

TRANSPORT OF DREDGED SEDIMENTS AFTER DISPOSAL OPERATION IN LAKE ERIE<sup>1</sup>

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*Abstract.* A dredged material disposal operation was monitored on a location in Lake Erie 8 km offshore Ashtabula, Ohio, June to November, 1975. Some 200 sediment cores were collected in the periods before and after dredging and analyzed for the grain-size distribution of the sediments. Two current meters and a wave sensor moored nearby monitored the movement of the water masses. The sediments were dredged in the Ashtabula River and Harbor and discharged at a pre-designated location by a hopper dredge. A control site was established nearby. These sediments proved to be very similar to the ones from the lake bottom at the disposal site and the control site. Because of this similarity, it was extremely difficult to distinguish between the dredged material and the lake sediments without tagging the dredged material. Plotting the percentage of sand, silt and clay in several replicates collected at one site before and after disposal of dredged material allowed distinction between local and dredged sediments. Sediment transport could approximately be determined by the use of a modified computer program (SEDMOT), which calculates and plots progressive vector diagrams based on pre-assigned critical erosion and deposition velocities for specific grain sizes. The results showed that silt-sized sediments could have been transported over distances as large as 20 km. The main direction of transport was northeast and southwest, following the bottom topography.

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A dredged material disposal operation was monitored on a location 8 km offshore Ashtabula, Ohio, in Lake Erie. One of the objectives of the program was to study the movement of dredged sediments. In order to achieve this objective, the grain size population of the sediments from the Ashtabula Harbor and River, which was to be dredged, and of the lake bottom at the disposal site was analyzed. After dredged material was disposed, we again collected lake bottom sediments at the disposal site. With the aide of current meters and a wave sensor, we attempted to interpret the resulting differences in sediment distribution and to determine possible directions and distance of transportation.

Many attempts have been made to determine the amount and direction of sediment transport in water environments similar to that in Lake Erie.

Three basic methods are generally used to estimate the sediment transport:

1. analyzing sediment grain-size distributions by use of moment statistics over several time intervals and estimating the direction of transport by comparing changes in the geographic distribution patterns (Pezetta 1975)
2. estimating the direction of transport by using measured water current values (McClennen and Kramer 1976)
3. tagging the sediments with radioactive cations and tracking their movement (Leahy *et al* 1976).

These three methods (or slight variations of them) have been used with limited success in tracking sediment movement.

McBride (1975) used trend surface analysis on several statistics computed from particle-size distributions of sediments collected in the western basin of

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Lake Erie to determine the direction of sediment transport in Maumee Bay. This method, however, does not always work for tracking dredged material because the sediments of the original lake bottom may be indistinguishable from the disposed material and trends in the sediment distributions may not be apparent.

Predictions of sediment transport by measuring water current values have also met with limited success. The problem is in accurately determining

the critical erosion velocity of the current (or boundary-shear stress). Attempts to measure this parameter for various grain sizes have been made in both the marine environment and in the laboratory (e.g., Sternberg 1972, Sundborg 1967, and Hjulstrom 1939). Results from these studies, however, show considerable variation, and estimates of sediment transport based on this method can be considered only an approximation.

