DOES LOCAL RESUSPENSION MAINTAIN THE BENTHIC NEPHELOID LAYER IN SOUTHEASTERN LAKE MICHIGAN?

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ABSTRACT: **Time-series observations of water temperature, water transparency, and current velocity at four stations in southeastern Lake Michigan show that the benthic nepheloid layer is probably not maintained by the local resuspension of bottom sediment. Local resuspension may occasionally occur in the deep parts of the lake, but it seems likely that vertical mixing and offshore advection of sediment-laden water maintain the benthic nepheloid layer during most of the year. Although sediment trap data have been interpreted as indicating that local resuspension does occur, it is more likely that the increased sediment fluxes observed near the bottom are due to vertical redistribution of material already in suspension.**

INTRODUCTION

Benthic nepheloid layers (BNL) have been observed in the deeper parts of all of the Great Lakes (Bell et al. 1980) and are also found in the world's oceans. These layers are generally believed to be due to local resuspension of fine-grained bottom material that is then transported along isopycnal surfaces (McCave 1986). Chambers and Eadie (1981) studied the BNL in southeastern Lake Michigan in water depths up to 90 m. They found that the BNL was present in the hypolimnion throughout the stratified period and postulated that the layer was caused mainly by local resnspension, augmented by material that was resuspended in the area where the thermocline intersects the bottom (about 10–40 m) and then transported down the slope. From a series of water transparency profiles during and immediately after an autumn storm, Bell and Eadie (1983) found that upwelling currents generated by the storm redistributed material within the BNL and also reintroduced this material into both the nearshore area and the epilimnion. In a sediment trap study, Eadie et al. (1984) concluded that resuspension of bottom sediment occurred in the profundal areas of the lake throughout the year, a conclusion also reached by Robbins and Eadie (1991) based on the modeling of radionuclide concentrations in sediment trap samples. Studies of the BNL in Lake Ontario (Sandilands and Mudroch 1983; Rosa 1985) and in Lake Superior (Baker and Eisenreich 1989; Halfman and Johnson 1989) have also suggested that local resuspension is an important source of material for the BNL, but in none of these studies have both currents and TSM concentrations actually been measured. Thus, although there is indirect evidence that the BNL is maintained by episodes of local resuspension, there are no direct observations of these events. Simultaneous measurements of both currents and suspended sediment load have been described at only two locations in Lake Michigan: Lesht and Hawley (1987) made measurements in 28 m of water, and Lesht (1989) made measurements in 10 m of water. This paper reports the first time-series observations of temperature, current velocity, and suspended sediment concentration from the hypolimnion of the lake. Our goal was to determine to what extent local resuspension supplies material to the BNL.

STUDY AREA AND METHODS

Time-series measurements of current velocity, suspended sediment concentration, and water temperature were made in southeastern Lake Michigan during four deployments between 1984 and 1988. The first was made west of South Haven, Michigan; the other three were made near Grand Haven, Michigan (Fig. 1). Water depths varied between 65 and 100 m. Depth contours are relatively smooth and run approximately north-south at Station 19 and north-northwest to south-southeast at the other stations. Transects of the bottom depth at the Grand Haven stations and at South Haven are shown in Figure 2.

The instruments were mounted on bottom-resting tripods, with additional sensors mounted on the mooring wire in 1987 and 1988. The heights of the sensors and the sampling schemes are given in Table 1. All measurements of water transparency were made with 25 cm pathlength Sea Tech transmissometers. These readings were recorded to the nearest 0.001 volt over a nominal 5 volt scale. Temperature was measured with either an Analog Devices or a Yellow Springs thermistor; both of these devices are accurate to 0.1°C. Current velocity was measured with a variety of electromagnetic current meters. A Marsh McBirney 512 current meter with a separate directional sensor was used during the first two deployments, Interocean S4 current meters were used during the third deployment, and a Marsh-McBirney 585 current meter was used in 1988. All of these meters were calibrated in a towing tank prior to deployment. These tests confirmed that the meters had a resolution of 0.5 cm/s and that they were accurate to within 1 cm/s.

Profiles of water temperature and light transmission were also made during the deployments. When possible, profiles were made at the beginning and at the end of each deployment and, in some cases, at other times as well. We determined from these transparency profiles that significant fouling of the transmissometers occurred only during the latter part of the deployment at Station 26 (after 1 May). Since the fouling was quite severe, we have not included data collected after 1 May in our analysis. A set of cylindrical sediment traps (inner diameter = 10 cm, aspect ratio 5:1) was also deployed during each observation period to measure the vertical sediment flux.

Wind and wave measurements were obtained from the weather buoy (National Data Buoy Office #45007) located in the center of the southern basin (Fig. 1). The maximum wave period recorded during any of the deployments was 6.8 s. Linear wave theory shows that the effects of surface waves with this wave period will not reach depths greater than 36 m. Since all of our stations were in depths considerably greater than this, surface wave action could not have caused the resuspension of bottom material during any of our deployments.

We used Hawley and Zyrem's (1990) empirical equation for southern Lake Michigan to convert the beam attenuation coefficient calculated from the transmissometer observations to the concentration of total suspended material (TSM). This equation was developed using measurements of the TSM concentration made in conjunction with the vertical profiles mentioned above, as well as observations made at other stations in the southern basin. Hawley and Zyrem concluded that a single equation was sufficient to determine the TSM concentration with reasonable accuracy (0.3 mg/l) at all locations and depths within southern Lake Michigan, and that the equation was valid throughout the year. Moody et al. (1987) have shown that TSM concentrations during storm conditions are likely to be underestimated if they are calculated from equations based on observations during calmer conditions (as Hawley and Zyrem's were), but this restriction does not hinder the interpretation of our data, since the only data that we analyze quantitatively (the profiles) were collected during quiet conditions.

