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Estimates of sediment movement and resuspension in the New York Bight: Implications for dredged material disposal

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1 Introduction

The Environmental Protection Agency (EPA) must select a new dredged material disposal site in the New York Bight, to be located where dumping will cause minimal environmental impact and where dumping will be operationally and economically feasible. Important criteria for minimal environmental impact are that "(1) the physical environment must permit the material to reach the bottom within the designated area, (2) the material must remain in place and resist resuspension and transport away from the designated area, and (3) when a cap is used, it must physically protect the underlying material from subsequent transport," (Battelle, 1988). This report, prepared by the U.S. Geological Survey (USGS) at the request of EPA, addresses only the latter two concerns by focussing on the movement and resuspension of grains of different size classes in the Bight. It also briefly reviews the mechanics of sediment movement, describes what has been learned about the physical and geological environment in the Bight, and discusses the implications for dredged material disposal.

2 Mechanics of sediment movement

As water flows over the ocean bottom, it exerts a shear stress τ on the sediment. Shear stress is often represented by shear velocity u_* , defined as $(\tau/\rho)^{1/2}$, where ρ is water density. Significant movement of bottom sediment occurs when the stress on the particles exceeds a certain value, called the critical shear stress τ_c, (or critical shear velocity u_{*c}). The critical shear stress for uniform, noncohesive, sand-size sediments has been determined empirically in laboratory studies and can be calculated for particles of various sizes and densities using Shields curve (Yalin, 1977; Nowell, Jumars, and Eckman, 1981). In general, the shear stress required to initiate motion increases with particle size and density. There is little experimental data for particles smaller than about 0.100 mm (very fine sand and silt), however, and thus the critical shear stress is somewhat uncertain for particles of this size.

The transport of material is often separated into bedload and suspended-load modes. Bedload transport occurs when the critical shear stress on the bottom, τ_c, is reached and particles move along the bottom in a series of short trajectories or hops. Suspended-sediment transport occurs when the shear stress is sufficient to maintain particles in suspension or at least in very long trajectories relative to the bedload case. It is generally accepted that suspended-sediment transport occurs when the ratio of particle settling velocity to shear velocity is less than 1 (i.e. when the turbulent fluctuations, represented by u_* are greater than the particle fall velocity). Smith and Hopkins (1972) suggest $p < 0.8$, where $p = w_s/ku_{*s}$, and w_s is the particle settling velocity, k is von Karman's constant (0.4), and u_{*s} is the critical shear velocity for suspension, defined by $\tau_s = \rho u_{*s}^2$. The definitions of bedload and suspended load are for purposes of practical classification, and particles move over a continuous range of trajectories. The distinction is important, however, because fine particles maintained in suspension generally move much farther and faster than coarse particles that move as bedload.

The critical shear velocity required to initiate sediment movement, u_{*c}, and for suspended transport,u_{*s} are tabulated for quartz particles in table 1. The critical shear velocity increases from 0.8 to 1.7 cm s^{-1} as particle diameters increase from 0.031 to 0.500 mm. These empirically determined values from Shields curve can be used as a guide for determining the erodibility of sediments in the field; however, because Shields curve is for a flat bed of single-size, abiotic sediment particles, the values are only approximate. Most sediment on the continental shelf is composed of a mixture of grain sizes, and the seafloor is not flat. In addition, there is evidence that the critical shear stress required for incipient motion can be increased or decreased by benthic organisms. For example, sticky substances secreted by bacteria can form mats that decrease erodibility (Jumars and Nowell, 1984). Thus, in practice, the initiation of motion occurs over a band of critical stresses that span Shields curve, and there may be occasional movement

d (mm)	Sediment type	w (cm s^{-1})	u_{*c} (cm s^{-1})	u_{*s} (cm s^{-1})
0.031	Coarse silt	0.06	0.86	0.2
0.063	Very fine sand	0.26	1.07	0.8
0.125	Fine sand	1.0	1.25	3.1
0.250	Medium sand	3.0	1.38	9.4
0.500	Coarse sand	7.0	1.70	21.9

Table 1: Settling velocity (w) and critical shear velocities for threshold of movement (u_{*c}) and suspension (u_{*s}) for given grain diameter (d). From Butman (1987).

of sediment grains at stresses well below Shields value (Lavelle, Mofjeld, and Baker, 1984).

The movement thresholds for sediment transport have important implications for sediment transport in the New York Bight. For quartz particles 0.063 mm in diameter (very fine sand) and smaller, transport will mostly occur in the suspended mode because the stress required to maintain the particle in suspension is less than the stress required to initiate movement. However, 0.125 mm particles (fine sand) require a bottom velocity of 1.25 cm s^{-1} for bedload transport and about 3.1 cm s^{-1} for suspended transport. Since lower values of shear velocity are exceeded more frequently than higher values, particles of diameter 0.125 mm or more almost always move as bedload, while particles of diameter 0.063 mm or less move more frequently and always in suspension.

Direct field measurements of bottom stress on sediment particles or estimates of stress based on current measurements alone are difficult to make because the structure of the flow near the seafloor is complex. This complexity arises because the seafloor is generally not flat, and because the bottom flow is not always steady. (By "steady" we mean that the current is essentially constant for several minutes or more; "unsteady" refers to the oscillatory currents with periods of seconds that are caused by surface waves.) Away from the bottom, the flow field is composed of both unsteady currents and steady currents caused by tides, winds, and the density field. Near the bottom there is a layer typically several meters thick over which the currents decrease from this "freestream" velocity to zero at the seabed. This region of adjustment, where there is a vertical shear in the current and turbulent mixing induced by the shear at the boundary is called the bottom boundary layer. For the shallow water case where unsteady, back-and-forth currents caused by surface waves are frequently present (or both these and steady currents are present), the wave currents decrease to zero at the bottom across a thin wave boundary layer, which typically is only 1–20 cm thick. Rapid oscillation of the wave current does not allow a thicker layer to develop. The stress exerted on the bottom by the flow is determined by the vertical shear in the current, and thus for comparable currents the bottom shear stress is higher for the thinner boundary layer. Because the stress under steady and nonsteady flows is fundamental to understanding sediment movement in the New York Bight, the two cases are briefly described.

