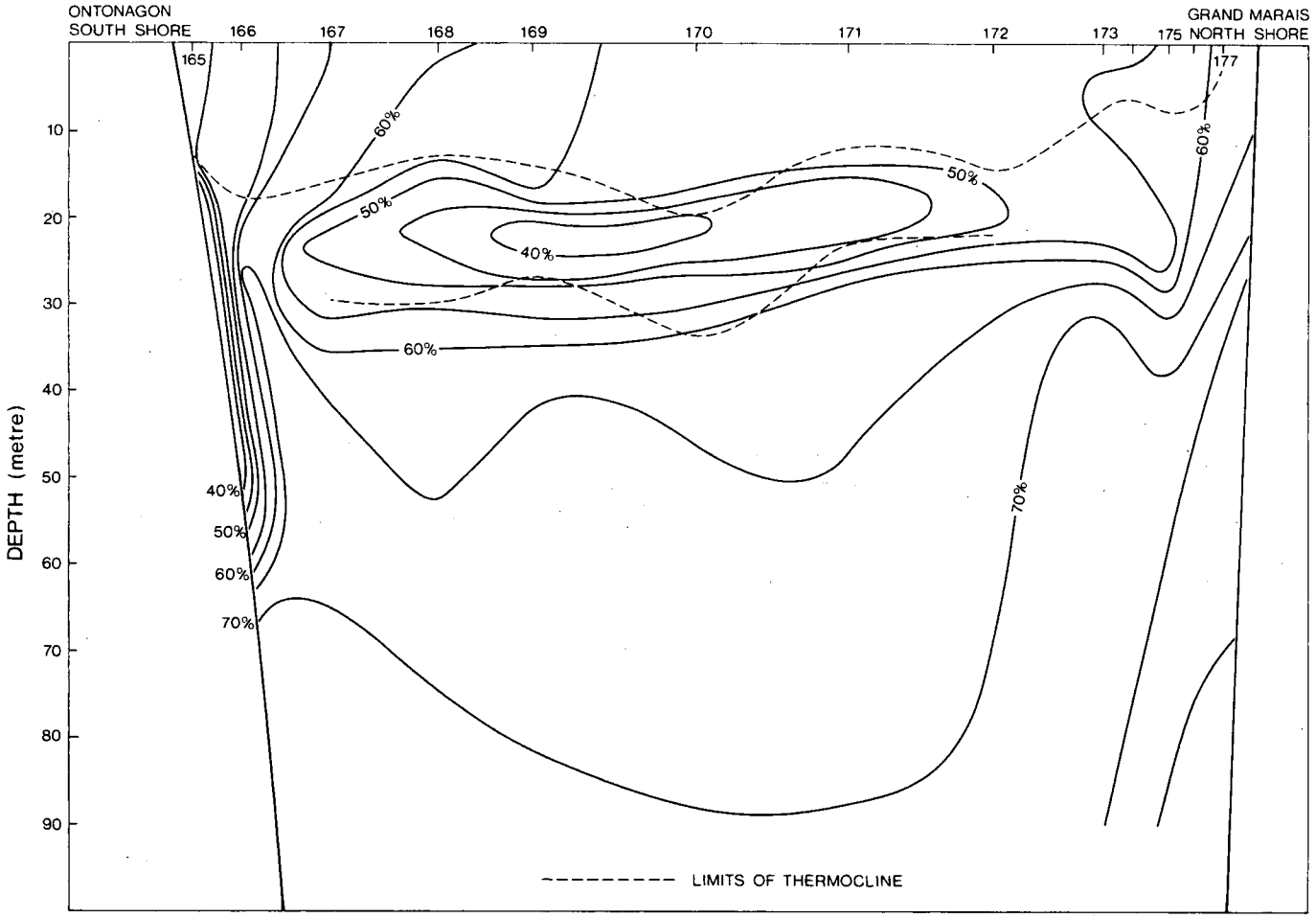

Figure 8. Vertical profile of transmittance, Lake Superior, September 1973.