Spectral analyses were done on all of the time-series data sets. These analyses showed no significant energy peaks at frequencies greater than 2

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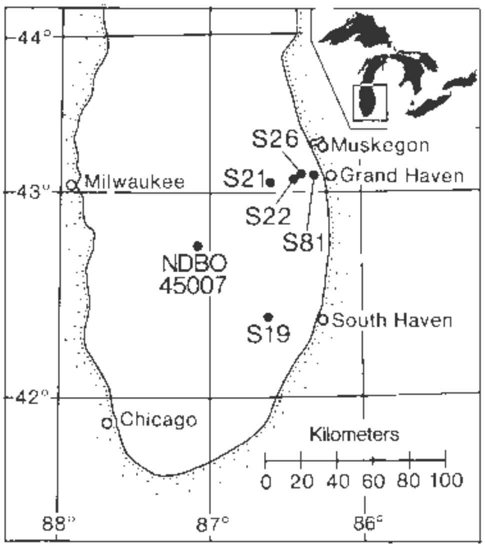

FIG. 1.—Locations of the moorings in southern Lake Michigan. The positions of the weather buoy (NDBO 45007) and the 1981 deployment (Station 81) are also shown.

cycles per day, but because the data sets cover a limited period of time the resolution of the low-frequency peaks is fairly poor—for a period of 18 hours the maximum resolution is only about 45 minutes. Prior to plotting, the data were passed through a 6-hour lowpass filter to remove the high-frequency variations. Hourly averages were computed prior to applying a fourth-order Butterworth recursive filter. A comparison of the filtered and unfiltered data for several different events shows that no important information was removed by applying the filter.

Examination of bottom samples (collected with a Ponar sampler) showed that the sediments at all four stations were cohesive. The material from the top centimeter was wet sieved to separate the sand fraction prior to determining the sediment size distribution with a Spectrex model ILI-1000 laser particle counter. Results from these analyses are shown in Table 2. All of the sediments are predominantly medium and coarse silt with minor amounts of fine sand. No clay-size material was fonnd in any of the samples.

To place our observations in context, some knowledge of the physical limnology of Lake Michigan is needed. Boyce et al. (1989) described the main features of thermal stratification and circulation in the Laurentian Great Lakes. Circulation in Lake Michigan is ultimately driven by the wind, but its large size (horizontal scales of hundreds of kilometers and vertical scales of 100 m) makes rotational effects important. During the unstratified period (roughly November–May) the effects of the surface wind stress penetrate to the bottom in the shallower parts of the lake, so near-

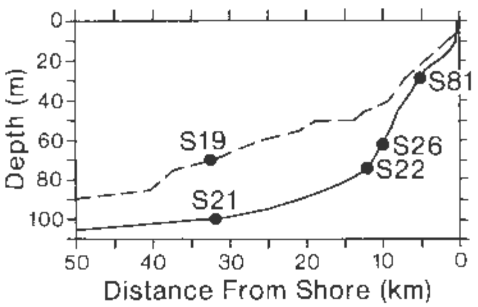

FIG. 2.—Bathymetric profiles of the lake bottom near Grand Haven (solid line) and South Haven, Michigan. Positions of the moorings are also shown.

TABLE 1.—*Deployment data**

	Station			
	19	22	26	21
Deployed	26 April 1984	4 October 1984	16 April 1987	18 July 1988
Retrieved	15 May 1984	25 October 1984	17 June 1987	12 August 1988
Latitude	42°21.67′N	43°0.95′N	43°2.76′N	43°0.72′N
Longitude	86°40.56′W	86°25.15′W	86°22.68′W	86°37.68′W
Water depth (m)	70	75	65	96
	Current measurements			
hts (mab)	0.77	0.28, 0.77	9, 27	0.5
Sampling period	continuous 15 min average	continuous 15 min average	1 min average every 10 min	1 min average every 15 min
Sampling rate	2 Hz	2 Hz	2 Hz	1 Hz
	TSM measurements			
hts (mab)	0.95	0.95	1, 2.5, 10, 25[a]	0.9, 16, 26
Sampling period	continuous 15 min average	continuous 15 min average	1 min average every 30 min	1 min average every 15 min
Sampling rate	2 Hz	2 Hz	1 Hz	1 Hz
	Temperature measurements			
hts (mab)	1.1	1.1	1, 9, 27	16, 26
Sampling period	continuous 15 min average	continuous 15 min average	1 min average every 60 min	1 min average every 15 min
Sampling rate	2 Hz	2 Hz	2 Hz	1 Hz

* mab = meters above bottom.
[a] Due to problems with the transmissometers only data through 1 May are discussed in the text.

shore currents are in the direction of the wind while a compensating return flow occurs in the center of the lake. The presence of a thermocline during the summer and fall (roughly June–October) inhibits vertical circulation, so a two-layer circulation is set up, with only the upper water responding directly to the wind stress. This causes both surface seiche action and tilting of the thermocline. In Lake Michigan south winds cause the thermocline to tip downward along the eastern shore (causing downwelling of warm surface water), whereas north winds cause it to tip upward (causing upwelling of cold bottom water).