For the case of steady flow over gradually varying topography, theory predicts that the velocity in the first few meters of the turbulent bottom boundary layer is described by a logarithmic profile,

$$u(z) = \frac{u_*}{k} \ln \frac{z}{z_o} \tag{1}$$

where u is the horizontal current, z is the distance above bottom, u_* is the shear velocity, k is von Karman's constant (0.4) and z_o is a roughness length scale. The roughness length can be though of as the distance above the seabed at which the current equals zero.

Observations (Smith and McLean, 1977, Cacchione and Drake, 1982; Grant, Williams, and Glenn, 1984) demonstrate that for many conditions typical of the New York Bight, the flow should be well described by (1). However, the interpretation of z_o is not simple in the field. If the seafloor is perfectly flat, the sediment is medium sand or coarser, and no transport is occurring, then z_o is proportional to particle diameter d ($z_o = d/30$ from laboratory studies), and the steady current at any level above the bottom required to produce a given u_* can easily be calculated. Bottom photographs on the continental shelf, however, typically show biologic debris (shells, feces, and so forth) and small depressions and mounds as well as ripples caused by currents. These larger roughness elements, the height H of which is typically a few centimeters in the New York Bight region, and sediment movement, if it occurs, determine z_o in (1). Thus in order to calculate the stress on the seafloor caused by steady flow using (1), both the near-bottom current and knowledge of bottom roughness are needed.

In the case where currents caused by waves are present, the mean-velocity profile above the wave boundary layer is still logarithmic, but the strong shear in the wave boundary layer has two effects. First, the stress at the

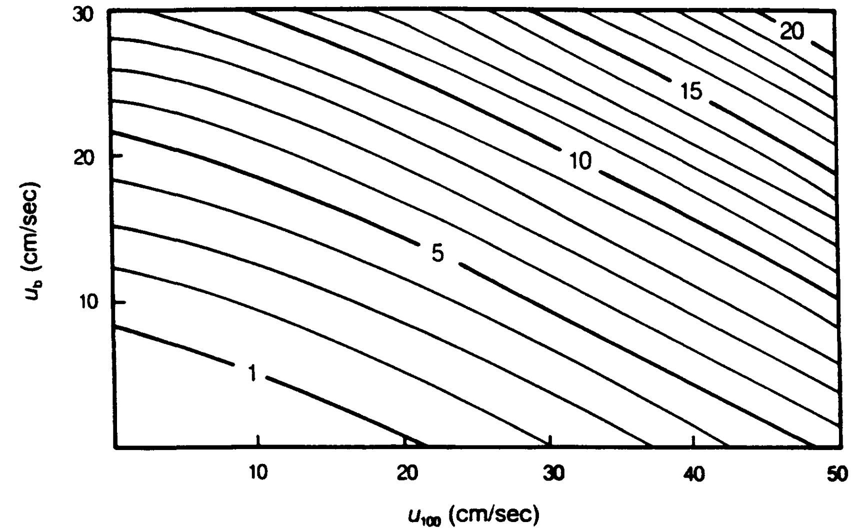

Figure 1: Bottom stress u_{*cw}^2 due to the combined effects of steady current and an oscillatory wave current inside the wave boundary layer as a function of wave orbital velocity (u_b) and steady bottom current speed measured 1 m above bottom (u_{100}) calculated using the model of Grant and Madsen (1979). The bottom stress was calculated for a wave period of 12 s and a bottom roughness of 0.5 cm. The solid lines are lines of equal bottom stress. The figure shows various combinations of u_{100} and u_b necessary to achieve a chosen stress.

bottom is increased by the unsteady wave currents. Secondly, the increased turbulence inside the wave boundary layer caused by both bottom roughness and waves increases the momentum transfer between the steady flow and the bottom, effectively increasing the bottom roughness "seen" by this outer flow. Thus when both a steady current and wave currents are present, two bottom stresses are important: the maximum stress at the seabed caused by the combined effect of the steady current and the unsteady wave currents, u_{*cw} and the mean stress in the bottom boundary layer outside the wave boundary layer, u_{*c}. It is the stress u_{*cw} that must be used to evaluate initiation of sediment movement, while u_{*c} is the stress that maintains particles in suspension above the wave boundary layer.

To illustrate the effect of oscillatory wave currents on bottom stress,u_{*cw} was computed using the model of Grant and Madsen (1979) for a particular wave period (12 sec) and bottom roughness (0.5 cm), values appropriate during storms for some parts of the New York Bight (Figure 1). Even small-amplitude oscillatory wave currents cause a significant bottom stress. For example, a bottom stress of 4 dyn cm^{-2} (u_* =2.0 cm s^{-1}) is caused by a 12 s period wave current of about 18 cm s^{-1}In comparison, a steady current of about 43 cm s^{-1} exerts the same stress, as does a combined flow of a 10 cm s^{-1} wave current and a steady flow of 23 cm s^{-1}. Thus, a small wave-induced oscillatory bottom current superimposed on a steady flow can significantly increase the bottom stress over the stress caused by the steady flow alone. If waves are present, then bottom stress must be either directly measured or estimated using a model that includes the effects of waves.

Sediment movement and resuspension often occur during short, intense storms with large waves or during maximum tidal flow. The net transport of sediment is the cumulative effect of many of these transport events, which occur over a wide range of time scales–from hours (tides) to years (catastrophic storms). Estimates of sediment movement determined from the average current or average bottom stress, in which these intense event are averaged out, are not generally good measures of sediment transport.

Furthermore, wave and tidal currents alone are ineffective transporters of sediment. During part or all of an oscillation, the bottom stress may be strong enough to move sediment, but there is no net transport over the complete cycle if the flow is symmetric; material is first transported one way, then the other. Typically a combination of processes is required to effect net sediment transport. For example, a large bottom stress caused primarily by waves or energetic tidal currents may resuspend sediments; once material is placed and/or kept in the water column by these processes, a relatively weak, quasi-steady current, not strong enough by itself to initiate movement, can result in sediment transport over a long distance.