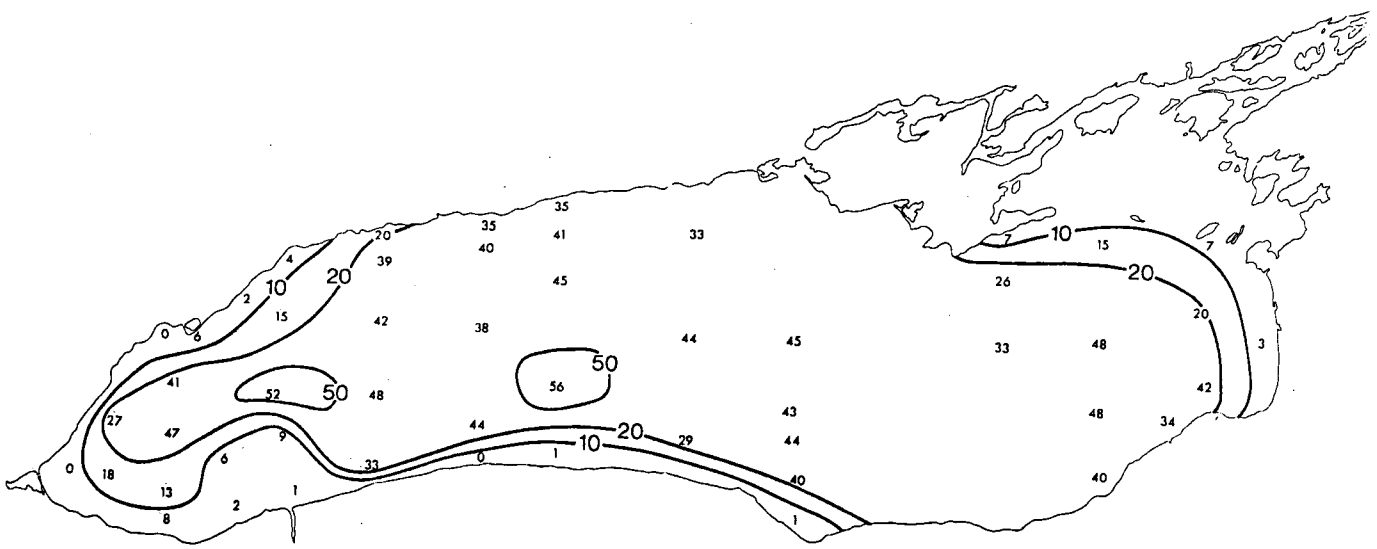

Figure 9. Transmittance values (%) at one-metre depth, Lake Ontario, October 30-November 3, 1973.

