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MONITORING OF DESCENDING DREDGED MATERIAL PLUMES[1]

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ABSTRACT. Monitoring of 2 disposal operations on Lake Erie near Ashtabula, Ohio, provided an opportunity to employ different approaches to study the physical impact of the disposal of dredged material on the hydraulic regime of the lake in this area. A study conducted in August 1975 involved utilization of several transmissometers placed on 4 anchored vessels and one moving vessel. The transmissometers were used to monitor the dispersing plume over time. Three-dimensional plots revealed that plumes tended to decrease in intensity beyond about 100 m from the point of discharge. Data interpretation was hampered due to difficulties in correlating data obtained from different transmissometers and because the direction of the plume could not always be anticipated with accuracy, resulting in that the major portion of the plume sometimes bypassed the boat further away undetected.

In May 1976 another dredging operation was monitored by utilizing over-the-side current meters and thermographs placed on an anchored vessel, as well as by tracing the plume with recording echo sounders. The measurements indicated that approximately a 2C temperature increase near the disposal site resulted from the discharged material falling to the bottom. The discharge also produced surges in the currents with speeds reaching 70 cm/sec. These changes, however, returned to normal within a few minutes. The sediment plumes were tracked with a moving vessel by using the echo sounder, which was able to accoustically detect the suspended sediments. The measurements showed that the material settled quickly and the conditions returned to ambient within an hour. Measurements of current speeds, transmissivity, and sediment plume movements taken in the disposal area indicate that the disposal of the dredged material has some short-term effect but no long-term effect on the physical nature of the area. Sediment piles from accumulating dredged material could be defined by employing bathymetric surveys, sediment traps, survey rods, and radiographs. The piles usually grew to a height of approximately 35 cm and were difficult to distinguish by means of echo sounders only. By employing discriminant analysis it was possible to discern the very similar dredged material and original lake bottom sediments based on their grain-size distribution.

The methodologies employed and some of the results obtained in this study are reported in this paper.

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INTRODUCTION

The Waterways Experiment Station (WES) in Vicksburg, MS, conducted an extensive interdisciplinary research effort to identify and to determine the short- and long-term impacts associated with the disposal of dredged materials, and in particular the significance of physical, chemical, and biological factors that govern the rate, extent, and diversity by which open water disposal sites are colonized by benthic communities. An investigation of the hydraulic regime and the physical nature of bottom sedimentation in Lake Erie was designed to be an integral part of DMRP in relation to the aquatic disposal field investigation at the Ashtabula, Ohio, disposal site.

The purpose of this investigation was to obtain baseline data on a dredged material

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disposal area in Lake Erie offshore from Ashtabula, Ohio. The data were required to establish seasonal variability of measured parameters, a controlled disposal site and a reference control area outside the disposal site. The control sites and 3 disposal sites are shown in fig. 1. Disposal sites D2 and D8 were monitored in 1975, and ND (new disposal site) was monitored in 1976. Groups from NALCO Environmental Sciences, Great Lakes Laboratories, and John Carroll University studied physical, chemical, biological, and fisheries aspects of this study. The general bathymetric profile of the study area is shown in figs. 2 and 3.

This article describes the results of the physical study obtained during monitoring of a dredging disposal operation at D2 and D8 in August 1975, and ND in May 1976. During the study period current speed and direction, temperature and transmissivity were determined within the water column, including monthly sampling at 7 different locations with permanently-installed current meters and thermographs, documentation of wave activity by means of a wave sensor and daily visual observations, monthly bathymetry and subbottom profile surveys, and meteorological measurements including wind speed and direction, air temperature, and solar radiation. Additional data such as precipitation, lake level, and discharge and suspended sediment concentration of the Ashtabula River were obtained from the United States Geological Survey.

In this article, the methodologies applied and the results which were obtained from the physical study during the disposal operation are briefly presented. This article is based on a report to WES by Danek et al. 1977.