Because of the complexity of sediment transport mechanisms, an understanding of the total flow field and of the stress on the bottom is required for determining the movement and transport of sediments on the shelf; careful identification of the frequency and distribution of individual current components is required so that the effect of the total flow field is adequately represented. The extent of the sediment transport in a particular region can be determined by evaluating (1) the spatial and temporal distribution of bottom stress strong enough to initiate movement or suspension, (2) the direction and rate of transport of the sediment, and (3) the spatial gradients of (1) and (2), which determine whether sediment will accumulate or be eroded. The bottom stress field is of fundamental importance, and thus is the primary focus in this report.

3 Approach

Ideally, the selection of a dredged material disposal site in the New York Bight would be based on a quantitative computation of sediment transport derived from long-term measurements (e.g. 20 years) of suspended sediment concentration and velocity profiles at all potential locations. The required measurements, of course, do not exist, and would be prohibitively expensive to obtain. When suspended sediment profiles are unavailable, but simultaneous bottom current and wave information is available at the same time, estimates of sediment transport can be obtained using models (e.g. Lyne et al, 1990), as described above, which relate the sediment profile to flow parameters and the nature of the bed material. Unfortunately, simultaneous measurements of waves and currents over long time periods do not exist in the New York Bight, either. The data that exists has patchy coverage in time and space, with very few simultaneous wave and current measurements.

Instead of quantitative estimates of sediment transport, therefore, the current and wave probability distributions are used to calculate the probability distribution of bottom stress, which in turn is used to calculate the percentage of time that the stress exceeds the threshold of movement for a particular size class of material. Where the waves and currents both contribute significantly to the bottom stress, the correlations between the waves and currents must be known before the probability distribution of bottom stress is obtained. If, for example, high waves and bottom currents typically occur at the same time, it affects the bottom stress probability differently than if the waves and currents are not correlated.

4 Bottom Currents in the Bight

A good description of the bottom currents in the Bight is possible due to the measurements made by the Marine Ecosystems Analysis (MESA) program (Mayer, 1982; Mayer et al, 1982), the USGS bottom tripod stations MB and ME, (Butman and Moody, 1983), Science Applications International Corporation at the potential disposal sites stations C2 and El (SAIC, 1990a), and the National Marine Fisheries Service (NMFS) in the Christiaensen Basin stations 1–6,9 (Manning, 1991). Station locations are shown in Figure 2.

The MESA program was by far the most extensive and provided a good description of the structure and magnitude of the current response over most of the Bight (Mayer, 1982). In particular, MESA showed that currents in the Bight, with the exception of the Hudson Shelf Valley, respond quite uni-