The baroclinic instability caused by tilting of the thermocline also leads to the formation of internal waves in the lake. Mortimer (1980) showed that both standing Poincaré waves (with a period of 17 hr) and progressive inertial waves (with a period of 17.7 hr) could exist in the southern basin of Lake Michigan, and that the presence of either one could explain the observations of temperature and current velocity made there. Both types of internal waves rotate in a clockwise sense—opposite to the counterclockwise residual circulation. Our data sets are not long enough to allow us to distinguish between inertial and Poincaré waves, so in the discussion below we have followed Mortimer (1980) and referred to these internal waves as near-inertial waves.

OBSERVATIONS

Identification of sediment resuspension events usually relies on satisfying two criteria: (1) an abrupt increase in the suspended sediment concentration should occur simultaneously with an increase in the physical forcing function (in this case the current speed), and (2) the concentration should decrease to background levels within a reasonable time after the forcing ceases (the actual time for the decrease depends on the settling velocity of the material and the height to which it has been suspended).

TABLE 2.—*Grain-size characteristics*

	Station			
	19	22	26	21
% Clay	0	0	0	0
% Silt				
4–16 μm	1	0	0	2
16–32 μm	55	11	43	19
32–64 μm	31	74	36	74
% Sand	13	15	21	5

Those TSM events that cannot be identified as due to resuspension are usually described as advective episodes. In the analysis below we apply these criteria for resuspension to our time-series data. Two of our data sets (Stations 21 and 22) were collected during the stratified period, and the other two (Stations 19 and 26) were collected when the lake was well-mixed. We discuss the observations during the stratified period first, followed by the winter data.

Station 21

Two vertical profiles were made during the deployment, one on the first day of the deployment and the other on 9 August, 4 days before the instruments were retrieved. These profiles (Fig. 3) show that the lake was well stratified during the entire deployment with a well-developed thermocline at 70–85 mab. Both profiles also show a well-defined BNL, and that its thickness varied from 10 m on 18 July to over 30 m on 9 August. The sediment trap fluxes (Table 3) show a large increase near the bottom—a pattern interpreted by several investigators as indicating local resuspension (Eadie et al. 1984; Rosa 1989).

From 19 July to 31 July the TSM concentration 0.9 mab is quite high even though the current speeds are low, while later in the deployment the current speeds are high but the 0.9 mab TSM concentration is low (Fig. 4). The TSM records from 16 and 26 mab show the opposite pattern: they are low when the current speed is low and higher when the current speeds increase (note that the increase begins on about 1 August at 16 mab but not until 5 August at 26 mab). The peaks in the two upper TSM records show a high degree of correlation, but they also seem to correlate with decreased concentrations 1 mab. These changes in TSM concentration are consistent with vertical mixing and thickening of the BNL due to the higher current speeds that began on about 1 August, but they are not consistent with resuspension of bottom material. Vertical mixing would

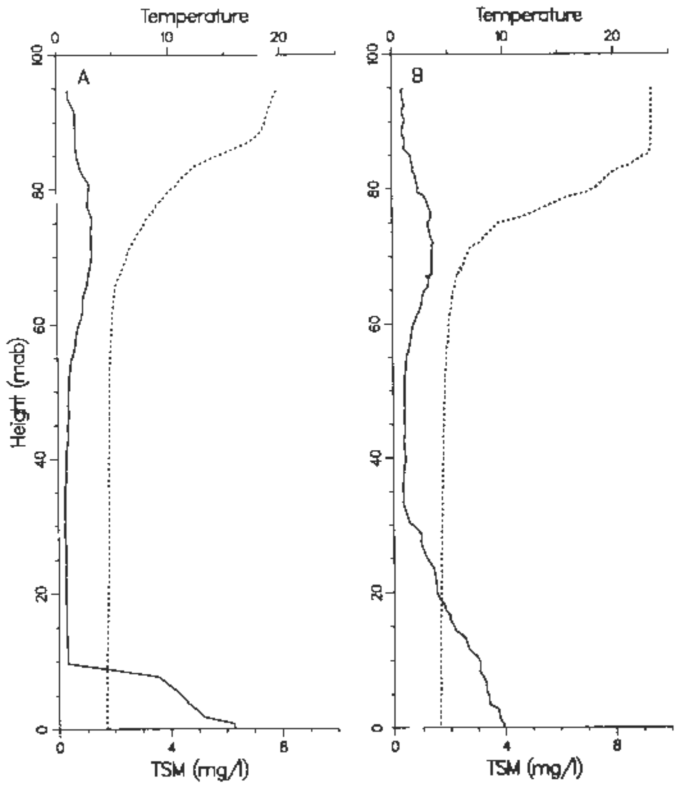

Fig. 3.—Profiles of TSM (solid line) and temperature taken at Station 21. A) Profile on 18 July 1988. B) Profile on 9 August 1988.