METHODS AND MATERIALS

1975 DISPOSAL. The first disposal operation was monitored on 5 and 8 August 1975 at D2 and D8 (fig. 1). Ashtabula Harbor sediments were discharged at D2, and Ashtabula River sediments were disposed at D8 by the dredge Markham. Sediment and water samples were collected at locations D1–D12 and control sites C1–C4 (fig. 1). Ambient

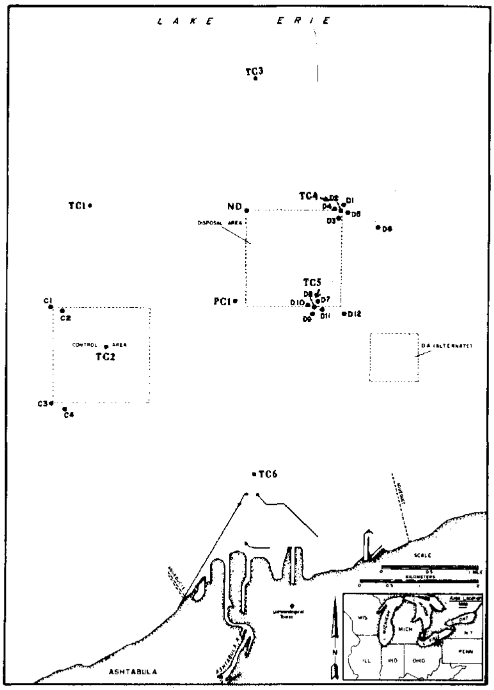

FIGURE 1. Location of sampling stations at the control and disposal sites.

measurements of temperature, transmissivity, and current speed and direction were taken prior to each discharge to determine the ambient conditions of the water column, to estimate the direction which the discharged sediment plume would take and to position the vessels. Four vessels then were anchored downstream from the respective disposal site at about 50, 100, 150 and 300 m distance from the center of the site (D2 or D8, fig. 1). The center of the location was marked with a Coast Guard buoy. In addition to the anchored vessels, a moving vessel was employed to follow the sediment plume. All boats were equipped with transmissometers, and the transmissivity of the water was monitored at approximately 10–min intervals and at 1–2-m depth intervals for 60–80 min after discharge, one profile being taken immediately before discharge. The transmissometers used were Montedoro Whitneys (Model TMA–1A), a Martek (Model 344), and a Hydro Product (Model 612A). The moving vessel was equipped with a Motorola Mini-Ranger Navigation System (lab. accur. ±3 m, field accur. approx. ± 10 m), a digital clock (NES Model DC 1205), and an on-board digital printer (Anadex Model DP-650A) which accurately records the position at approximately one-sec intervals. Two transponders were located on shore in Ashtabula, with a base line length of about 4,600 m. The transmissometer data were standardized to obtain a relative comparison

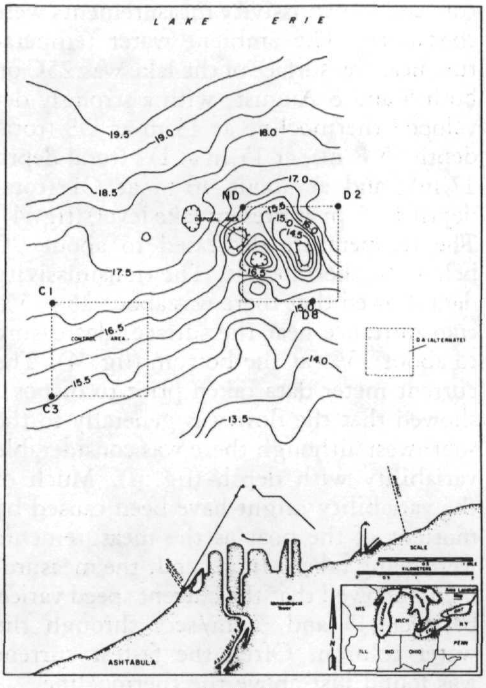

FIGURE 2. Large-scale bathymetry for July 1975; depth contours are in meters.

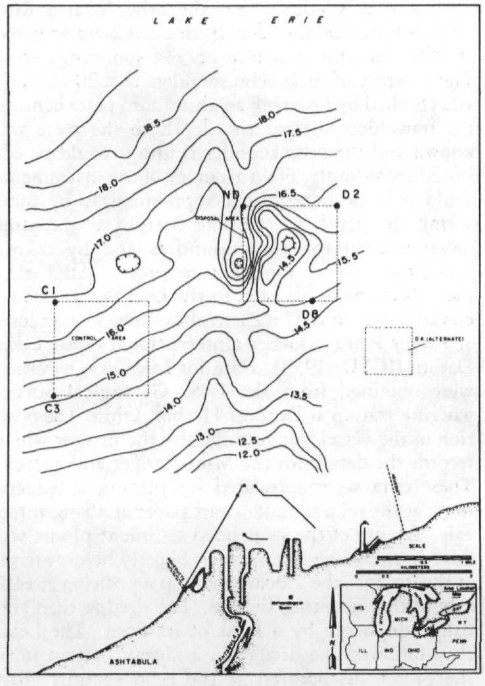

FIGURE 3. Large-scale bathymetry for September 1976; depth contours are in meters.

between the readings collected by the different vessels by dividing the highest reading obtained during measurements of one discharge by one instrument into all other readings. By this method a scale from one to 10% relative transmittance was obtained which allowed comparison of all measurements. Three-dimensional plots of transmissivity, depth and time that illustrate the flow of the sediment plume past the anchored vessels were then constructed by computer.