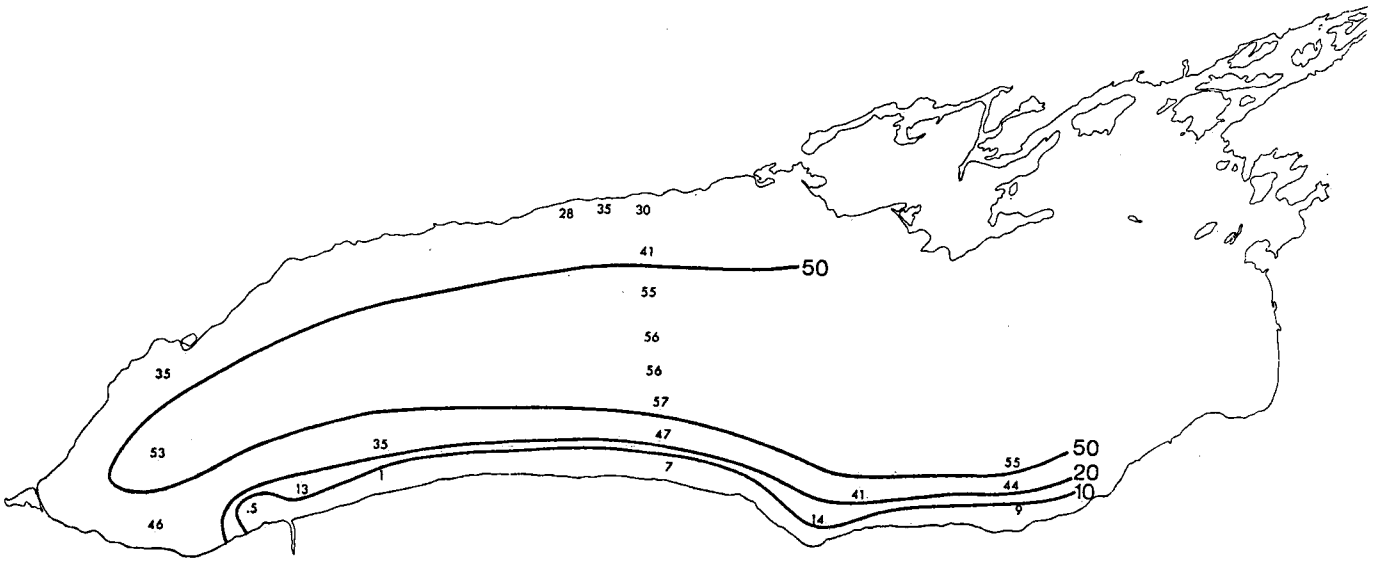

Figure 10. Transmittance values (%) at one-metre depth, Lake Ontario, December 4-6, 1973.

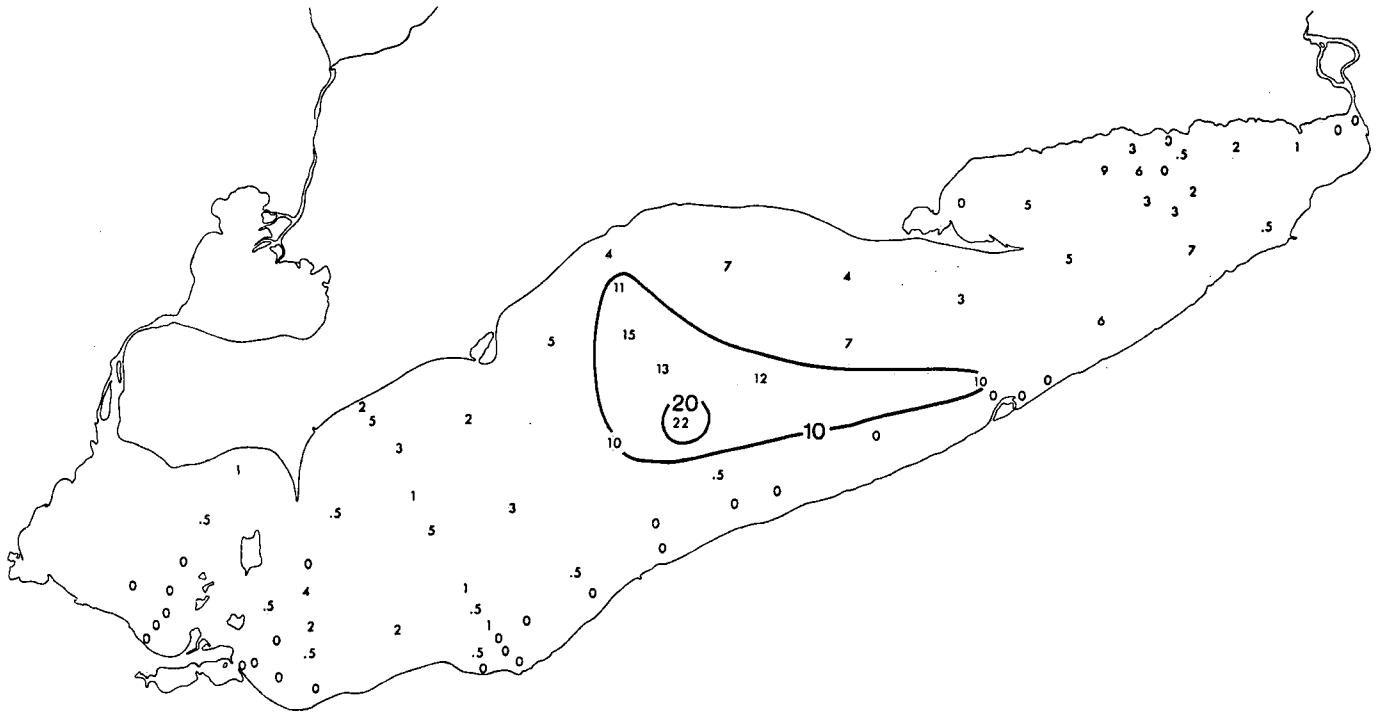

Figure 11. Transmittance values (%) at one-metre depth, Lake Erie, April 9-17, 1973.