The most promising and probably the

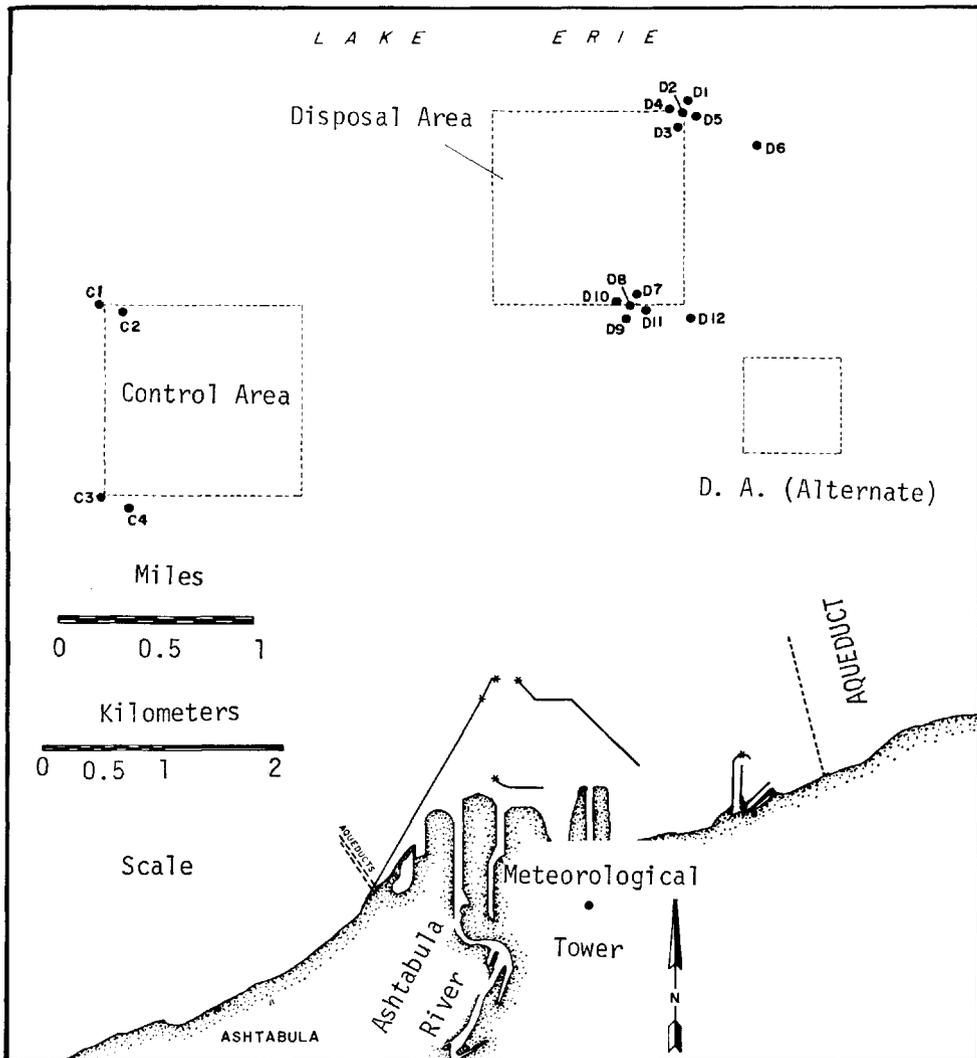


FIGURE 1. Location of sampling stations at the control (C1-C4) and disposal sites (D1-D12) in Lake Erie near Ashtabula, Ohio.

most accurate method for tracking dredged material is by tagging the material with radioactive cations before it is discharged into the aquatic environment. Analysis of sediment samples taken after the disposal operation can readily determine where the material has been deposited and/or transported. The major problem with this technique is finding an efficient method for tagging the material, which in many cases is cost-prohibitive. This study reports results on estimating the direction and distance of sediment transport by using measured water current values.

#### FIELD AND ANALYTICAL METHODS

Figure 1 shows the disposal area divided into two disposal sites with sampling stations D1-D6 in the northeast corner and D7-D12 in the southeast corner. A control area southwest of the disposal area includes four sampling stations, C1-C4.

Five replicates of over 200 sediment cores were collected by Great Lakes Laboratory with a Wilco Gravity Corer and by a diver at D1-D12 and C1-C4 at monthly intervals for a period of five months (July-November). Three different sections from each core, at approximately 7-cm intervals, were analyzed for particle-size distribution (7 size fractions) by means of the F.A.S.T. technique (Rukavina and Duncan 1970). These size fractions were -2.6, 0.2, 0.5, 1.0, 3.0, 5.8, and 8.6 phi (-log<sub>10</sub> of mm fraction).

The currents at 1 m and 3 m off bottom were monitored at a location at the southwestern corner of the disposal area by means of two ENDECO type 105 current meters, which were secured to a mooring on the lake bottom. The velocity data were used to estimate sediment transport rates in the area. We used a modified computer program (SEDMOT), originally written by McClenen and Kramer (1976), for this purpose. This program was included in another program that calculates and plots progressive vector diagrams called PROVECS.

PROVECS are formed by connecting the consecutive velocity vectors head to tail to produce a diagram that depicts the history of water motion past a given point. Such diagrams give a continuous picture of the speed and direction of the flow past the disposal site so that episodes of strong current or velocity changes can easily be recognized. Sediment transport is then determined in the following manner: the data from the current meter are included in the computer package. Erosional and settling velocities based on Hjulstrom's curve (Hjulstrom 1939) and 5 grain sizes that were found to be the most frequent in the sediments are transferred to the data storage of the computer. The program then scans the current meter records to locate episodes where resuspension of these grain sizes could be ex-

pected. The plot began whenever the currents exceeded the erosional velocity of the particle size of interest and ended when the speed fell below the depositional velocity. These plots were then used as a theoretical estimate of sediment movement.