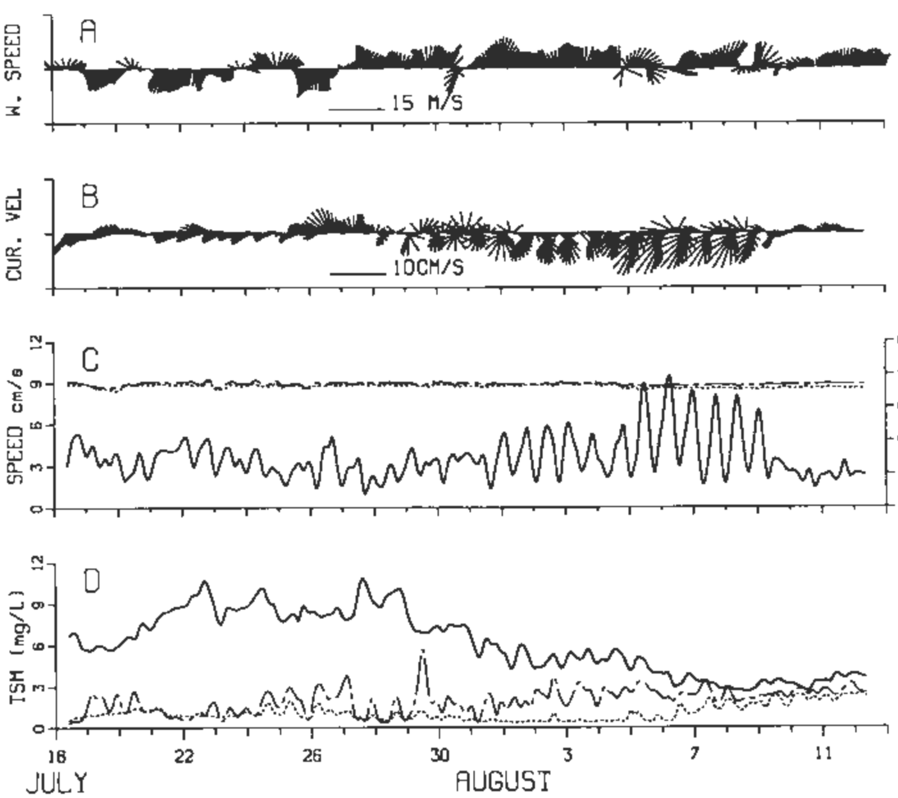

Fig. 4.—Hourly lowpass-filtered time-series data from Station 21. **A)** Stickplot of the winds measured at the weather buoy. **B)** Stickplot of the current velocity 0.5 mab. **C)** Temperatures 16 mab (interrupted line) and 26 mab (dashed line), and the current speed (solid line) 0.5 mab. **D)** TSM concentrations 0.9 mab (solid line), 16 mab (interrupted line), and 26 mab (dashed line).

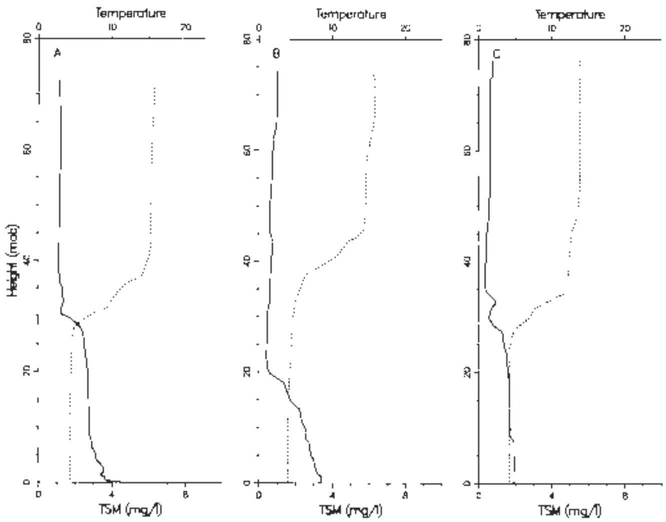

FIG. 5.—Profiles of TSM (solid line) and temperature taken at Station 22. A) Profiles on 4 October 1984. B) Profiles on 12 October 1984. C) Profiles on 25 October 1984.

TABLE 3.—*Vertical fluxes from sediment traps*

	Station			
	19	22	26	21
Deployed	23 April 1984	4 October 1984	16 April 1987	13 July 1988
Retrieved	16 May 1984	25 October 1984	17 June 1987	9 August 1988
Height (mab)	Flux in g/m²/day			
1	13.60	26.65	25.09	–
2	11.70	–	–	–
3	–	–	14.98	–
5	11.01	11.76	–	10.48
10	9.04	11.00	7.05	3.24
25	6.34	4.20	4.57	1.24
40	–	–	3.71	–
50	2.94	0.53	–	0.80

also explain the higher sediment fluxes observed near the bottom and is consistent with the increased thickness of the BNL at the end of the deployment.

Although wind speeds were low—they seldom exceeded 8 m/s—they appear to have been strong enough to generate iuternal waves. The rotary nature of the current velocities and the power spectrum of the current speed (which has a prominent peak at 18.2 hours) indicate the presence of near-inertial internal waves after 28 July. Since these internal waves were present at the same time that vertical mixing of the BNL occurred, they were probably at least partially responsible for the observed changes in the structure of the BNL.

Station 22

Vertical profiles were made at Station 22 on 4, 12, and 25 October. These show that the water column was well-stratified throughout the deployment (Fig. 5), and that the depth of the thermocline varied by about 10 m. The profiles also show that the BNL varied in both intensity and thickness; it sometimes included the entire hypolimnion. The sediment trap fluxes (Table 3) show a large increase near the bottom. Velocities at the two measured depths were very similar, so only those from 0.77 mab are shown in Figure 6. The rotary nature of the currents between 16 and 21 October and a peak in their spectral density at 18 hr indicate the presence of near-inertial internal waves during this period.

TSM concentrations during the deployment varied over a fairly narrow range and show little relationship to the changes in current speed. The poor correlation between the TSM and current velocity records indicates that no local resuspension occurred during the deployment. As at Station 21, the highest TSM concentrations 0.9 mab occurred when the current speeds were below average, whereas the TSM concentrations on 19–20 October—when the current speeds were the highest recorded during any of our deployments—were less than those recorded earlier.