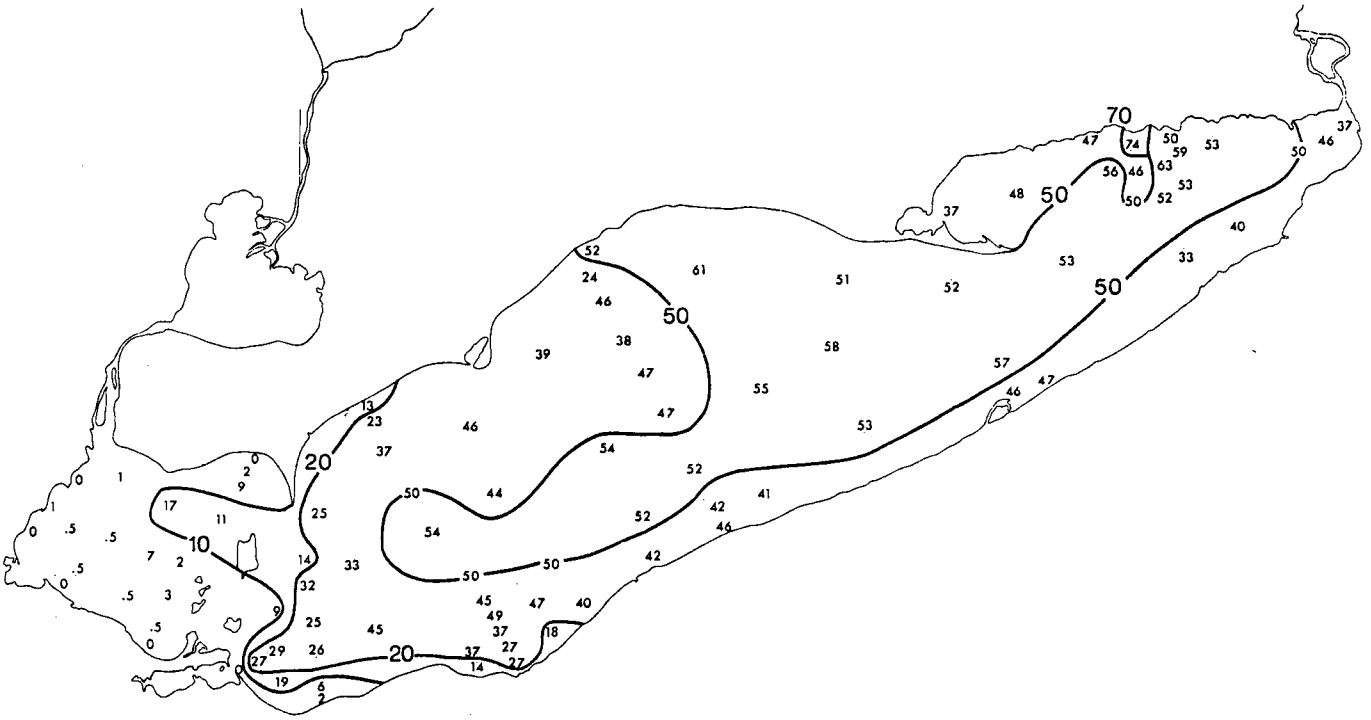

Figure 12. Transmittance values (%) at one-metre depth, Lake Erie, July 24-30, 1973.

