A RECENT OCCURRENCE OF THERMAL STRATIFICATION AND LOW DISSOLVED OXYGEN IN WESTERN LAKE ERIE[1]

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ABSTRACT

Instances of thermal stratification have been detected only occasionally in western Lake Erie during the past 40 years, but when it does occur it is of considerable importance because of associated dissolved oxygen (DO) depletion in the hypolimnion. Data collected in June of 1963 give an indication of the meteorological conditions necessary to produce this thermal stratification. These conditions are: daily wind speed of less than 3.1 m/sec (7 mph); highest wind speed of less than 6.7 m/sec (15 mph); and an average daily temperature of more than 18.5 C for approximately 5 consecutive days. Weather records for Sandusky, Ohio, show these conditions to have occurred on 33 separate occasions between 1953 and 1963. These data suggest stable thermal stratification occurs more frequently than heretofore suspected. The 1963 data also show that in only 5 days of stratification DO in the hypolimnion was reduced to less than 3 ppm, whereas 28 days were required in 1953. This increased rate of DO depletion is probably due to an increase in the oxygen demand of the bottom sediments in recent years.

The Western basin of Lake Erie is a shallow, essentially estuarine area with a mean depth of only 7.3 m and a surface area of 3276 km.^{2} Two peninsulas and a cluster of islands partially separate it from the main body of the lake. A long fetch is presented, regardless of wind direction, by a near-rectangular form measuring 80 by 64 km at its greatest dimensions. This shallow "estuary" receives a massive inflow of 5040 m^3/sec (178,000 cfs) from the Detroit River and lesser discharges from the Maumee River, Raisin River, and numerous smaller tributaries (U.S. Army Corps of Engineers, 1960).

These physical characteristics, augmented by the low relief of the surrounding land and the continental nature of the climate, make thermal stratification in the Western basin seem unlikely. That it has occurred, perhaps more frequently than suspected, is suggested in a scattering of reports spanning the past 35 years. Brief periods of thermal stratification were detected in 1928–30 (Wright, 1955) and in 1938–42 (Chandler, 1940, 1942, 1944; Chandler and Weeks, 1945). These investigators found no evidence of chemical stratification concomitant with thermal stratification. Chandler (1944), in fact, stated that "Oxygen in western Lake Erie is never at any time seriously depleted and its vertical distribution is essentially uniform."

The first significant decrease in dissolved oxygen (DO) at a time of thermal stratification in western Lake Erie was found by Britt (1955a) in September 1953 after nearly a month of hot, calm weather. During 3 days at the end of this period the maximum DO at the bottom was only 1.2 ppm at his most frequently visited station near South Bass Island. The lowest DO that he recorded was 0.7 ppm at a station 2 miles west of this island. Although strong winds and cool weather restored complete circulation 4 days after chemical stratification was first found, the effect of the low DO on the mayfly (*Hexagenia*) population was catastrophic over a large area. Immediately after the period of stratification, Britt found large numbers of dead mayfly nymphs, but no live ones at locations where more than 1,000 per square meter were collected in 1952 (Wood, 1953). In other areas of the bottom between the Canadian shore and Catawba Island,

[1]Manuscript received March 14, 1964.

the number of mayfly nymphs per square meter was only 44 where earlier in the year there had been 300 (mean densities). The mayfly population was almost completely restored by the following year (Britt, 1955b).

No thermal or chemical stratification was found during cruises of the U.S. Bureau of Commercial Fisheries M/V *Cisco* in the Western basin during the summer months of 1957 and 1958. The average number of mayfly nymphs per square meter, however, was only 40 in bottom samples taken in the same area studied by Britt (Beeton, 1961). This reduction in mayfly numbers to the same level as that found after the stratification in September 1953 suggests strongly that severe oxygen depletion in the bottom waters must have occurred at least once again after recovery of the mayfly population in 1954. It is evident now that the oxygen demand of the waters and/or bottom mud has become sufficiently great in the last decade to reduce the DO in the bottom waters rapidly whenever complete circulation is inhibited (Carr, 1962).

This report documents a second known occurrence of low DO accompanying stable (i.e., not diurnal) thermal stratification over a major portion of the Western basin of Lake Erie, compares the climatic conditions that led to thermal and chemical stratification in 1953 and 1963, and comments on the implications of these data.