We can compute a rough estimate of the mass of material in the BNL from the TSM profiles. These calculations show that the mass of material suspended within the BNL is not constant: for the three profiles shown in Figure 5, the totals are 72, 39, and 35 g for a column of water with a cross-sectional area of one square meter. Similar calculations for the two profiles shown in Figure 3 give loads of 41 and 59 g. Maximum uncertainties for these calculations due to the possible error in converting the transparency measurements to TSM are between 5 and 10 g, so there are real differences in the total amount of material suspended on different days. If only vertical

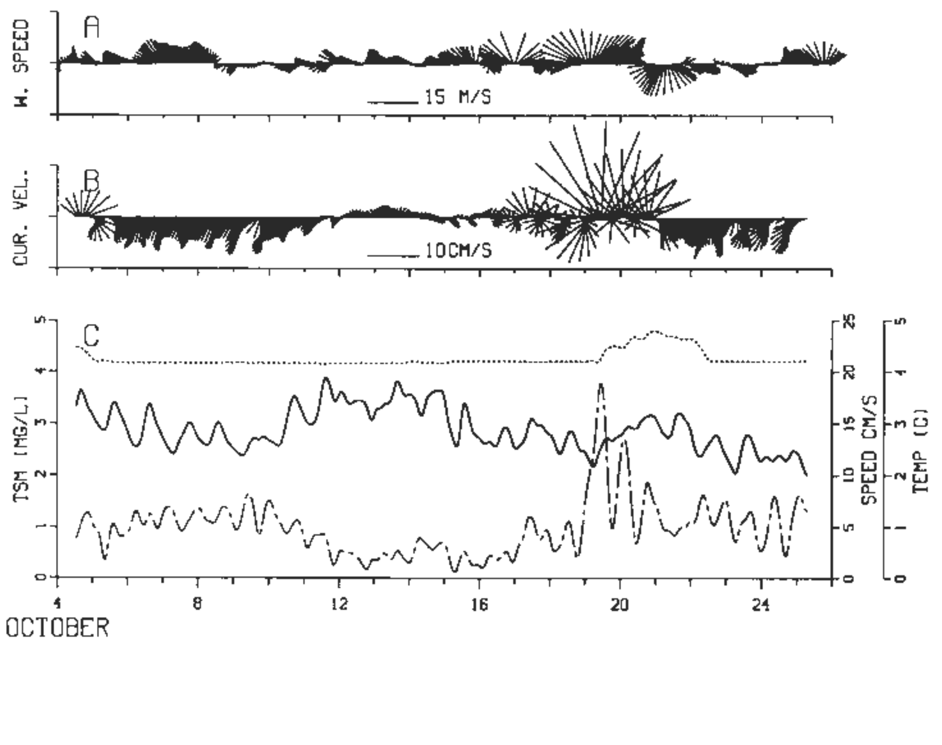

FIG. 6.—Hourly lowpass-filtered time-series data from station 22. A) Stickplot of the winds measured at the weather buoy. B) Stickplot of the current velocity 0.77 mab. C) Plots of temperature (dashed line), current speed (interrupted line) and TSM (solid line). TSM was measured 0.95 mab, temperature 1.1 mab, and speed 0.77 mab. Currents 0.28 mab (not shown) are similar to those 0.77 mab.

mixing were occurring we would expect the amount of material to remain relatively constant. Since this is not the case, and since there is no evidence of local resuspension, it seems likely that advection is also occurring.

Station 26

The 50-day deployment at Station 26 spanned the period when the thermocline was established. Unfortunately the TSM records after 1 May are suspect, so we have limited our analysis to only the first part of this deployment. Vertical profiles taken at the station on 16 April and on 27 May show that the lake began to stratify during this interval (Fig. 7), while profiles made on 23 April at Station 22 and on 1 May at Station 21 (not shown) indicate that the water was still isothermal at those stations. Although we cannot be certain, we believe that stratification began at Station 26 on about 10 May, because after this date both the velocity and temperature records show a strong oscillatory component with peaks in their energy spectra at 18 hr. If stratification did begin after 1 May, then all of the observations shown in Figure 8 were made while the water was unstratified. The sediment trap fluxes (Table 3) show a large increase near the bottom, similar to that seen at Stations 21 and 22, but that increase may have occurred after stratification began.

Three distinct episodes of high TSM concentrations (beginning on 19 April, 21 April, and 23 April) are evident in the 1.0, 2.5, and 10 mab records, and the third can be seen in the 25 mab record as well. As one moves away from the bottom, the TSM records in all three of these episodes show both a decrease in the maximum concentration and a delay in the onset of the increased concentration. Although both of these patterns are consistent with local erosion of bottom sediment, none of these three episodes can be identified as resuspension events because there is no simultaneous increase in TSM and velocity. The first event began during a period when the velocity was actually decreasing, and in the second event

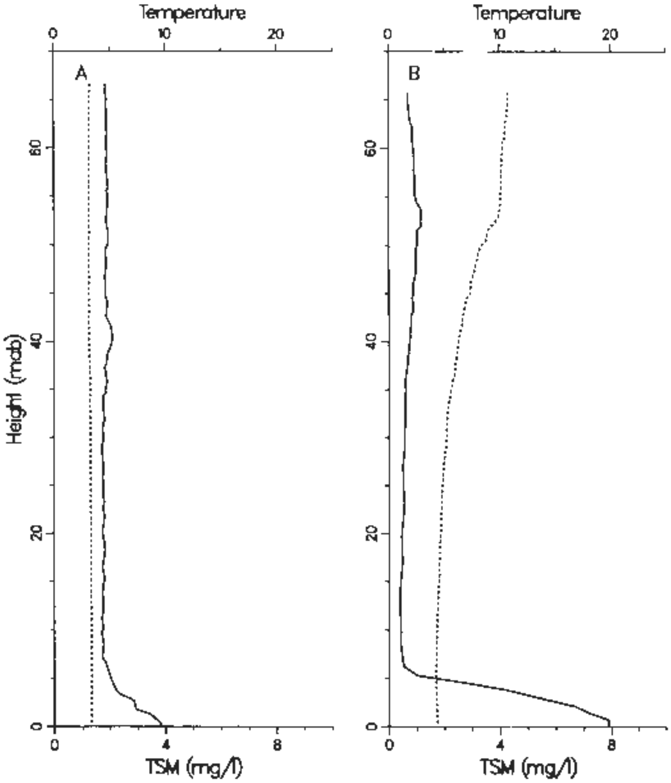

FIG. 7.—Profiles of TSM (solid line) and temperature taken at Station 26 in 1987. A) Profile on 16 April 1987. B) Profiles on 27 May 1987.