#### SEDIMENTOLOGICAL SETTING

The sediments in the study area consist of deposits of sand, silt, and clay, which often contain shale fragments, sand pebbles and shells. The total thickness of the sediments overlying the bedrock surface in the disposal area varies from 20 m to about 40 m (C. E. Herdendorf 1975). The collected sediments consist of approximately 90% quartz with about 4% feldspars and 2% dolomite and other carbonates. The remainder consists of a number of other minerals such as garnets, pyroboles, ilmenite, appatite, micas and clays (NALCO ES 1976). The top 10 to 15 m of sediments are of recent origin (deposited in the last 8,000 to 10,000 yr.) and were, in part, eroded from the bluffs by rain, frost, and wave action and deposited on numerous narrow beaches or carried a short distance offshore (Hutton 1940). The underlying lacustrine sediments were deposited in the glacial lakes Warren, Lundy, and early Lake Erie (Hough 1958) and rest on top of hard till deposited during the Valdres Substage and the Two Creeks Interval of the Wisconsin Glaciation. The entire unconsolidated sedimentary overburden rests on top of the Ohio Shale (Hough 1958).

The sedimentation rate near Ashtabula (Lat. 42°2.6', Long. 80°52') is a maximum of 0.3 cm per year based on Cs<sup>137</sup> dating (Evans 1973). An investigation by Kemp *et al* (1974) revealed a mean annual accumulation rate of 0.51 mm at a site some 30 km offshore to the northwest of Ashtabula (Lat. 42°0.2', Long. 81°36.2'). The results of studies carried out during the past two decades show that the surface portions of the sediments near the disposal site are 99% medium fine sand. At locations adjacent to the disposal site, the sediments consist of more than 80% silt with some clay and very little sand (C. E. Herdendorf 1975).

Sediments are eroded and transported away by currents and waves. The

shallow and coastal areas of Lake Erie are often exposed to wave activities that result from storms and resuspend sediments. Rippled sandy bottom and scour marks, which were often observed by a diver in this study (Danek *et al* 1977), attest to this finding. Currents flow predominantly parallel to the shoreline in a southwest to northeast direction (Danek *et al* 1977), so it follows that most sediment transport would also be in that direction. Average speeds of currents were 12 cm/sec at 3 m and 5 cm/sec at 1 m off bottom. The wave field is controlled by local winds, and waves as high as 2 m were observed during storms (Danek *et al* 1977).

#### PRE- AND POST-DISPOSAL SEDIMENT SIZE DISTRIBUTION

The grain size distributions of the sediments, measured from sediment cores collected at the control sites and near the two disposal sites D2 and D8, were first plotted as weight percent versus grain size. We used seven size intervals in the analysis, and results were based on the mean of four replicates. Variability within the replicates was not investigated.

An example of the grain-size distributions (figure 2) shows that the sediments at the control sites, the Ashtabula Harbor and River, were bimodally distributed (perhaps two overlapping normal distributions). At the control site, the sediments consisted of about 45% sand, 45% silt, and 10% clay. At the river and harbor, we observed higher percentages of sand, which was expected because the sand settles out, therefore leaving less transportation of sand into the lake. Generally, only minor variations were observed in the distributions with both time and depth. Most of these variations observed over time were probably caused by sampling from slightly different sites, since it was difficult to sample at exactly the same spot every time. Total percentages of sand, silt, and clay remained fairly constant at these sites.

Since grain-size distribution plots were ineffective in determining qualitative changes in the sediments, we used other methods of analysis. The percentages

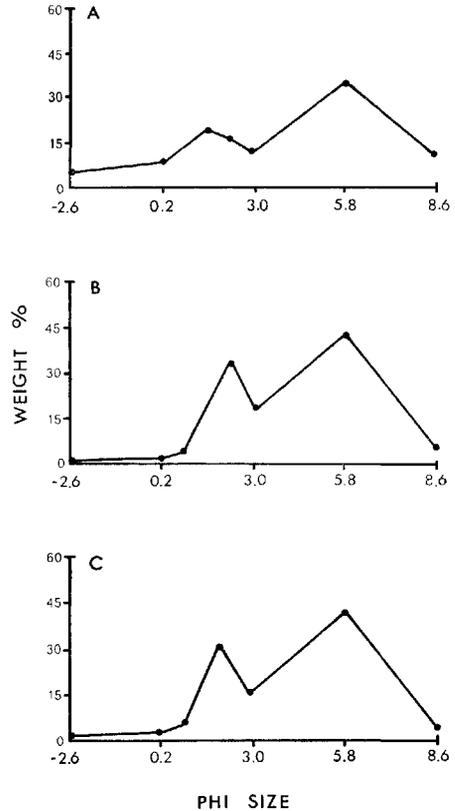


FIGURE 2. Typical grain size distributions found in sediments from Control Site C1 (A), Ashtabula Harbor (B), and Ashtabula River (C), ( $\phi = \log_2$  of mm fraction).