THERMAL AND CHEMICAL STRATIFICATION IN JUNE 1963

A synoptic survey of the Western basin of Lake Erie was made on June 23, 1963, by the Geological Survey and Division of Wildlife, Ohio Department of Natural Resources. Limnological data were collected at 300 stations, including bathythermograph (BT) casts at 65 and DO measurements at 23 of these. Some degree of thermal stratification was shown by 38 of the BT recordings. Stratification evidently resulted from surface warming at most of these stations since all temperature changes were within 1.5 m of the surface. Definite signs of the beginning of more stable stratification were present at a few stations near the Sister Islands and Pelee Passage areas (fig. 1). The differences between surface and bottom temperatures at all stations were usually less than 3 C and changes within the metalimnion were less than 2 C.

The DO measurements during the synoptic survey were made in an area east of a north-south line from the middle of the Detroit River to Locust Point, Ohio, and west of a north-south line from Colchester, Ontario, to Catawba Island, Ohio. Dissolved oxygen in water samples taken 1.5 m below the surface ranged from 8.9 to 13.9 ppm at temperatures of 22.5 to 23.0 C; concentrations varied from 7.4 to 10.1 ppm at temperatures of 20.9 to 21.5 C in samples taken 0.6 m above the bottom. The DO on June 23, therefore, was near saturation at all depths and thermal stratification was just beginning.

The 4 days following the basin-wide synoptic of June 23 were almost cloudless, daytime temperatures were above 32 C, and winds were light and variable—ideal conditions for the formation of thermal stratification. Because of this somewhat unusual weather, data were collected on June 28–29 with the U.S. Bureau of Commercial Fisheries M/V *Musky II* to determine the effects of the hot, calm weather on the thermal structure of the waters of the Western basin. Sampling was limited to a series of stations along an east-west transect from the mouth of the Raisin River to the north tip of Pelee Island and to scattered stations along a north-south axis at the eastern end of the basin (fig. 1). Stations on the east-west transect were visited on June 28. Data were collected at the remaining stations on June 29.

Stable thermal stratification and low DO in the bottom water were found at nearly all stations (table 1). The metalimnion along the east-west transect had a relatively uniform thickness and was slightly deeper at the eastern than at the western end. It was bounded by a 24-C isotherm at the top and a 20-C isotherm

