LIGHT PENETRATION STUDIES IN THE MILWAUKEE HARBOR AREA OF LAKE MICHIGAN

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INTRODUCTION

Biologists have long recognized the importance of light in natural waters and its relationship to biological productivity. A number of papers have been published bearing on light penetration, such as that of Birge and Juday (1929) which concerned submarine illumination in a number of Wisconsin lakes, the work of Sauberer (1939) on several Alpine lakes, and Strickland's (1958) review of solar radiation in the oceans. Of particular interest in this study was the work of Chandler (1942) on light penetration and its relation to turbidity in Lake Erie, as well as the studies by Beeton (1958, 1962) on light transmission in the Great Lakes.

Five stations were visited in this investigation which were located in Lake Michigan, near the Milwaukee harbor (Fig. 1). It is at this point that the Milwaukee River empties into Lake Michigan. Just before the river enters the lake, its waters are joined by the Kinnickinnic and Menomonee Rivers. All three flow through the highly industrialized section of southeastern Wisconsin. By the time their waters reach Lake Michigan, they have been subjected to a wide variety of influences from farms, cities and industries.

The purpose of this study was to discover the extent to which the highly turbid waters of the Milwaukee River influences light penetration in nearby Lake Michigan and to interpret the relationship of the Secchi disc determinations to photometer measurements.

EQUIPMENT AND METHODS

Light penetration measurements were made with a submarine photometer, number 268 WA, from the G. M. Manufacturing and Instrument Corporation. Light intensity was recorded in microamperes as registered on the microameter in the boat and the microameter readings were converted to footcandles. The photometer was calibrated by the Electrical Engineering Department of the Univ-

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1 Contribution No. 2, Center for Great Lakes Studies, University of Wisconsin—Milwaukee.
ersity of Wisconsin using an incandescent tungsten filament lamp. Paired surface and subsurface light intensity measurements were made at one meter depth increments at each station and the data presented are of total visible light.

A standard Secchi disc, with a diameter of 20 centimeters divided
into black and white quadrants was used to measure transparency. The greatest depth in feet at which the Secchi disc was visible was determined and then the photometer was lowered to that depth and light intensity measured.

Five stations were established near the mouth of the Milwaukee River. An attempt was made to visit them at weekly intervals between June and November, 1965.

Station 1 was located inside the seawall at the mouth of the Milwaukee River (Fig. 1), where the depth of the water was 6 meters.

Stations 2 and 3 were located one and one-half and three miles from shore, east of the mouth of the Milwaukee River. The maximum depth at station 2 was 15 meters; at station 3, 24 meters. Most of the comparative data was obtained at these three stations.

Station 4 was located north of the harbor entrance, about two miles from shore and in water 17 meters deep.

Station 5 was located south of the harbor entrance, two miles from shore and in water 11 meters deep. Light penetration measurements made at stations 4 and 5 showed no significant differences from those taken at stations 2 and 3.

Except for some special studies on diurnal changes in light intensity, the data presented in this study were taken on fairly clear, calm days between the hours of 0800 and 1600.

Weather conditions made it impossible to obtain measurements as often as desired and prevented all stations from being visited at weekly intervals. Certain segments of the data were omitted which were incomplete or of questionable value.

**Effect of River Water on Light Penetration**

The amount of incident light penetrating to various depths is greatly reduced in the harbor as compared to that in Lake Michigan, one and one-half miles from shore (Fig. 2). In the harbor, penetration of one percent of the incident light to a depth greater than one meter occurred only in summer. Light penetration in the fall was drastically reduced. This is believed to be due in part to the angle of incident light falling on the surface of the water and in part to the greater turbidity of the water caused by wave action and heavy rainfall.

Light penetration to the 5 meter depth in the harbor is negligible (Table 1), whereas about 10 percent of the total visible light penetrates to that depth at station 2 (one and one-half miles from shore) and nearly 15 percent at station 3 (three miles from shore).

The transmission of incident light to a depth of 5 meters compares favorably with measurements reported by Beeton (1962)
for another area of open Lake Michigan. He wrote that the percent transmission of various wave-lengths of light to the five meter depth fell approximately between 3.5 percent for the red and 25 percent for the green. In the present study, the penetration of total surface illumination ranged from about 7 to 19 percent (Table 1). Light transmission was 10 to 14 percent greater at station 2 in Lake Michigan during July and August than in western Lake Erie at the five meter depth during a comparable period (Chandler, 1942).

The curves at station 2 (Fig. 2) tend to be somewhat irregular, particularly in the fall of the year. This indicates that the column of water is not optically homogeneous throughout and may be caused by concentrations of plankton at certain depths or to turbidity differences resulting from water movements.

The optical properties of waters can be described by vertical extinction coefficients ($K$).

\[ K = 2.30 (\log I, h - \log I (h + 1)) \]

$I, h$ and $I (h + 1) =$ light intensity at depths $h$ meters and $(h + 1)$ meters. The 2.30 compensates for the use of base $- 10$ logarithms.