The disposal sites were also surveyed with a Raytheon DE–719B continuous recording echo sounder and a Ratheon RTT–100A Portable Survey System to measure and to record water depth and subbottom profiles. These surveys were conducted before, during, and after the disposal operations on a monthly basis during the entire study period in order to define: (a) the sediment piles, and (b) changes of the configuration of the sediment piles with time. A large-scale bathymetric survey was carried out over the entire area (15 km^2) at the beginning and end of the entire study period to detect large-scale sediment movements that could have taken place over time.

Lastly, 3 survey rods (graduated steel rods) were installed, one at the center of each disposal site (D2 and D8), and at control site C1 (fig. 1). These survey rods served to determine the height of the sediment pile at the center of the disposal sites and were serviced monthly by a diver. Two permanent current meters (ENDECO Type 105) and thermographs (ENDCO Type 100) along with a wave sensor (Bass Engineering Model WG/100M) were installed at one and 3 m off lake bottom (excluding the wave sensor) at the southwest corner of the disposal area to gather additional information (Danek and Alther 1982, 1983).

1976 DISPOSAL. The second disposal operation was conducted on 24, 25 and 26 May 1976 by the dredge Hoffman at the new disposal site ND (fig. 1). A fine-scale array of stations centered on the new disposal area (marked with a Coast Guard buoy) was established to closely monitor the distribution of sediments resulting from this disposal operation. Sediment traps and survey rods were installed at 17 locations, including control site C4, and were serviced monthly (Alther and Wyeth 1980). Bathymetric surveys before and after disposal were also carried out over the new disposal site. The locations were marked with red-painted cedar posts which were secured to the lake bottom by means of a polypropylene line attached to 2 concrete blocks.

The physical measurements during this disposal operation were concentrated mainly on mapping the sediment plume resulting from the dredged material disposal operation. This objective was carried out by 2 boats each carrying an echo sounder and the previously-described navigational equipment. One boat used a Raytheon and the other boat a Ross Laboratories echo sounder. Both units were operated at 200 Khz and at a rate of 534 soundings/min. The accuracy of these echo sounders is ±20 cm, and was checked by lowering an aluminum plate beneath the transducer so that the depth to the plate was known and the echo sounder readings could be adjusted accordingly. Field accuracy of the instruments could only be determined approximately by measuring the depth to the lake bottom at the same location with the echo sounders and by taking soundings with a temperature probe. All bathymetric data were adjusted to the Low Water Datum elevation which is 173.21 m above mean water level at Father Point, Quebec (International Great Lakes Datum (IGLD) 1955). Data for Lake Erie elevation were obtained from the U.S. Geological Survey gauging station at Fairport Harbor, Ohio. The position of the vessel was recorded by the printer which records the data from the Mini-Ranger and a clock. These data were correlated by placing a feducial mark at the echo sounder chart paper at 15-sec intervals. Tracing of the suspended sediment plume was done in the following manner: Shortly before arrival of the dredge, the 2 boats took up a position at each side of the incoming dredge. The dredge then signalled discharge by a blast of its horn. The boats then followed the dredge in a zigzag pattern until the plume disappeared at the echo sounder chart paper, thereby recording the descending plume. The data then were plotted by computer with a "CALCOMP" plotting package. This method had been successfully applied by Proni et al. 1975. WES personnel placed a transducer in an inverted position near lake bottom at a fixed position and were able to map the size of the discharging sediment cloud (B. Holliday, pers. comm. 1976).

On 26 May both boats collected water samples which were then analyzed for suspended sediment content and turbidity. The results were plotted on the accoustic profiles to show the detection limits of the echo sounders and how different suspended sediment concentrations appear on accoustic profiles.

A boat was tethered to the center buoy at the disposal site at a distance of 50 m. A Marsh-McBurney Model 1727 electromagnetic current meter with a Rikadenki 3-pen analog recorder (Model B38) and a thermistor temperature probe (M & F Engineering) which has an accuracy of ±0.05C were placed on the boat. Temperature and current speed and direction then were monitored continuously at one and 3 m off lake bottom and at mid-depth. On 26 May wind shade current drogues were employed at the surface and 1 m off bottom to help predetermine the direction the sediment plume was going to take.