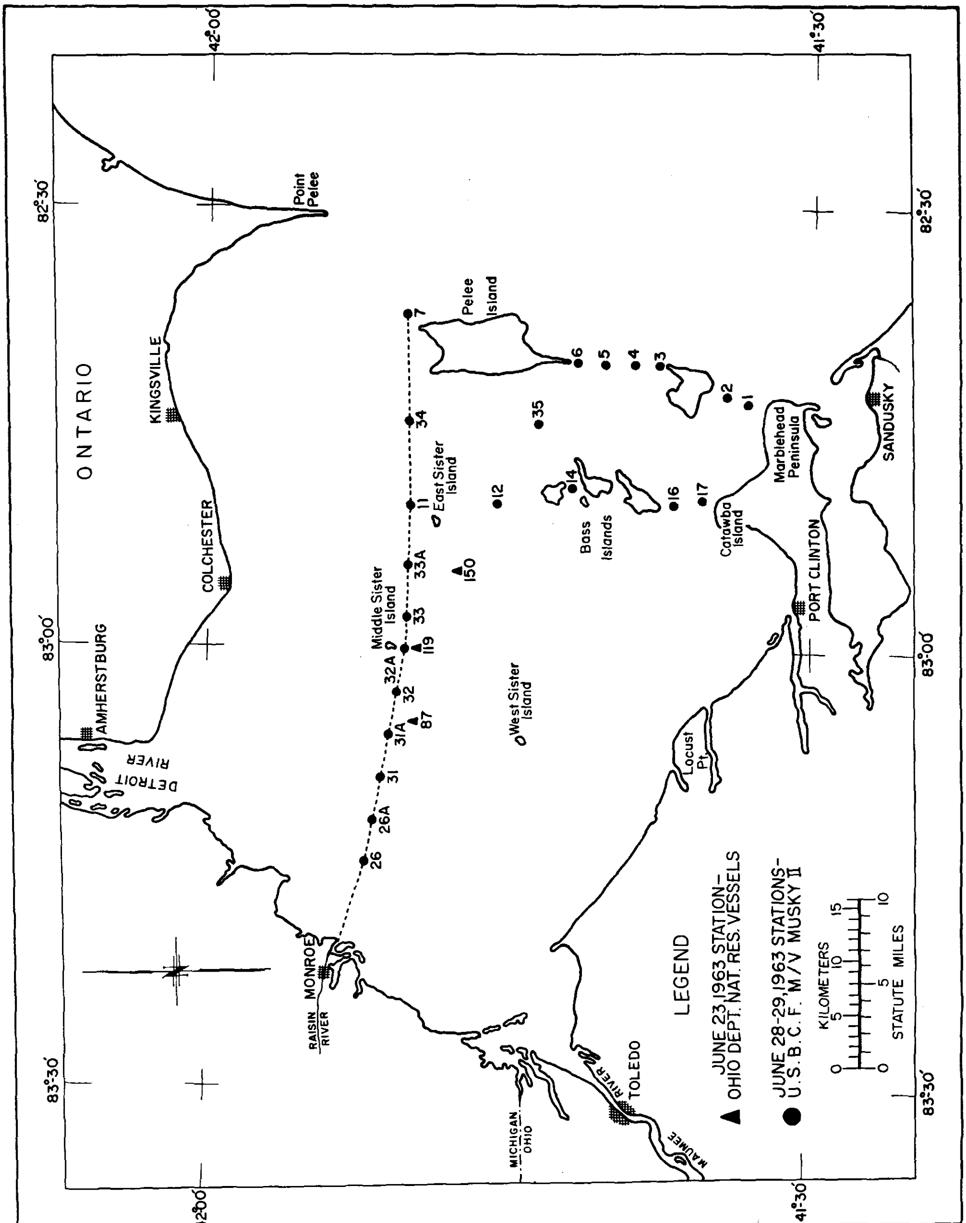

FIGURE 1. Map of the Western basin of Lake Erie showing certain limnological stations visited in June 1963. The transect of stations used to construct the profile in figure 2 is indicated by a broken line.

at the bottom (fig. 2). The mean depths of the 24 C and 20 C isotherms were 3.0 m and 6.1 m. The change of 4 C within this 3-m depth identified the zone as a thermocline in the classical sense, i.e., a drop in temperature of at least 1 C with each meter of increasing depth. Temperature extremes along the transect were 24.2 C at the surface at station 26 and 17.8 C on the bottom at station 32 (figs. 1 and 2).

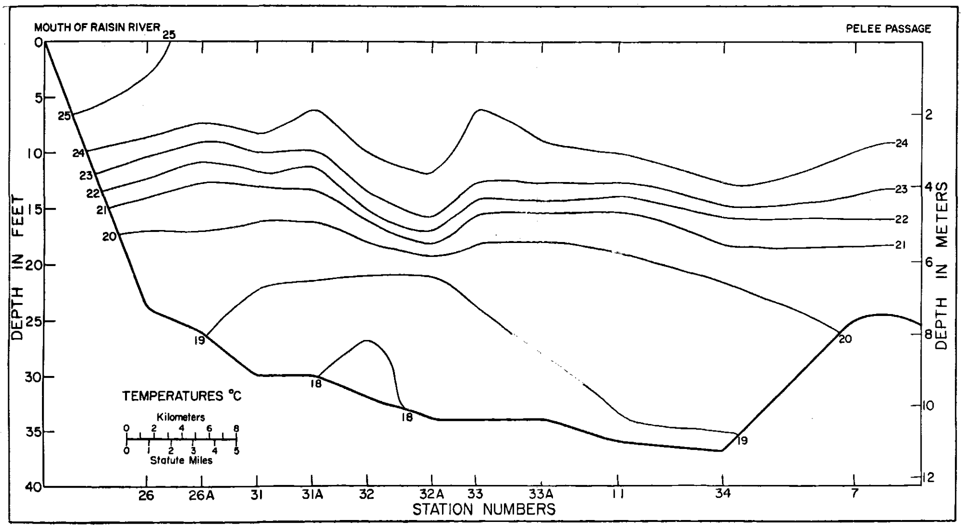

FIGURE 2. Profile of the Western basin of Lake Erie and isotherms found on June 28 along the east-west transect shown by the broken line in figure 1. Bottom conformation is based on depths shown on BT tracings. Isotherms indicated at intervals of 1 C were read from BT tracings.