of sand, silt and clay from the surface sections of sediment cores were plotted on ternary diagrams (figure 3). By plotting the data of all replicates, separation between the pre-disposal and post-disposal data collected at disposal site D2 was clearly apparent. Most of the other plots for the disposal site data showed similar results with separate grouping of the pre-disposal and post-disposal values. The data from the control sites, however, showed only small changes in the pre-disposal and post-disposal data. This observation suggests that, even though the grain size distribution was nearly the same, the homogeneity of the grain sizes within each sample was different, which was probably a result of disturbing the natural homogeneity of the sediment

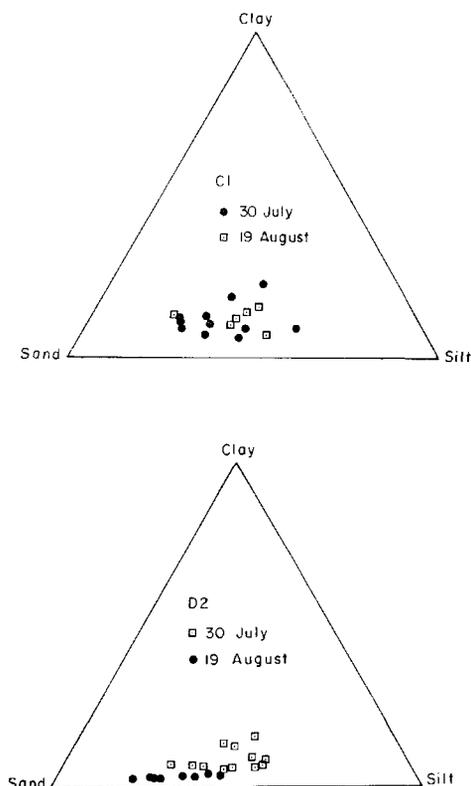


FIGURE 3. Ternary diagrams showing the distribution of sand, silt, and clay at control site C1 and disposal site D2. Each point represents one sample determination.

sizes due to the dredging and disposal action, *i.e.* differential settling and carrying away of fines. These mechanisms were not further investigated but seem to be the most likely reason. Tracking of the sediment plume immediately after disposal with fathometers revealed that the bulk of the sediments settled to the lake bottom within 10 min, but fines remained suspended for hours and formed a fish shaped plume that eventually dispersed (Danek 1977). This change in homogeneity, however, did not seem to be of any consequence since the process was so difficult to discern.

#### SEDIMENT TRANSPORT

Sediment transport had probably taken place because the distribution of the sediment grain sizes changed after August. In order to estimate rates and

directions of transport, PROVECS were developed from the current-meter data with a program called SEDMOT. The erosion velocities used for developing the PROVECS were based on Hjulstrom's curve (Hjulstrom 1939); therefore, the results gave only an approximate measure of erosion and transportation. The results were only estimates because Hjulstrom's curve does not give the exact erosional and depositional velocities that will apply under the precise lake bottom conditions present at the disposal site, and it applies mainly to unidirectional flow. The erosion velocities used did not account for possible resuspension of sediments due to wave activity. The oscillatory water particle motion never exceeded 10 cm/sec during the sampling period, implying that this force would help only in conjunction with currents to resuspend sediments.

The SEDMOT plots revealed that no significant sediment movement took place in July or during the disposal operation because of low velocities but that sediment transport occurred frequently from late August 1975 to May 1976. An example showing a maximum of seven storms that caused currents capable of resuspending sediments is shown in figure 4. Most of the transport was either in a northeasterly (primary) or in a southwesterly (secondary) direction parallel to the regional slope and the shoreline. The results showed that the eroded material theoretically could have traveled several kilometers before it settled out of the water column. The results also showed that the range of sediment sizes transported was from medium-sized silt to coarse sand with medium sand being the most mobile.

Progressive vector diagrams suggested that the direction of sediment transport followed the bottom topography in a northeast-southwest direction, primarily to the northeast (Danek *et al* 1977). Sediment resuspension had taken place based on the fact that currents reached speeds of 60 cm/sec during early November gales and transport could have taken place over distances as large as 20 km.