**Figure 2.** Relation between depth and total visible light expressed as a percentage of the light falling upon the surface of the water.
The coefficient indicates the rate of decrease of light as the depth increases. It is based on Lambert’s Law and represents the percentage of original light held back at each depth.

The average vertical extinction coefficients for the curves in Figure 2 are given in Table 1. The extinction coefficients for the turbid waters of the Milwaukee harbor are particularly high, most of them surpassing those of western Lake Erie (Beeton, 1962), although not as high as Little Star Lake, Wisconsin (Whitney, 1938).

Light penetration in the waters of Lake Michigan at Milwaukee, Wisconsin (stations 2 and 3), as indicated from the vertical extinction coefficients, was less than those reported by Beeton (1962) for another area of Lake Michigan. These data (Table 1) suggest that the turbid waters from the Milwaukee River are influencing light transmission at one and one-half, and as far as three miles from shore.

TRANSPARENCY

Forty-nine Secchi disc measurements were compared with the photometer readings made at the same depths and are expressed as the percentage of surface light present at the depth of Secchi disc extinction. The 22 Secchi disc readings made in the harbor were consistently shallower than the 27 readings obtained from Lake Michigan proper (Fig. 3). However, the average percentage of surface light intensity at Secchi disc depth was 28.1 percent, in the harbor and 16.5 percent in Lake Michigan. Beeton (1958) reported 14.7 percent from Lake Huron, whereas Poole and Atkins (1929) reported 15.8 percent from the English Channel, and Clarke (1941) gave a value of 15.2 percent for the Atlantic Ocean.

This disparity between percentage of surface light intensity in the harbor and in Lake Michigan at Secchi disc extinction is undoubtedly due to the highly turbid waters which are concentrated at the mouth of the Milwaukee River. Sauberer (1939) reported similar results from turbid waters. He obtained a greater percentage of surface light at the Secchi disc depth which he attributed to the suspended materials which caused diffusion and scattering of light. Chandler (1942) showed that in Lake Erie, Secchi disc measurements were inversely related to turbidity.

Several investigators (Riley, 1941; Halicki, 1958) have attempted to derive a value at which Secchi disc reading could be converted into the depth at which one percent of the surface light, as determined by photometer measurements, was present. This is termed the euphotic depth and Strickland (1958) reported that this should be about 2.5 times the Secchi disc depth. Riley (1941) used
a conversion factor of 3 for the Atlantic Ocean and Halicki (1958) obtained 4.3 for western Lake Erie.

In this study, factors of 3.1 were obtained for Lake Michigan at stations 2 and 3 (Table 1). However, a value of 2.1 was obtained at station 1, in the harbor.

Several authors (Jones and Wills, 1956; Halicki, 1958; Vollenweider, 1960; Graham, 1966) have indicated that conversion factors and values derived from Secchi disc readings are applicable only within the specific body of water. These data suggest that the
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**Symbols**
- \( K \) — vertical extinction coefficient.
- \( \% \) — percent of incident light reaching the 5 meter depth.
- \( D \) — Secchi disc depth in meters.
- \( I \) — euphotic depth, in meters, where one percent of the surface light is present.
- \( 1/D \) — conversion factor; the relationship between the Secchi disc reading and one percent of surface light.
harbor water and Lake Michigan water should be treated as distinct entities in so far as Secchi disc measurements are concerned.

SUMMARY

The higher percentage transmission of surface light intensity at Secchi disc depth (16.5 percent) as compared with previous reports for other bodies of water (Poole and Atkins, 1929; Clarke, 1941) and particularly with Lake Huron (Beeton, 1958) indicates that Milwaukee River water had some effect on light penetration in Lake Michigan, at least to a distance of one and one-half miles from shore.

Vertical extinction coefficients substantiate this conclusion. The percentage of surface light held back at each depth gradually increased, from .37, three miles from shore to .44, one and one-half miles from shore at Milwaukee, Wisconsin. The increase is even greater in the Milwaukee harbor where the average vertical extinction coefficient was 2.29. All three values are higher than that reported from another area of Lake Michigan (Beeton, 1962).

The percentage transmission of surface light intensity at Secchi disc depth is greater in turbid water.

Further studies are necessary in order to determine more precisely the integration of Milwaukee River water into the waters of Lake Michigan.

ACKNOWLEDGEMENTS

The author is indebted to Dr. Arthur T. Tiedemann of the University of Wisconsin for calibrating the photometer and to Mr. Donald Martinson and Mr. Gerald Ludwig for assistance in gathering the data. I should also like to thank Drs. Alfred Beeton and John Blum of the University of Wisconsin-Milwaukee for their comments on the manuscript.

The work was partially supported by the Wisconsin Alumni Research Foundation.

LITERATURE CITED