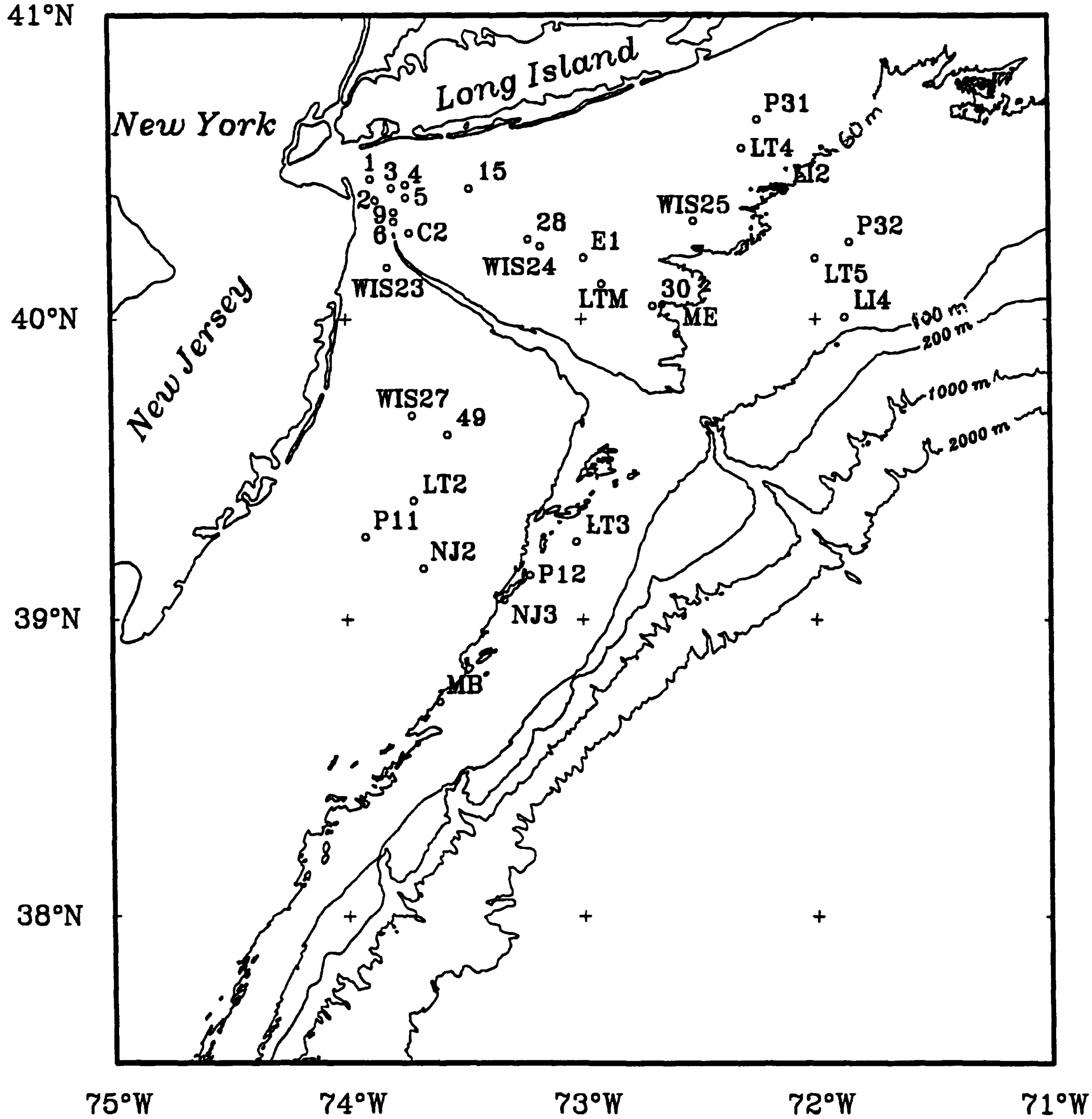

Figure 2: Station locations for current meter measurements in the New York Bight and wave hindcast stations from WIS. Stations 1–6 and 9 were occupied by the NMFS, stations MA, MB, and ME were occupied by the USGS, stations WIS23-25 and WIS27 are the WIS wave hindcast sites, and all other stations were occupied by the MESA program.

formly to tide and wind forcing. Over most of the shelf the mean flow was approximately alongshelf at 5 cm s^{-1} toward the southwest, semi-diurnal tidal current ellipses were oriented cross-shelf with major axis amplitudes of 5–10 cm s^{-1}, and sub-tidal currents were usually alongshelf with typical amplitudes of 8–15 cm s^{-1} for instruments within 10 m of the bottom (Figure 3). The MESA results showed that during the winter season (the important season for sediment resuspension due to the increased number and intensity of storms) the water column is vertically well-mixed, and currents respond most efficiently to alongshelf winds, with about 50–70% of the energy attributable to local winds. An analysis of currents at the four stations LT2–LT5 over 6 months (October 1975 to April 1976) revealed that 78% of the energy was contained in a nearly uniform alongshelf oscillation mode, presumably as the result of wind forcing and fluctuations in the southwesterly flow through the Bight.

Although the bottom currents over much of the Bight are quite similar, there are regions where the bottom current regime is markedly different. In the Hudson Shelf Valley, the MESA workers determined that strong up and down-valley flows occur in response to alongshore wind events as a result of the channelized geometry (Mayer et al, 1982). This response in the Hudson Shelf Valley has also been documented by the recent NMFS measurements at the head of the Hudson Shelf Valley and nearby locations in the Christiaensen Basin (Manning, 1991). In addition, measurements have shown that bottom current activity increases dramatically near the shelf break, especially in the vicinity of canyons. Csanady et al (1988) report, for example, that approximately 8% of the time, bottom currents at the 200 m isobath typically exceed 25 cm s^{-1}, which corresponds to the threshold of movement for medium sand, assuming a bottom roughness length $z_o = 0.07$ cm.

From the MESA and other circulation studies, it appears that without waves, bottom currents are not very effective at initiating sediment movement over most of the Bight, with the exception of regions close to the Hudson River plume, the Hudson Shelf Valley and the shelf break. A frequency distribution analysis of bottom stress inferred from current measurements at the USGS tripod MB, for example, yields the threshold exceedence information shown in Table 2. A bottom roughness length $z_o = 0.07$ cm was used to determine bottom shear velocity from currents 1 m above bottom. The table shows that bottom currents alone (no waves) are strong enough to move 0.031 mm particles (medium silt) 22% of the time, 0.125 mm particles (fine sand) 4% of the time, and medium sand 1.8% of the time.

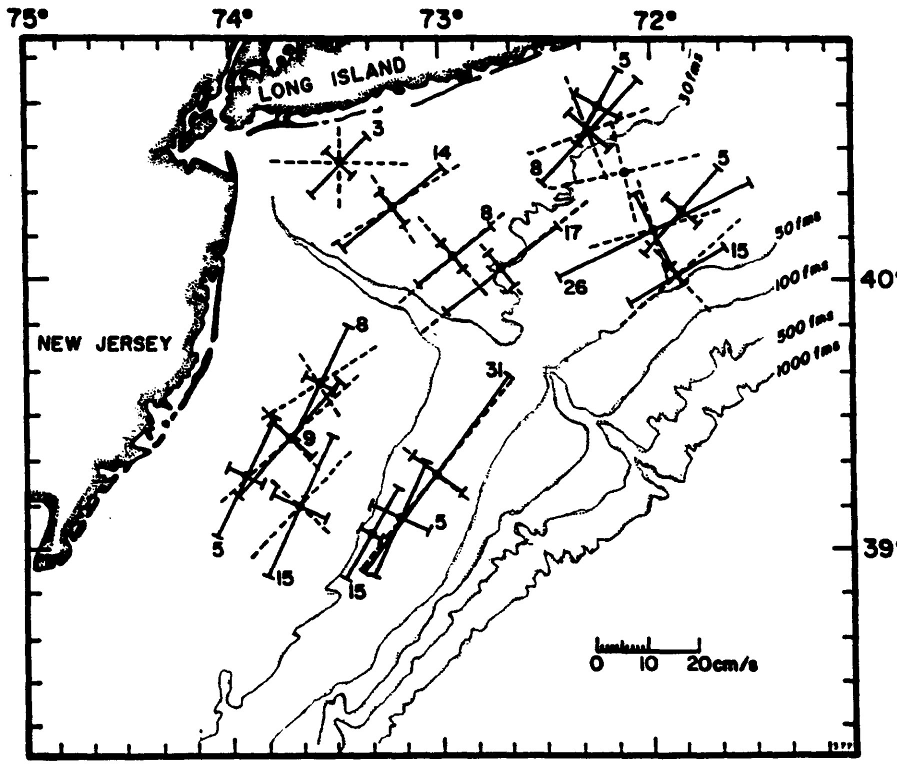

Figure 3: Principal axes of sub-tidal currents from the MESA program. All near-surface records indicated by dashed lines were obtained 3 m below the surface. The numbers indicate the depth in meters above bottom. Note that the primary orientation for sub-tidal flow is parallel to the local isobaths and that the magnitude of the flow within 10 meters of the bottom does not vary greatly over the Bight. Figure from Mayer, (1982).

d (mm)	Sediment type	$u_* > u_{*c}$ (%	$u_* > u_{*s}$ (%)
0.031	Coarse silt	22.1	22.1
0.063	Very fine sand	9.6	9.6
0.125	Fine sand	4.1	0.0
0.250	Medium sand	1.8	0.0
0.500	Coarse sand	0.3	0.0

Table 2: Percentage of time that the bottom shear velocity generated by bottom currents only (no waves) exceeds the threshold for movement ($u_* > u_{*c}$) and suspension ($u_* > u_{*s}$) based on a bottom roughness length z_o = 0.07 cm at the USGS station MB. The mean speed at MB (10.3 cm s^{-1}) is similar to other near bottom mean speeds in the Bight.