RESULTS AND DISCUSSION

1975 DISPOSAL. The boats were anchored near the center buoy at increasing distance from the buoy and over-the-side temperature and transmissivity measurements were conducted. The ambient water temperature near the surface of the lake was 25C on both 5 and 8 August, with a strongly developed thermocline at 13 m at D8 (total depth 15.8 m), at 15 m at D2 (total depth 17 m), and at about 16 m at C1 (total depth 17.5 m at present lake level) (fig. 4). The temperature decreased to about 9C below the thermocline. The transmissivity data showed that there was about 25–35% transmittance near the surface, decreasing to about 15% at the bottom (fig. 4). The current meter data taken prior to disposal showed that the flow was generally to the southwest although there was considerable variability with depth (fig. 4). Much of the variability might have been caused by motions of the boat as the measurements were being taken. In general, the measurements showed that the current speed varied between 15 and 3 cm/sec. through the water column. Often the fastest current was found just above the thermocline.

The transmissivity data were first tabulated and standardized and then plotted in 3 dimensions as percent transmittance versus depth versus time (fig. 5). Values between the actual data points were extrapolated by the computer plotting routine. The values at time 0 represent the conditions immediately prior to disposal. The figure presents data from D8. Labels A1–A4 correspond with the location of the 4 boats within the plume. Fig. 5 shows that at station A1 there was a drop in transmissivity after about 10 min at all depths except near the surface. The greatest decrease, however, occurred at depths of 8 m and 13 m which implied that there were concentrated sediment plumes at these depths, perhaps sitting on top of the thermocline. The plume at 8 m was caused by the concentration of finer-grained sediments, perhaps flocculated clays, while the plume at 13 m may have been produced by slightly heavier material at the thermocline. A double thermocline may have been responsible. Decreases in transmissivity were also measured at sta-

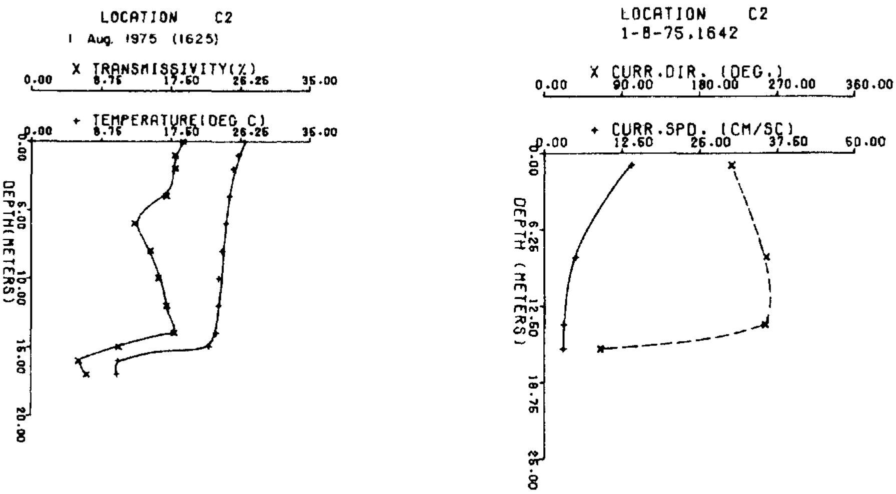

FIGURE 4. Vertical profiles of temperature, transmissivity and currents measured between 1 and 5 August 1975.

tion A2, especially near the lake bottom, although the decrease is not as pronounced as at A1, the point of disposal. Virtually no changes are observed at A3 and A4, 100 and 200 m away from the point of disposal, which implies that only the outer edge of the plume was picked up by the transmissometers, the main plume having either already sunk or that the boats were not positioned in the general direction of the plume. Generally, the plume was only detected by the 2 nearest vessels which implied that it did not spread out over a large area but rather drifted with the current.

Difficulty in positioning the vessels exactly downstream frequently allowed the plume to drift away undetected by the outlying stations. It must also be realized that the majority of the sediments settle immediately to the bottom upon discharge, as further studies have shown, and that for this reason the sediments which are detected farther away from the point of discharge should be of a progressively finer-grained nature. The frequently lower readings observed at 8 m depth were also often observed at these and other locations during surveys on 1 August (before dredging) and on 15 August (after dredging). It is suspected that planktons favor this depth and therefore caused this decrease in transmissivity. This theory cannot be proven, however, for the transmissometers do not distinguish between organic and inorganic matter.