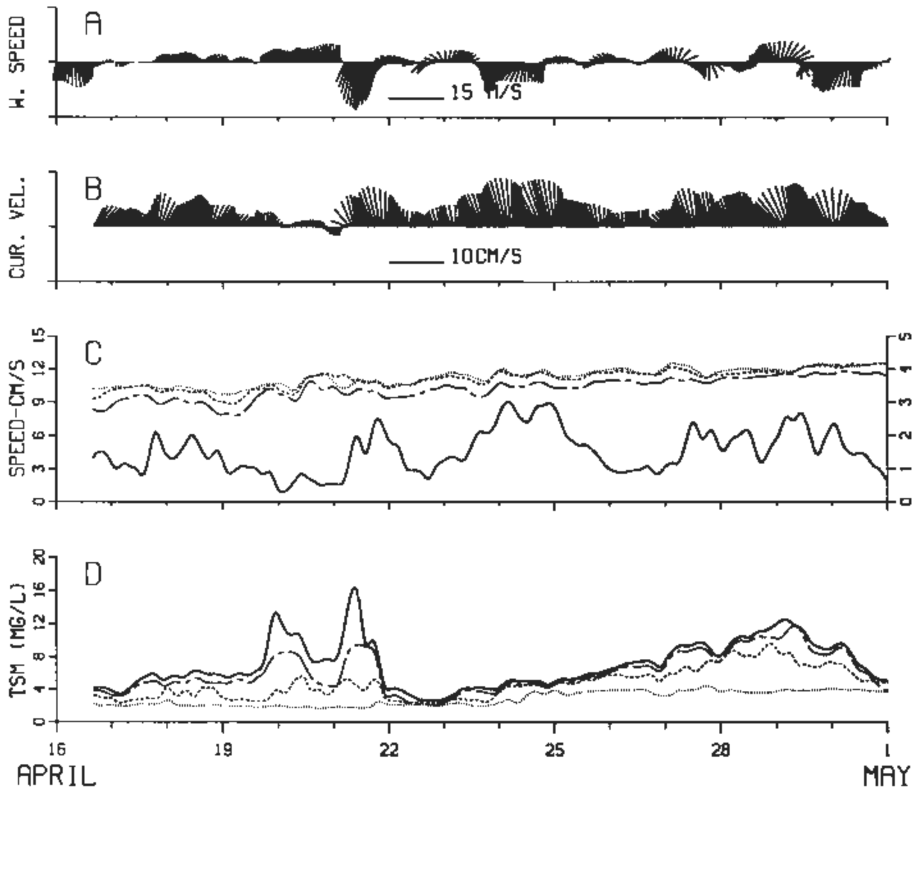

FIG. 8.—Hourly lowpass-filtered time-series data through 1 May at Station 26. A) Stickplot of winds at the weather buoy. B) Stickplot of current velocity measured 9 mab. The currents 27 mab are similar. C) Temperatures at 1 mab (interrupted line), 9 mab (dashed line), and 27 mab (dotted line), and the current speed 9 mab (solid line). D) TSM concentrations 1 mab (solid line), 2.5 mab (interrupted line), 10 mab (dashed line), and 25 mab (dotted line).

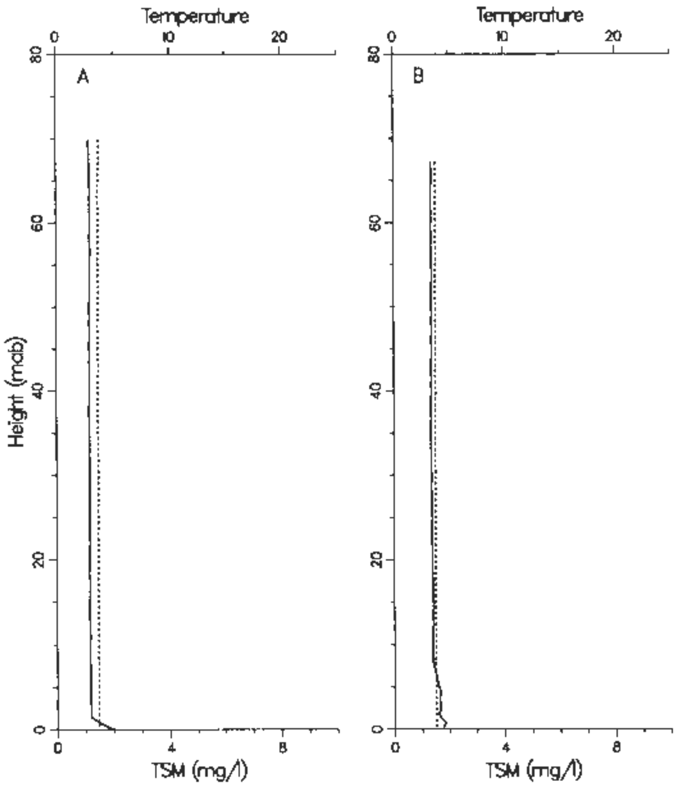

FIG. 9.—Profiles of TSM (solid line) and temperature taken at Station 19. **A)** Profile on 14 May 1984. **B)** Profile on 15 May 1984.

the increase in TSM began prior to the increase in the current speed. The third episode (23–30 April) lasted much longer than the other two; there was a gradual TSM increase for about five days followed by a decrease over the next two days. Although maximum concentrations occurred during a period when the velocity is higher than normal (27–29 April), even higher current speeds on 23–25 April produced only a small increase in TSM.