5 Waves in the Bight

Over much of the New York Bight, surface waves play an dominant role in sediment resuspension. On the outer shelf, incoming swell of 10–15 s begins to affect the bottom in approximately 80–180 m of water. On the inner shelf, the shorter period local wind sea waves also affect the bottom. Wave-induced bottom orbital velocities in the Bight typically range from 5–40 cm s^{-1}, which are comparable to the larger bottom currents driven by tide, wind and density forcing. The shear stress exerted by wave orbital velocities, however, is typically an order of magnitude larger than the shear stress exerted by a current of the same magnitude. Therefore waves will often suspend material when the currents are to weak too initiate motion of material at the bed.

Several years of surface wave observations are available from a few locations in the Bight, but the only long-term wave climatology for the region is available from the U.S. Army Corps of Engineers Wave Information Study (WIS), Phase II (Jensen, 1983). In this study, winds were determined for the 20 year period 1956–1976 using surface pressure fields, then input into a numerical wave model to hindcast waves over the east-coast continental shelf. Specific stations were selected along the shelf at which 20 year time series of significant wave heights, periods, and direction were output. Many locations were compared to actual shorter term measurements to ensure accuracy. Typical deviations between model and observations were 10% in wave height and period, and 10° in wave direction.

Summary statistics of mean and maximum wave for WIS stations 23, 24, 25 and 27 in the Bight were compared by Battelle (1989b) and showed little variation between stations (Figure 4), indicating that further than approximately 20 km from land, the wave climatology is similar over the entire Bight region. This is consistent with the findings of the SAIC wave refraction study (SAIC, 1990b) which showed that although the Hudson Shelf Valley can markedly focus wave energy from long period (9-11 s) waves, slight differences in the orientation of the incoming waves resulted in dramatic differences in the regions of focusing and defocusing. Analysis of the WIS data shows that waves causing large bottom shear velocities in the Bight do not dominantly approach from a single direction, but approach over a broad range of angles. The result is that although the wave energy during a particular event may vary dramatically in the Bight due to refraction over the Hudson Shelf Valley, the wave climatology varies little since it averages over a large number of such events from different directions.

Since the wave climatology is similar throughout the Bight, the climatology from the WIS study can be used to calculate the percentage of time that the threshold for sediment movement is exceeded due solely to wave effects, given the sediment particle diameter and the water depth. The 20 year hindcast record at WIS station 24 was selected, and the bottom shear velocity for wind sea and swell was independently calculated using the method of Grant and Madsen (1979). The shear velocity exerted on the bottom was computed as the square root of the sum of the squares of the bottom shear velocity due to the wind sea and the swell (there is no presently accepted formulation for stress caused by a spectrum of waves). The percentage of the time that the threshold for movement was exceeded was calculated at 20, 40, 60, 80 and 100 m (Table 3 and Figure 5). The exceedence calculations show that frequent movement of all size classes of sediment grains occurs at 20 m, but that the frequency of movement drops dramatically with increasing water depth. Fine sand, for instance, moves 75.4% of the time at 20 m, 25.8% of the time at 40 m, and only 5.6% of the time at 60 m. How much material is in suspension and how much transport occurs, of course, is a function of the bottom currents as well as the waves. These results, however, clearly indicate the dominant importance of surface waves over most of the Bight in determining the potential for sediment movement. These findings are consistent with the Battelle SITE model (Battelle, 1988), which used estimated bottom currents and observed wave climatology to predict the occurrence of sand movement over the entire Bight. The SITE model