1976 DISPOSAL. The second disposal operation was monitored on 24, 25 and 26 May 1976. Two vessels were anchored near the center of the disposal site. One boat was tethered directly to the center buoy with a 50-m line. On 26 May, wind shade current drogues were deployed to measure the speed and direction of the currents as an aid to position the other vessel downcurrent. These drogues consist of a float to which, by means of a rope, a sail is attached. The current pushes the sail, and the marked float can be tracked. The results of the drogue measurements showed very slow surface currents with considerably faster currents at 16 m flowing to the southwest.

During the disposal the dredge Hoffman discharged its material to the northwest of the buoy which was typically about 70 m from the tethered vessel. The Hoffman discharged a total of 48,000 m^3 into the designated area. This material consists of fine-grained silts and clays (Alther 1981).

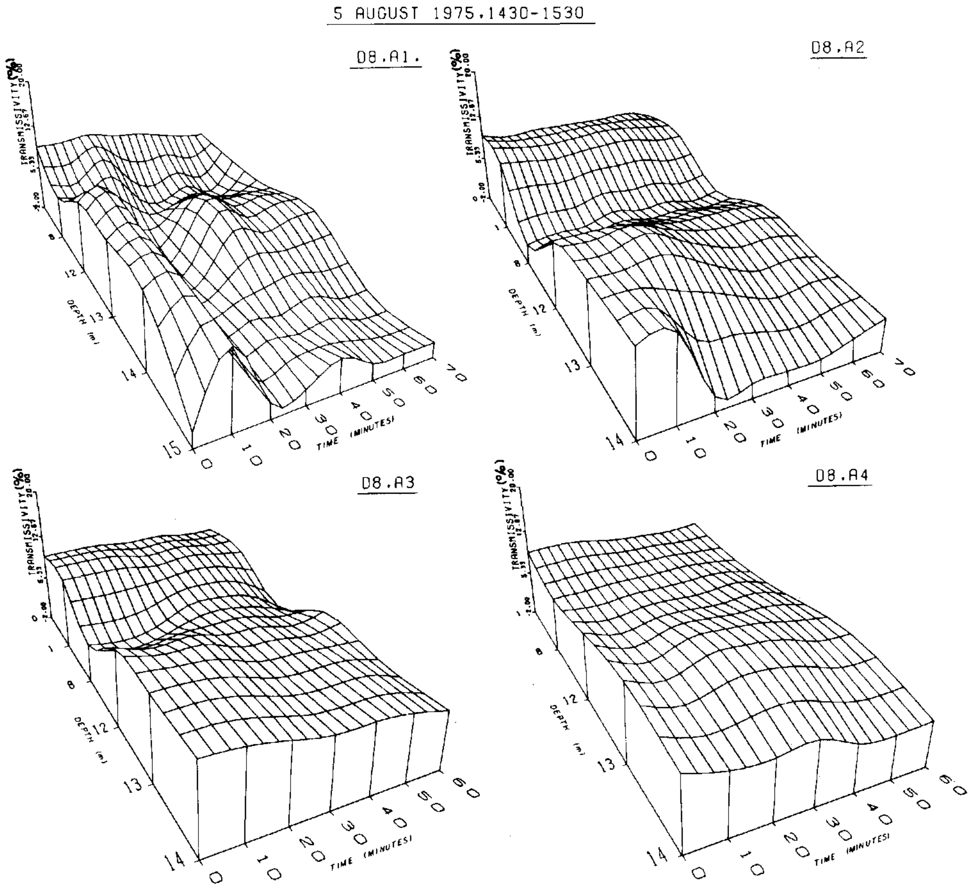

FIGURE 5. Three-dimensional plots depicting the movement of the sediment plume past the anchored vessel stations during river sediment disposal.

Dumping was conducted over a period of 4 days. The dredge opens its hopper doors, and the sediments plunge to the bottom. Continuous temperature readings were taken during several of the discharges (fig. 6). The descending material produced a 2C increase in the water temperature even near the bottom. The temperature increased sharply and then either decreased steadily or decreased with large flocculations as the turbulent plume spread past the temperature sensor. It took between 3–5 minutes for the plume to reach the sensor which indicated that the plume traveled at a speed of between 20–40 cm/sec. It was difficult to make a more accurate estimate of the speed because the exact distance to the dredge was not known. Approximately 20 min after the plume reached the sampling station the temperature returned to the ambient temperature. The rise in temperature was caused mainly by 2 events: first, the disposed material was warmer since it was dredged from the shallower harbor and the river, and second, the entrainment of warm surface water by the descending sediment material and subsequent mixing brought temporarily warmer surface waters to the bottom.