TABLE 1

Physical and chemical data collected in the Western basin of Lake Erie by the U.S.B.C.F. M/V Musky II, *June 28–29, 1963**

Station number	Date	Time (EST)	BT number	Surface temperature (C)	Station depth (m)	DO sampling depth (m)	DO (ppm)	Sample temperature (C)	Percent saturation of DO
26	6–28	1105	1	25.4	7.3	6.1	2.6	20.0	30
26A	6–28	1124	2	25.0	7.9	6.4	3.5	19.8	40
31	6–28	1145	3	25.0	9.1	7.6	3.7	19.1	41
32	6–28	1225	5	24.6	9.8	7.9	4.5	18.3	49
32A	6–28	1251	6	25.0	10.4	7.6	4.1	19.0	46
33	6–28	1330	7	24.8	10.4	8.5	4.2	19.2	41
33A	6–28	1351	8	25.0	10.4	0.3	10.7	24.9	136
"	"	"	"	—	"	6.4	6.8	19.7	79
"	"	"	"	—	"	8.2	3.8	19.2	43
34	6–28	1505	10	24.8	11.3	9.1	3.8	19.4	43
7	6–28	1550	11	24.7	7.6	4.6	6.7	20.7	79
16	6–29	0955	15	24.3	9.1	4.0	4.4	20.6	52
"	"	"	"	—	"	7.6	3.3	20.2	38
14	6–29	1105	17	25.2	9.1	0.3	11.7	24.4	148
"	"	"	"	—	"	7.3	3.3	20.1	38
12	6–29	1205	19	25.6	10.4	6.4	5.9	20.2	69
"	"	"	"	—	"	7.6	4.5	20.0	53
"	"	"	"	—	"	8.8	2.0	19.6	23
35	6–29	1320	20	25.6	10.4	7.0	—	19.8	—
"	"	"	"	—	"	8.5	2.7	19.8	32
"	"	"	"	—	"	9.1	2.6	19.1	30
5	6–29	1410	22	25.1	9.4	8.5	4.2	20.3	49
4	6–29	1418	23	24.5	13.4	12.8	2.7	19.2	31
3	6–29	1430	24	24.2	13.4	12.5	3.8	20.0	43
2	6–29	1550	26	24.2	7.9	7.0	5.3	20.0	61
1	6–29	1555	27	23.1	9.4	8.8	3.8	19.2	43

*Does not include 4 stations at which only BT recordings were made. Recordings for stations 11 and 31A are incorporated in figure 2; those for stations 17 and 6 are illustrated in figures 4 and 5, respectively.

The striking change in vertical temperature profiles that took place between June 23 and 28 is well illustrated by BT recordings at 4 stations within a small area south and west of Middle Sister Island (fig. 3). In this locality the upper waters warmed about 3 C and the bottom waters cooled about 2 C in the 5-day interval. The reason for the increase in the upper waters is clear, but the cause of the decrease of temperature in the bottom waters is less easily explained. As a general rule, the main stream of the Detroit River is much cooler than the water of the Western basin during the summer. On June 24, however, water temperatures at the mouth of the river were above 19 C or approximately 1.5 C warmer than the coldest bottom water in the Western basin on June 28. Either heat loss to the bottom sediments or the intrusion of colder water from the Central basin by internal waves are the most probable causes of this difference.