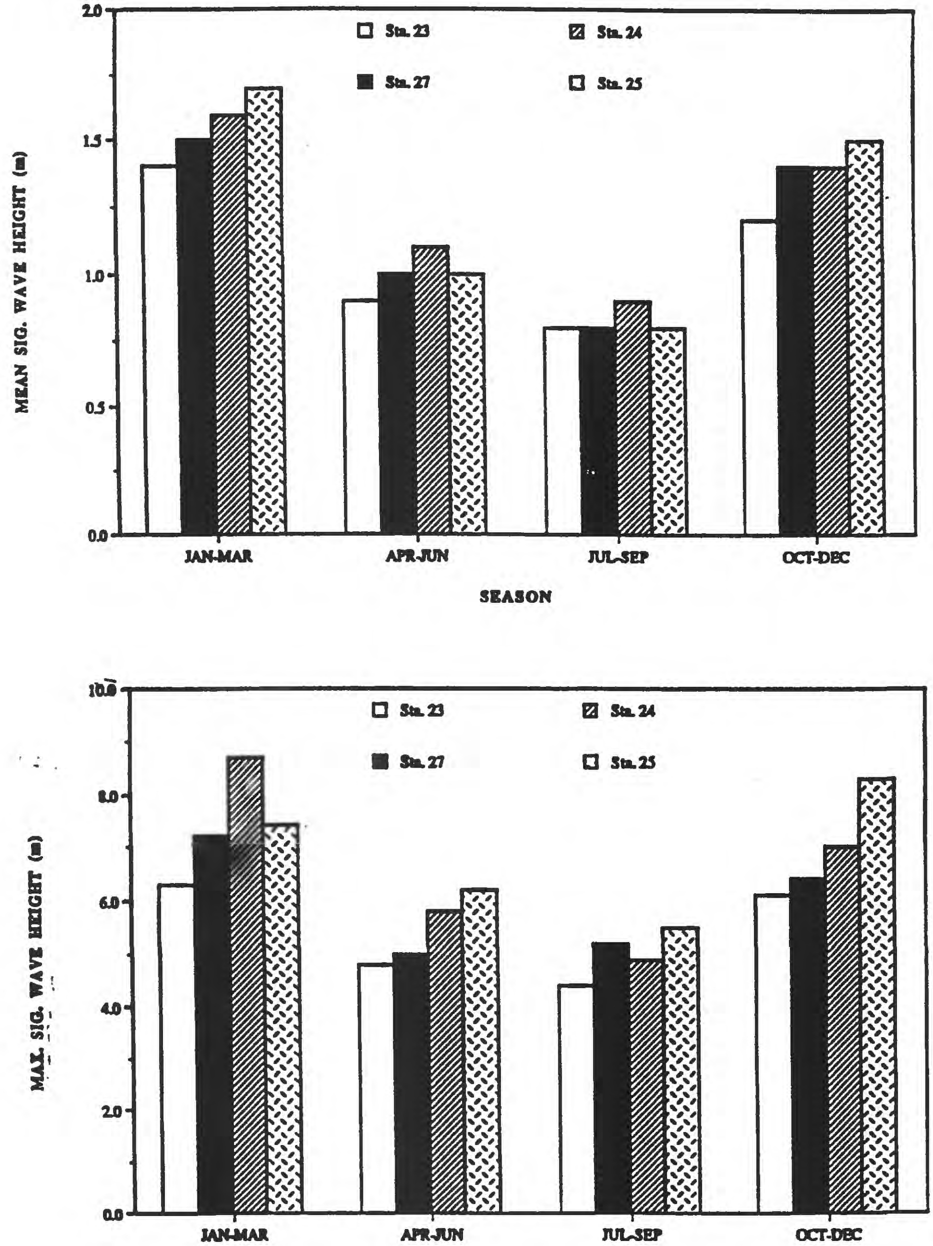

Figure 4: Mean and maximum significant wave height from the U.S. Army Corps of Engineers Wave Information Study (WIS) for four stations in the New York Bight (see Figure 2 for locations). The relatively small variation in the wave statistics between stations indicates the wave climate does not change much over much of the Bight. The WIS results were hindcast for the 20 year period 1956-1975 using wind data derived from atmospheric pressure charts to drive a wave model. The maximum wave height refers to the average peak significant wave height recorded over 20 seasons, as opposed to the peak significant wave height over 20 seasons.

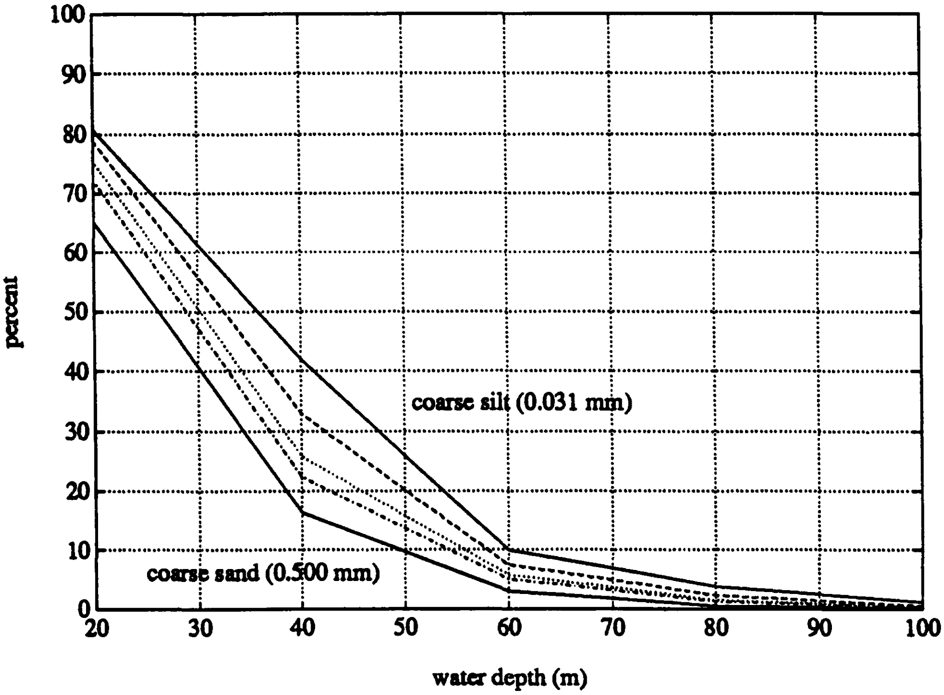

Figure 5: Percent of wave-generated bottom shear velocities that exceed the threshold for movement, as a function of water depth and grain size. The percentage decreases dramatically with increasing water depth, and decreases slightly with increasing grain diameter (data for 0.500, 0.250, 0.125, 0.063 and 0.031 mm diameters are shown). The calculations are based on WIS station 24, and a physical bottom roughness of 3 cm.

d (mm)	Sediment type	Depth (m) 20	40	60	80	100
0.031	Coarse silt	80.8	41.9	9.9	3.7	1.1
0.063	Very fine sand	78.8	32.9	7.4	2.2	0.4
0.125	Fine sand	75.4	25.8	5.6	1.4	0.2
0.250	Medium sand	72.1	22.3	4.9	1.2	0.2
0.500	Coarse sand	65.1	16.3	2.9	0.4	0.1

Table 3: Percentage of the time that the bottom shear velocity generated by waves only (no currents) exceeded the threshold of movement at different water depths. The wave information was obtained from the WIS 20 year hindcast at station WIS 24 (see Figure 2 for location), with a physical bottom roughness of 3 cm.

run 3, for example, showed the 70% exceedence contour line (threshold for movement exceeded 70% of the time) following the 20 m isobath, the 30% exceedence contour line following followed the 40 m isobath, and the 20% exceedence contour line following the 60 m isobath (Figures 6 and 7). Over the inner Bight, the SITE model is very similar to the findings determined from the wave climatology alone (Table 3 and fig. 5). On the outer Bight (water deeper than 60 m), the SITE model predicts a higher frequency of sediment movement, since the SITE model includes estimates of bottom currents.