Station 19

The observations at Station 19 were also made during the unstratified period. The profiler did not work on the deployment date, and although point measurements made at several depths show that the water was isothermal we do not have enough data to determine if a BNL was present. By the end of the deployment the water was still isothermal and a weak BNL was present (Fig. 9). The fluxes determined from the sediment traps (Table 3) show a relatively small variation with depth; the fluxes near the bottom are only about two times that measured 25 mab and four times that at 50 mab. This is consistent with the conclusion of Eadie et al. (1984) that the entire water column is well-mixed during the unstratified period.

Again there is little correlation between the TSM concentrations and the current speed. As at Station 22, TSM concentrations were low (Fig. 10) and varied over only a narrow range (1–2.5 mg/l). The maximum current speed occurred on 30 April, during a storm in which the wind speeds exceeded 15 m/s. The TSM concentration decreased on this date, so this may also be another example of vertical mixing. If vertical mixing did occur on 30 April—and the sediment was mixed through the entire water column—then it would explain the relatively constant sediment trap fluxes. The other TSM fluctuations shown in Figure 10 can be explained by small variations in the thickness of the BNL similar to those shown in Figure 9.

DISCUSSION

There are instances in our data in which relatively high current velocities do not produce sediment resuspension (for instance, during the deployments at Stations 19 and 22). If one assumes a logarithmic velocity profile and a surface roughness of 0.05 cm, then the maximum bottom shear stresses during the deployments are 0.72, 0.99, 0.61, and 0.77 dynes/cm^2 at Stations 21, 22, 26, and 19, respectively. If the sediments were noncohesive, Mantz's (1977) diagram for granular material indicates that these shear stresses would be adequate to resuspend bottom material at all of the stations. Because the sediments are cohesive, however, it is much more difficult to determine the critical shear stress. The only estimate of the shear stress required to erode cohesive sediments in Lake Michigan was reported by Hawley (1991), who used an *in situ* flume to determine the critical bottom stress at Station 26. His results show that erosion occurred at shear stresses of 0.09 and 1.34 dynes/cm^2. The lower value probably

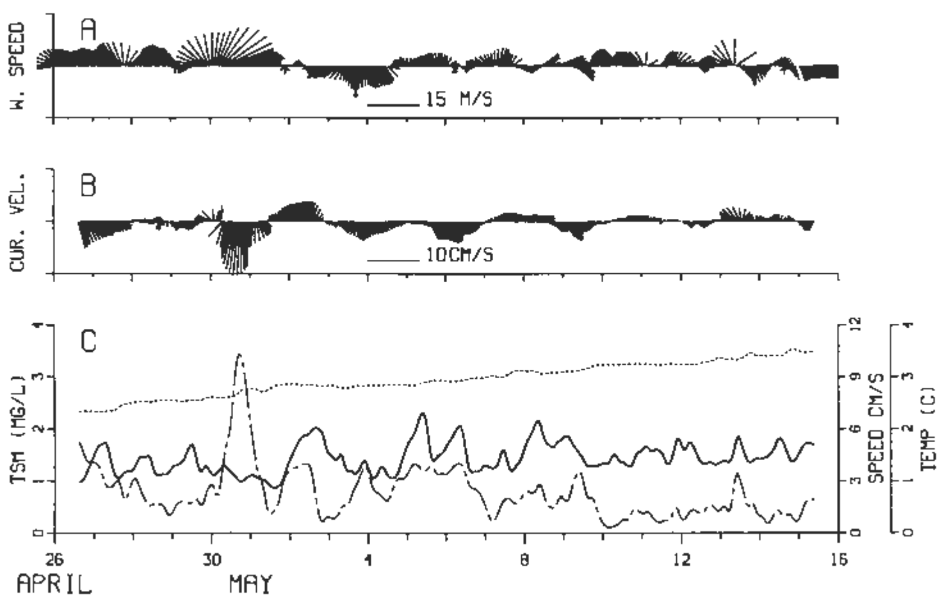

FIG. 10.—Hourly lowpass-filtered time-series data from Station 19. **A)** Stickplot of winds measured at the weather buoy. **B)** Stickplot of the current velocity 0.77 mab. **C)** Temperature 1.1 mab (dashed line), current speed 0.77 mab (interrupted line), and TSM 0.95 mab (solid line).

indicates erosion of a very thin layer of surface material, whose resuspension may not be evident more than a few centimeters off the bottom (due to dilution), while the larger value is somewhat higher than the shear stresses calculated from the deployment data. This larger value is equivalent to a current speed of 22 cm/s measured 1 mab.

Higher wind speeds could generate currents strong enough to resuspend bottom material, but such events must be fairly rare. There were no major storms during the deployment at Station 21—wind speeds seldom exceeded 8 m/s and none of these occurrences lasted more than a few hours—but at least once during each of the other deployments wind speeds continuously exceeded 10 m/s for between 18 and 24 hr, with maximum speeds of 14–16 m/s. A survey of the Lake Michigan wind records over a 32-year period (Transport Canada 1991) shows that storms of this size or larger constitute only about 8% of the total wind record each year, with the majority of the storms occurring during the winter. If our observations are representative, local resuspension either must be caused by other mechanisms or not occur very often.