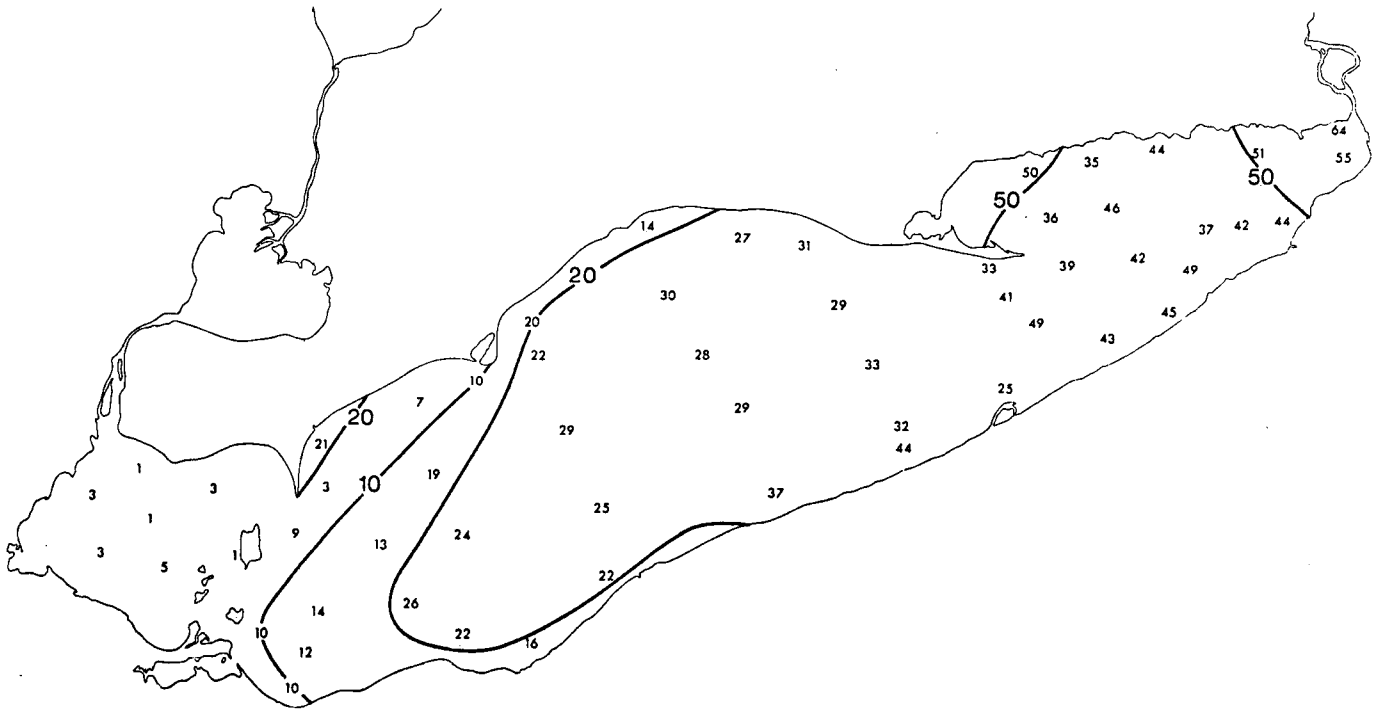

Figure 13. Transmittance values (%) at one-metre depth, Lake Erie, August 26-31, 1973.

Chlorophyll values (Nicholson, 1974) for the August cruise are generally slightly higher for the central basin than the values observed in July.

CONCLUSIONS

The data obtained with the transmissometer in its first year of routine use have proved to be of great value to water quality monitoring programs. From a monitoring or surveillance aspect, the data have direct input to the determination of the evolution of the biological growth cycle, the movement of suspended sediments, and other physical processes. On a relative scale, the transmittance data alone provide an important synoptic overview of the optical state of a large lake.

ACKNOWLEDGEMENT

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REFERENCES

Bennett, R. 1974. Personal communication, CCIW.

Clarke, G.L. and H.R. James. 1939. "Laboratory Analysis of the Selective Absorption of Light by Sea Water," *J. Opt. Soc. Am.*, Vol. 29, pp. 43-55.

Larsen, E. 1973. *An In Situ Optical Beam Attenuance Meter,* Bedford Institute of Oceanography Report B1-R-73-3.

Nicholson, N. 1974. CCIW unpublished report.

Thomson, K.P.B., J. Jerome and R. McNeil. 1974. "Optical Properties of the Great Lakes," *Proceedings* of the 17th Annual Conference on Great Lakes Research, McMaster University. In press.

Watson, N., K.P.B. Thomson and F.C. Elder. 1974. "Subthermocline Biomass Concentrations Detected by Transmissometer in Lake Superior," *Proceedings* of the XIX SIL Congress, Winnipeg, Manitoba. In press.

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