A similar sudden change was observed in the currents (fig. 7), which were monitored simultaneously with the temperature. As the plume reached the current

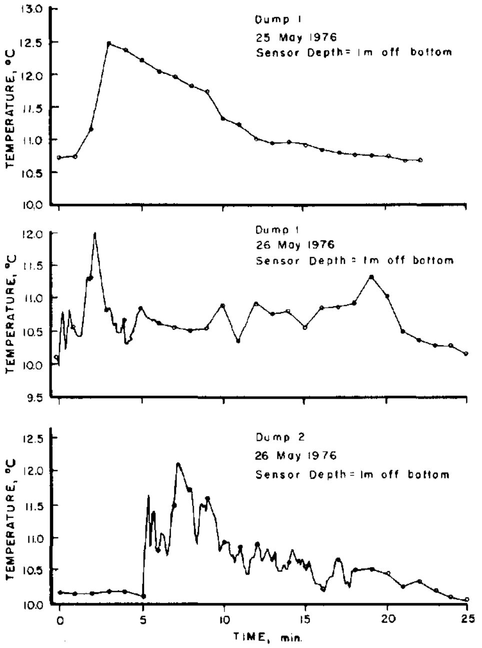

FIGURE 6. Continuous temperature measurements obtained during discharge of dredged material.

meter sensor, the current speed increased to values as high as 70 cm/sec which were usually accompanied by large fluctuations in the direction. The speed frequently dropped to its background value within a few minutes, but occasionally large fluctuations persisted for 10 min or longer. The impact on the current speed was less at 3 m from the bottom and at mid-depth than right near the bottom, which implied acceleration due to gravity and that the plume upon impact spread out along the lake bottom.

An important part of the study was to define the movement of the sediment plume following the discharge of the dredged material. A vessel was used to follow the plume and the distribution of the suspended sediments was measured with echo sounders. A typical profile of the plume (fig. 8) showed that generally there was a very high concentration of dredged material and air bubbles in the near surface area immediately following the discharge. Most of the dredged material descended to the bottom as soon as the hopper doors on the dredge were opened. Finer-grained material stayed in suspension for about 12 min and travelled with the currents for more than 100 m. A brown cloud of very fine-grained material was usually visible from the air for about an hr but the material could not be detected by the echo sounders.

Since the technique of tracking the sediment plume with an echo sounder proved to be useful, an attempt was made to determine what suspended sediment concentrations could be detected acoustically by the echo sounder. On 26 May both boats were used to collect water samples at the edges of the sediment plume. The water was then analyzed for suspended sediments (ppm) (Rukavina and Duncan 1970) and turbidity (NTU, nephelometric turbidity units). The exact depth where the samples were collected was accurately determined as the sample bottles and the descending messenger which triggers the closing mechanism of the sampler frequently appeared on the acoustic profiles (fig. 8). When the water samples were analyzed and the results correlated with the readings from the echo sounder, it was determined that the echo sounder would detect suspended sediment concentrations down to 2 ppm and turbidity as low as 2.9 NTU.

In order to determine approximately how much sediment was accumulating during the disposal operation, readings were taken by a diver on the survey rods. On 24 May, after the first day of disposal operations, about 18 cm of sediment had accumulated near the center of the disposal site. On 26 May following the completion of the operations, the readings showed that an additional 10 cm had been deposited, implying that the pile spread out.

Two radiographs and X-ray scans of sediment cores that were collected on 20 May (predisposal) and 13 June (postdisposal) were examined to determine some of the changes produced by the disposal operation. The 2 cores were collected at the same location but the results (Alther and