Our observations show that the BNL is a dynamic region; neither its thickness nor the amount of material in the BNL remains constant with time. Vertical mixing of material already in suspension can redistribute sediment already suspended in the BNL, but it cannot be a source of new material. If local resuspension is not supplying additional material, the source must be material advected from elsewhere. Some material could be supplied by settling from above, but the 50 mab trap fluxes indicate that the amount of material available from higher in the water column is relatively small, at least during the stratified season.

One likely source of additional material is more turbid water from farther inshore. Nearer shore the shallower water depths may allow bottom material to be resuspended more frequently by either currents or surface waves. If this water is then advected to the deeper parts of the lake, it could furnish material to the BNL. Progressive vector diagrams of the currents at all of our stations show at least some periods of offshore movement. If the currents are similar farther inshore, then advective transport of turbid nearshore water could occur.

Advective TSM episodes associated with the passage of a hydrographic front were described by Churchill et al. (1988) from a location on the outer continental shelf. Similar transport may occur during downwelling events in Lake Michigan. We have previously reported (Lesht and Hawley 1987) observations made during October 1981 at a site in 28 m of water just southwest of Grand Haven, Michigan (Station 81, Fig. 1); the instrument configuration was identical to that used at Station 19. In that investigation we found that increased TSM concentrations correlated with either surface wave activity, movement of the Grand River plume, or increased current speeds associated with upwelling events (this is different from what Chambers and Eadie proposed; they suggested that movement of the thermocline across the bottom caused sediment resuspension due to internal waves). Although it is not noted in our previous paper, the data also show that high TSM concentrations were associated with downwelling events.

Water temperature records from the Muskegon municipal water intake (located approximately 1.5 km offshore in 13 m of water) show that downwelling events occurred during the deployment at Station 21 and possibly during the deployment at Station 22 (note the temperature increase shown in Figure 6) so it is possible that material was resuspended farther inshore by the same wind events that caused the downwellings, and that this material was then transported across the shelf and down the slope with the downwelling water; Lesht and Hawley (1987) reported a net offshore sediment flux of 4.3 kg/m^2/day during their deployment. During the unstratified period, a similar mechanism may have been in operation; bottom material may have been resuspended in the shallower waters by either currents or surface waves and then transported offshore.

Our observations during the unstratified period do not agree with those of Robbins and Eadie (1991), who found that the concentration of ^{137}Cs was almost constant throughout the water column in depths up to 160 m. Because ^{137}Cs is known to be associated with fine-grained bottom material, they suggested that bottom material from the deeper parts of the lake was continuously resuspended throughout the water column during the fall and winter. We think it more likely that the resuspension occurred in the shallower nearshore water during storms, and that this water was then transported offshore. Rea et al. (1981) suggested that downslope transport occurred during storms after the fall overturn, but we have no data to either support or refute this speculation.

It is also difficult to reconcile our observations during the stratified period with the results of geochemical studies (Baker and Eisenreich 1989; Robbins and Eadie 1991) that strongly suggest bottom material is recycled during the summer. Part of the problem is semantic. If the term resuspension is taken to include reworking of material near, but not actually on, the bottom, then the vertical redistribution of material in the BNL observed by us (as at Station 21) could be termed resuspension. Robbins and Eadie (1991) do exactly this by defining a "resuspendable pool" of material that includes material both on the bottom and within the bottom 20 m of the water column. If the material on the bottom and in the BNL is chemically identical, then the distinction between resuspension and redistribution may not be important, but both Baker and Eisenreich (1989) and Olivarez et al. (1989) have shown that there are chemical differences between bottom material and material suspended in the BNL. For this reason, and because in sedimentological studies the term resuspension refers to bottom material, we prefer to use the term vertical redistribution to emphasize that the material being recycled is already in suspension and is not a part of the lake bed.

CONCLUSIONS

Our data show no examples of sediment resuspension at depths greater than wave base in southern Lake Michigan. Current velocities are usually low, and are not strong enough to resuspend bottom material, although they do appear to be strong enough to redistribute material already in suspension in the BNL. Although resuspension may occur when the winds are stronger than those we observed, such episodes must be rare.

Given that resuspension events are infrequent, it is unlikely that the BNL is maintained by local resuspension, as suggested by Chambers and Eadie (1981), nor is it likely that the increased sediment fluxes near the bottom observed by Eadie et al. (1984) are due to local bottom resuspension. It is more likely that these enhanced fluxes are due to changes in the structure of the BNL that redistribute material already in suspension, as suggested by Robbins and Eadie (1991). Although this may appear to be a trivial distinction, it could be important if the chemistry of the material in the BNL is different from that of the material on the lake floor.

The BNL is probably maintained mainly by vertical mixing and by episodic downslope transport of material from nearer shore. Internal waves are common during the stratified period and may supply at least some of the energy required for mixing of the BNL. Resuspension of bottom material is more likely to occur in the shallower water closer to shore, and some of this material may then be transported to the deeper areas of the lake, thus maintaining the BNL.

Many of the features in our observations cannot be explained from the data available. We do not really understand how the BNL changes in thickness and in concentration. Our hypothesis that downslope transport of turbid water occurs needs to be tested, and the possible relation between internal waves and the mixing of the BNL needs to be investigated. An array of stations with sensors at several elevations will be required to address these questions.

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