Plotting ternary diagrams of the sand, silt and clay concentration in replicates of a number of lake bottom samples col-

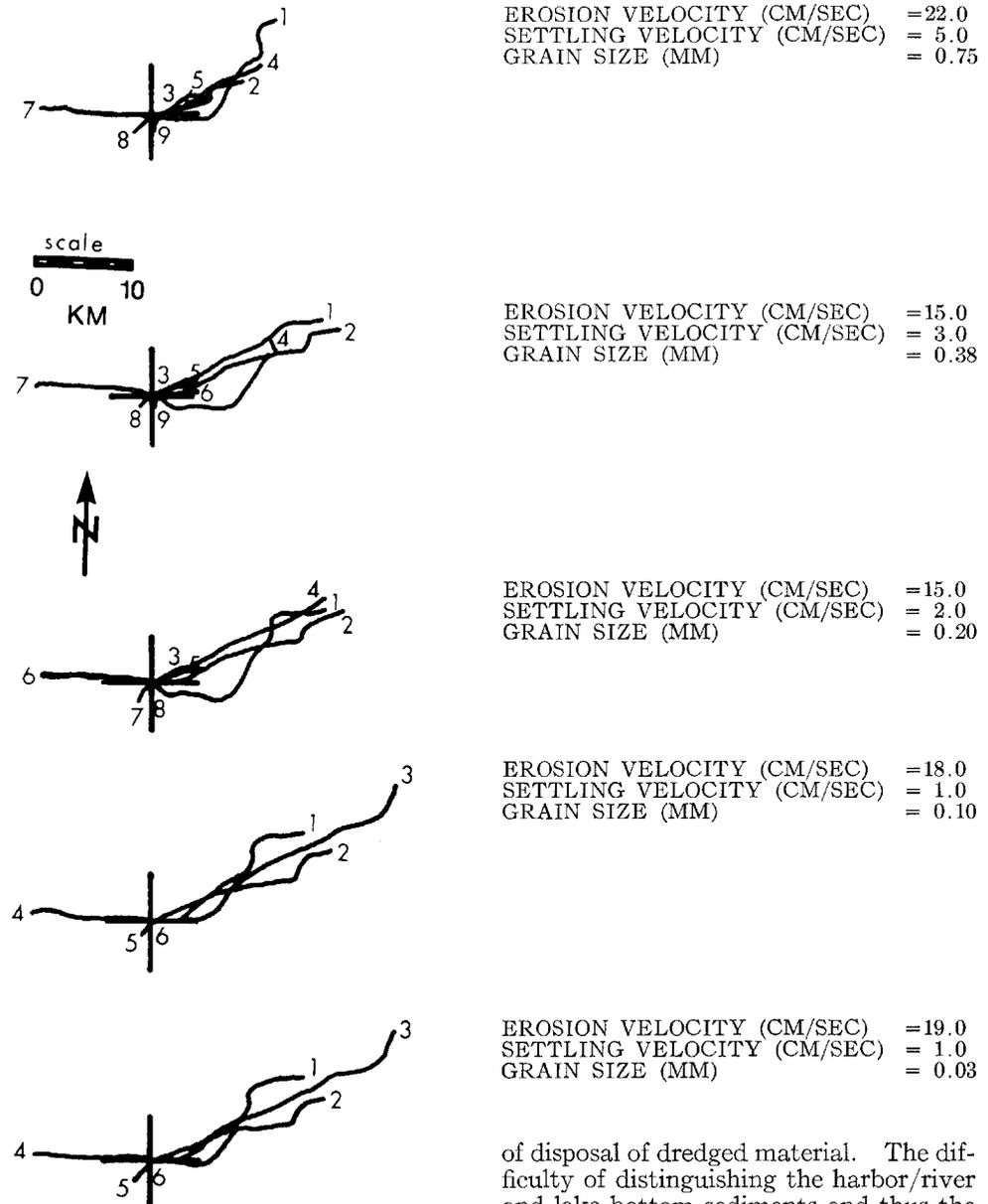


FIGURE 4. PROVECS representing direction of sediment movement, September, 1975 (PROVEC=Progressive Vector Diagram). Numbers on PROVECS depict a storm, plus sign denotes location of current meters.

lected before and after the dredged material disposal operation revealed that the homogeneity of the sediment grain size distribution had changed as a result

of disposal of dredged material. The difficulty of distinguishing the harbor/river and lake bottom sediments and thus the rate, distance and direction of transportation of the dredged sediments was only partially overcome by these methods. River/harbor sediment grains, however, should be much more angular than lake sediments since their distance of travel is much shorter. It is recommended that future studies of this kind should apply Fourier grain shape analysis using quartz as natural tracer (Mrakovich et

al 1976, Ehrlich et al 1974, Ehrlich and Weinberg 1970).

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