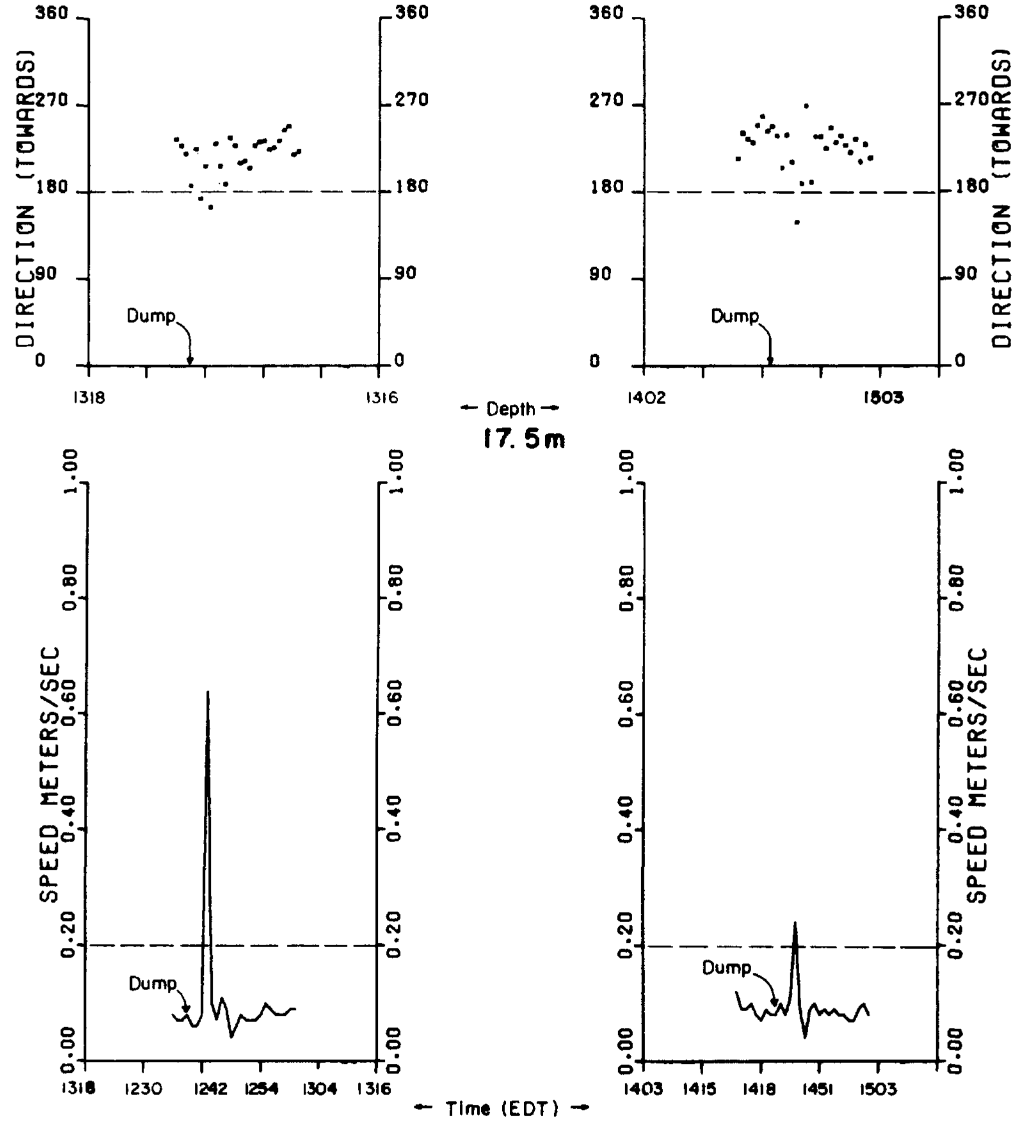

FIGURE 7. Current speed and direction of changes observed during 2 dumps of dredged material on 26 May 1976.

Wyeth 1980) showed that the characteristics of the sediments were quite different. Prior to the disposal the surface consisted mainly of mud with some sand, whereas after disposal the surface sections showed distinct laminations resulting from the periodic discharging of the dredged material. A pronounced density discontinuity was noticeable on the June X-ray scan which marked the interface between the old and new sediments. The sediments above the discontinuity contained plant fragments, cinders, and other debris that were discharged with the dredged material.

The use of discriminant analysis enabled differentiation between the lake bottom sediments and the dredged material based on their grain-size distribution (Alther