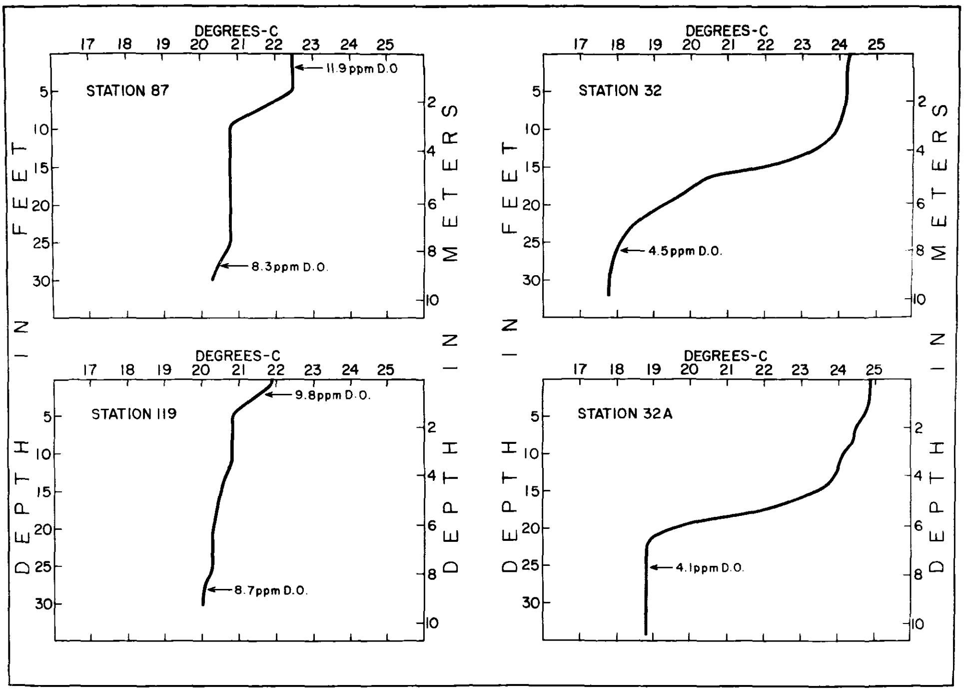

FIGURE 3. BT recordings at stations 87 and 119 on June 23, 1963, and at nearby stations 32 and 32A on June 28, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations.

The DO in the bottom waters was below 50 per cent of saturation at all stations along the east-west transect except station 7 northeast of Pelee Island (table 1). The lowest DO was 2.6 ppm (30 per cent of saturation) at station 26, near the outer buoy of the Raisin River shipping channel. Since a Nansen bottle was used for all water samples collected on June 28, no DO measurements could be made deeper than 1.4 m above the bottom. Dissolved oxygen at the mud-water interface was undoubtedly lower than the lowest values we report for the "bottom waters." The substantial decrease in oxygen content that accompanied a small change in depth and temperature is illustrated by conditions at station 33A (fig. 4). The difference in depth between two sampling points below the metalimnion at this station was about 1.8 m and the difference in temperature was only 0.5 C; yet within this interval the DO decreased by 3 ppm. If a similar rate of change occurred between the deepest sample and the bottom, the expected DO at the mud-water interface would be about 1 ppm. The inability of conventional water sampling devices to take samples in a narrow stratum just above the bottom may explain why previous studies have not reported more incidents of low DO in the bottom waters in Lake Erie (Carr, 1962).