6 GEOLOGICAL EVIDENCE

The surficial sediment characteristics and morphology in the Bight provide additional information concerning the potential for sediment movement. The gross surficial sediment distribution in the Bight presented by Freeland and Swift (1978) shows that the Hudson Shelf Valley neatly divides the Bight into two distinct regions (Figure 8). To the northeast of the Hudson Shelf Valley, fine and medium sand dominates the distribution; to the southwest, significantly coarser gravelly sand dominates the distribution. Much of the Christiaensen Basin and the Hudson Shelf Valley appear to be depositional areas, dominated by muddy, fine sand consisting of 5-30% clay. The textural distribution is consistent with the physical description of the Bight: averaged over many resuspension events, resuspended fine-grained material

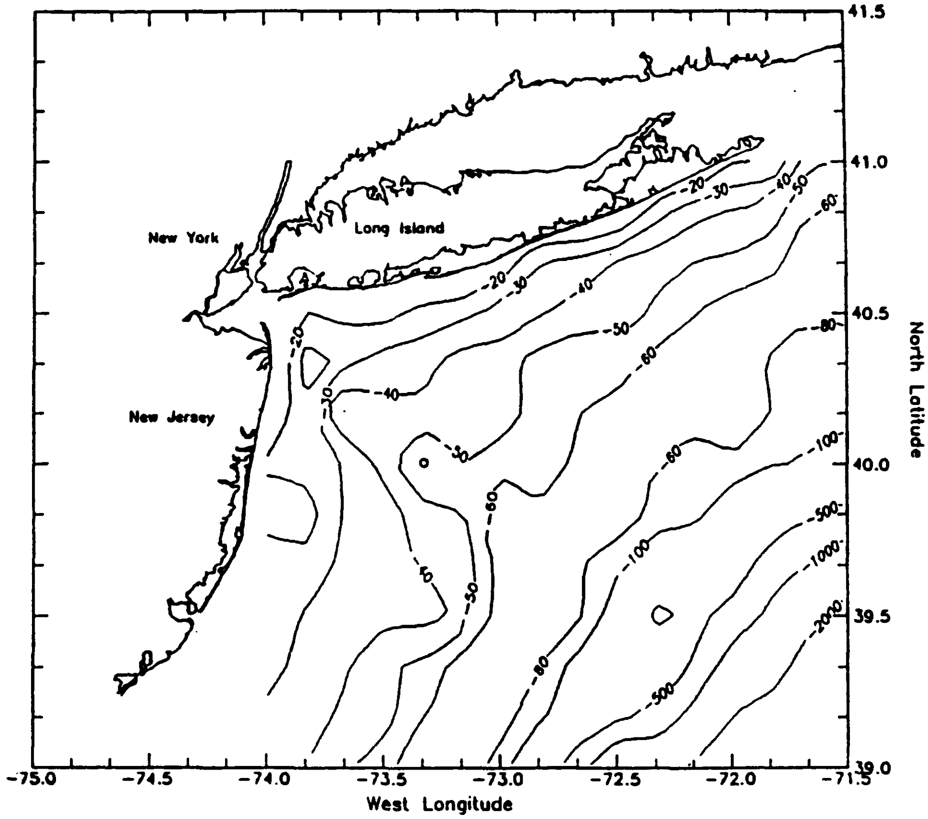

Figure 6: Bathymetry used in the Battelle SITE model, which used estimated bottom currents and observed wave climatology to predict the occurrence of sand movement over the Bight. Figure from Battelle (1988).

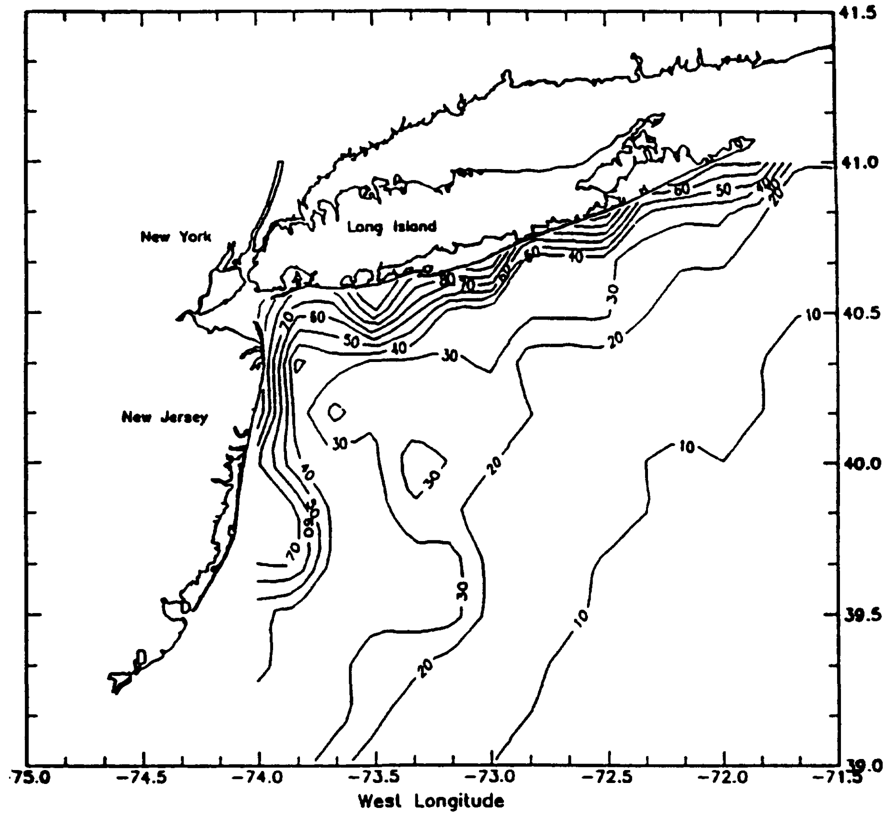

Figure 7: Percent of bottom shear velocities greater than the threshold for medium sand movement from SITE model run 3. The results are consistent with Table 3 and Figure 5, with the percent lines following the isobaths and strongly decreasing in magnitude with increasing depth. Figure from Battelle (1988).