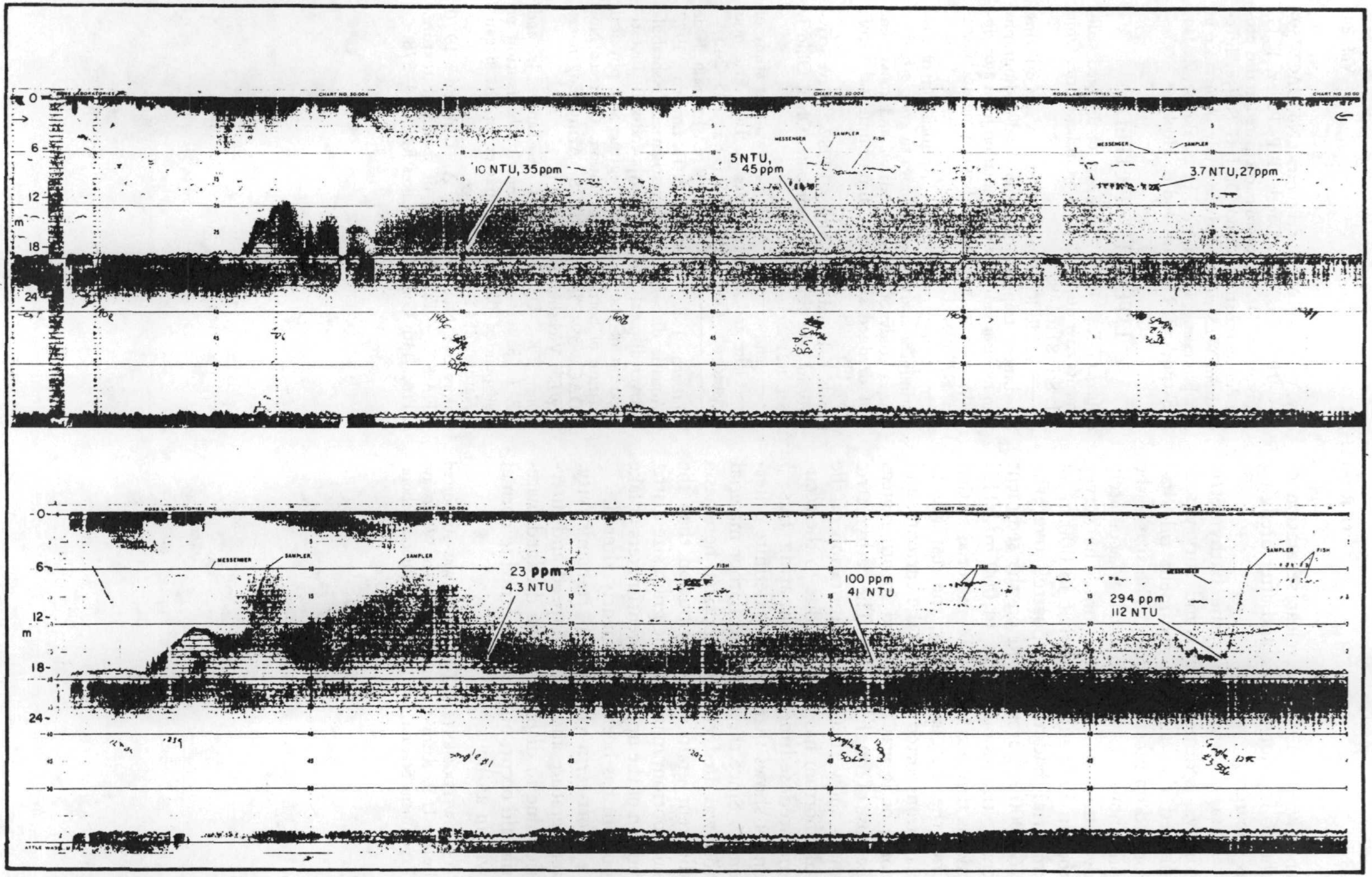

FIGURE 8. Accoustic profiles of suspended sediment collected during the fourth dump (top) and third dump (bottom) on 26 May. PPM denotes concentration of suspended sediments and NTU describes turbidity measurements.

and Wyeth 1981). A clear separation of the 16 locations before and after dredging is apparent.

Data obtained from the bathymetric surveys, sediment traps and survey rods showed that a small sediment pile had formed on most locations. The size of the pile, however, was too small to accurately determine its configuration. The survey rods in 1976 suggested that 18,000 m^3 of material had been deposited over the 160,000 m^2 area; based on the sediment traps, the amount was 14,000 m^3. This means that less than 40% material settled into the designated area; the rest was in part transported away by the currents, and some of it was discharged in other areas because of rough weather. The bathymetric maps show that the configuration of the lake bottom has changed due to the accumulated sediments. Comparing figs. 3 and 4 shows that there are definite differences. Since the river and harbor material that was dredged and deposited here has a different grain size distribution than the lake bottom material, the grain size distribution of the upper few centimeters of lake bottom has been permanently altered.

Short-term changes in transmissivity, temperature and current speed and direction due to disposal of the dredged material did occur, but they returned to normal within an hour.

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