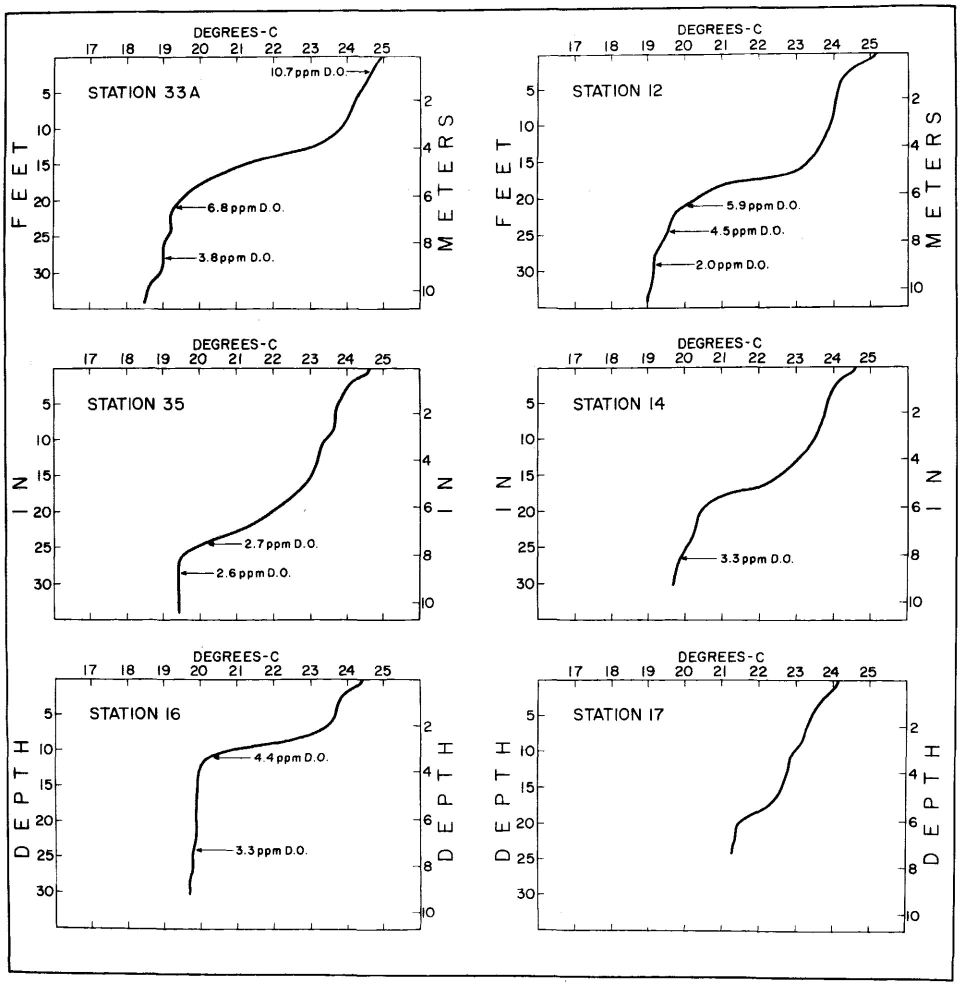

FIGURE 4. BT recordings at stations 12, 14, 16, 17, 33A, and 35 on June 28–29, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations.

Most of the stations visited, other than those on the east-west transect, were located in passages between islands and are not necessarily typical of conditions in the more open waters. Diversity of thermal structure and DO content apparently were as great among stations in the same passage as in different passages (figs. 4 and 5). Differences were particularly pronounced between stations 16 and 17 and, to a lesser extent, between stations 1 and 2, all of which are in the South Passage. Conditions were similar at stations 3, 4, 5, and 6 between Kelleys and Pelee Islands.

The area with the greatest depletion of DO on June 29 lay north and east of the Bass Islands and due west of Pelee Island (stations 12 and 35, fig. 1). The lowest level of dissolved oxygen found during the 2 days was 2.0 ppm at station 12. At the point nearest station 12, visited on June 23 (station 150, fig. 1), the water was homothermous with a DO content of 8.9 ppm at a depth 0.6 m above the bottom. In the 6 days between samplings, the average rate of oxygen consumption in the general area represented by the two stations was over 1 ppm per day. A similar rate of reduction was found in all areas in which comparisons could be made between conditions on June 23 and June 28–29. At this high rate of oxygen use, only a few days of stable conditions would be required before the oxygen deficiency would be lethal to sensitive bottom fauna.

Records of the U.S. Weather Bureau at Sandusky, Ohio, show that the hot,

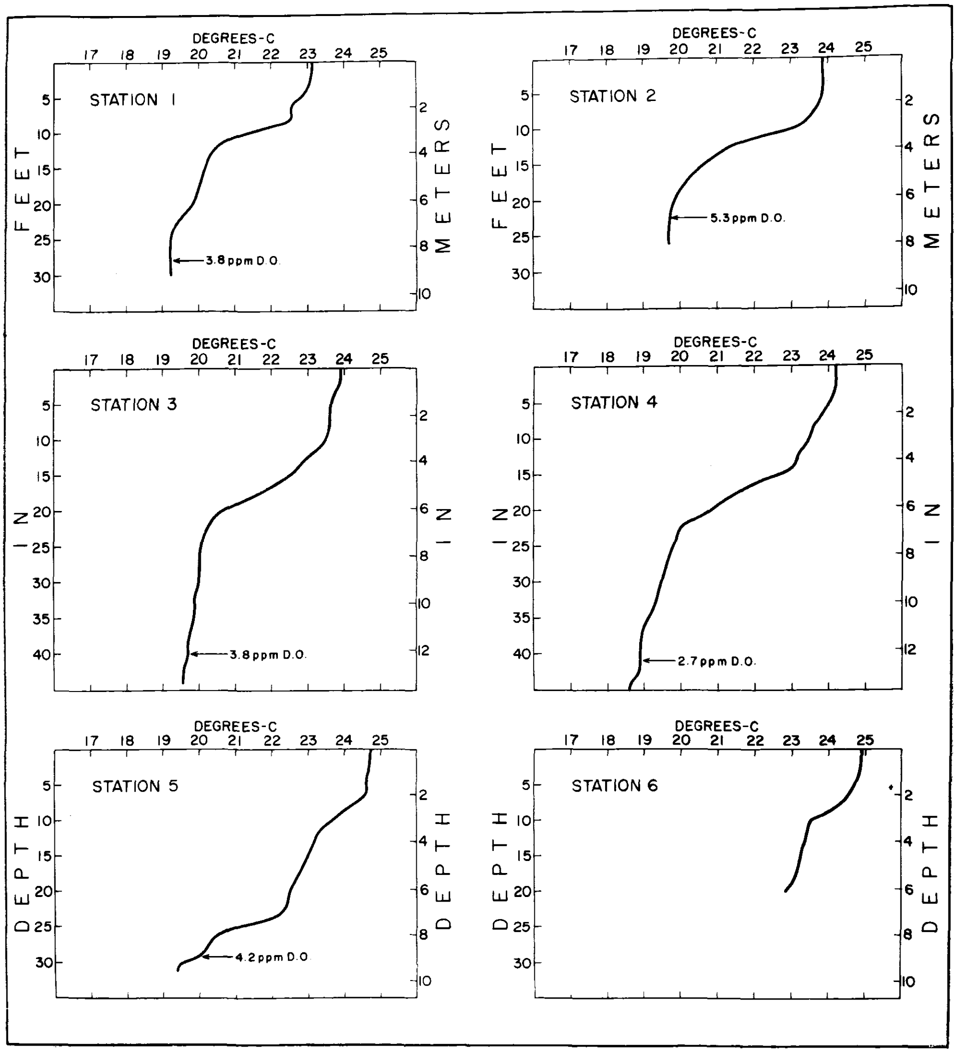

FIGURE 5. BT recordings at stations 1–6 on June 29, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations

calm weather that produced the stratification found on June 28–29 lasted until July 2. Oxygen depletion in the bottom waters obviously could not have continued at a rate of 1 ppm per day. It is very likely, however, that the DO in the bottom waters was less on July 1 than on June 29 when the last measurements were made. Water samples taken on July 9 during a subsequent cruise of the U.S. Bureau of Commercial Fisheries M/V *Kaho* revealed no thermal stratification or low DO in the entire island area of the Western basin.

CAUSES AND EFFECTS OF THERMAL STRATIFICATION IN WESTERN LAKE ERIE

We have given previously several reasons why western Lake Erie would not be expected to stratify thermally. Stratification does occur, however, when certain extreme climatic conditions prevail for a sufficient period to overcome the physical features of the basin. Our observations on June 23 and June 28–29 and records of the U.S. Weather Bureau during this period permit us to delineate the climatic conditions that should induce thermal stratification in a 5-day interval in any month from June to September. These conditions are: a daily average wind speed of less than 6 knots; a highest wind speed of less than 13 knots; and an average daily temperature of more than 18 C.

Weather records for Sandusky, Ohio, show that these or greater extremes of hot, calm weather occurred for 5 or more days on 33 occasions in the years 1953–1963. At least one such period occurred during each of the 11 years. The length of these periods varied from 5 to 28 days (average 7.5). The data strongly suggest that stable thermal stratification occurs in western Lake Erie more regularly and frequently than was heretofore suspected.

Not all periods of possible thermal stratification were necessarily accompanied by low DO in the bottom waters. In 1953, 28 days of hot, calm weather were required to reduce the oxygen in the bottom waters of the Western basin to critical levels, whereas only 5 days were required in 1963. We attribute this change to increased oxygen demand of the bottom muds in recent years.

Thermal stratification in western Lake Erie, unaccompanied by oxygen depletion, is largely of academic interest. On the other hand, oxygen depletion during these periods of thermal stratification has profound practical significance. Low DO in the bottom waters not only kills important benthic organisms but occasionally leads to significant fish mortalities. The volume of urban and agricultural drainage discharged into western Lake Erie has increased steadily for decades. Apparently some critical level was passed between World War II and 1953, which has brought about serious oxygen depletion during extended periods of thermal stratification. Since the rate of "enrichment" continues to increase, we can expect low DO in the bottom waters to occur with increasing frequency as less pronounced incidents of thermal stratification become capable of producing the same degree of severe depletion. If we again experience a 28-day period of calm, hot weather similar to that of 1953, it is likely that mortalities of fishes as well as other aquatic organisms in the Western basin will be without precedent.

ACKNOWLEDGMENTS

We wish to thank Robert P. Hartley, Geological Survey Division, Ohio Department of Natural Resources, who provided data collected during the synoptic survey of June 23, 1963, and the many staff members of the Ohio Wildlife and Geological Survey Divisions and the U.S. Bureau of Commercial Fisheries who aided in the collection of data.

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