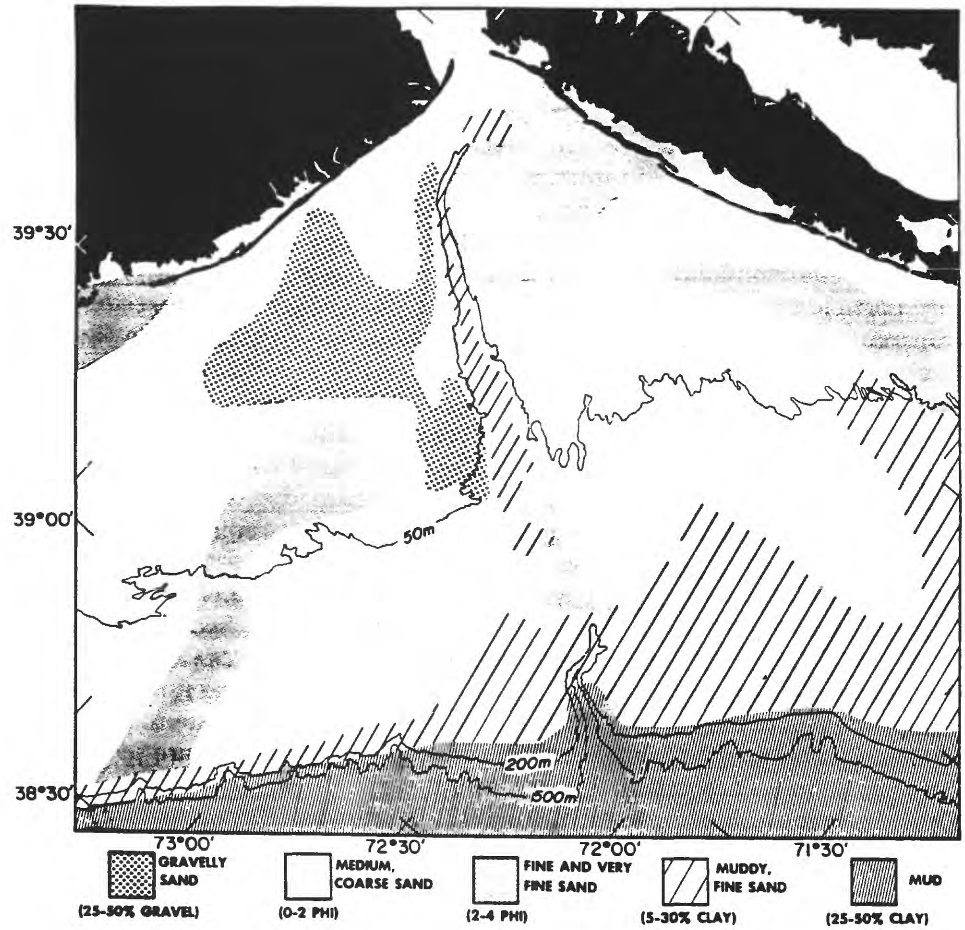

Figure 8: Surficial sediments of the New York Bight. Sediments to the northeast of the Hudson Shelf Valley are markedly finer than sediments to the southwest of the Hudson Shelf Valley, indicating that the Hudson Shelf Valley traps fine grained sediment moving southwestward with the Bight mean flow. From Vincent et al (1981).

moves with the prevailing mean flow in a southwesterly direction along the Bight. There is therefore a large flux of material into the Hudson Shelf Valley, and the Hudson Shelf Valley becomes a leaky trap for fine-grained material due to the confined geometry and the reduced influence of wave energy. The region to the southwest of the Hudson Shelf Valley, therefore, has coarser surficial sediments than the region to the northeast of the Hudson Shelf Valley not because it is more erosional, but because there is a greatly reduced contribution of fine-grained material from the northeast.

Sonar and photographic evidence shows that the bedform assemblage that characterizes the Bight, like most of the east coast continental shelf, is a combination of flow-parallel and flow-transverse bedforms with frequent dragger scars (Swift et al, 1979; Freeland et al, 1981). Detailed mapping of the potential sites C1–C4 and E1–E2 using side-scan sonar and REMOTS© technology confirmed the presence of large scale and/or small scale bedforms at all the sites surveyed (Battelle, 1989a). An example of the REMOTS© process map at E1 is shown in Figure 9.

7 Discussion

Based on the physical observations, the evaluation of the 20 year WIS wave climatology, and the SITE model results, we infer that the frequency of sediment movement on the shelf will be minimized at a location where the water is deep enough to escape the strongest influence of the surface wave field and is far enough landward from the shelf break to avoid the strong bottom currents that are frequently found there. The relatively deep water of the Hudson Shelf Valley makes it attractive from the point of view of reduced surface wave energy, but unfortunately the Hudson Shelf Valley has strong along-valley flows that transport material both onshore into the Christiaensen Basin, and offshore into the Hudson Canyon (Vincent et al, 1981). The Christiaensen Basin itself, although possessing a relatively high percentage of fine grained material, has bottom current magnitudes similar to other locations in the Bight (Manning, 1991) and is frequently subject to wave resuspension due to the relatively shallow water depth.

Based on the SITE model results, Battelle (1988) recommended that the water depth at the proposed disposal site be at least 40 m. Table 3, based on WIS wave climatology, is consistent with this finding in that increasing water depth is shown to greatly reduce the frequency of sediment movement. As an example, the percentage of the time that medium sand (0.250 mm diameter) moves is 72.1% at 20m, 22.3% at 40 m, and 4.9% at

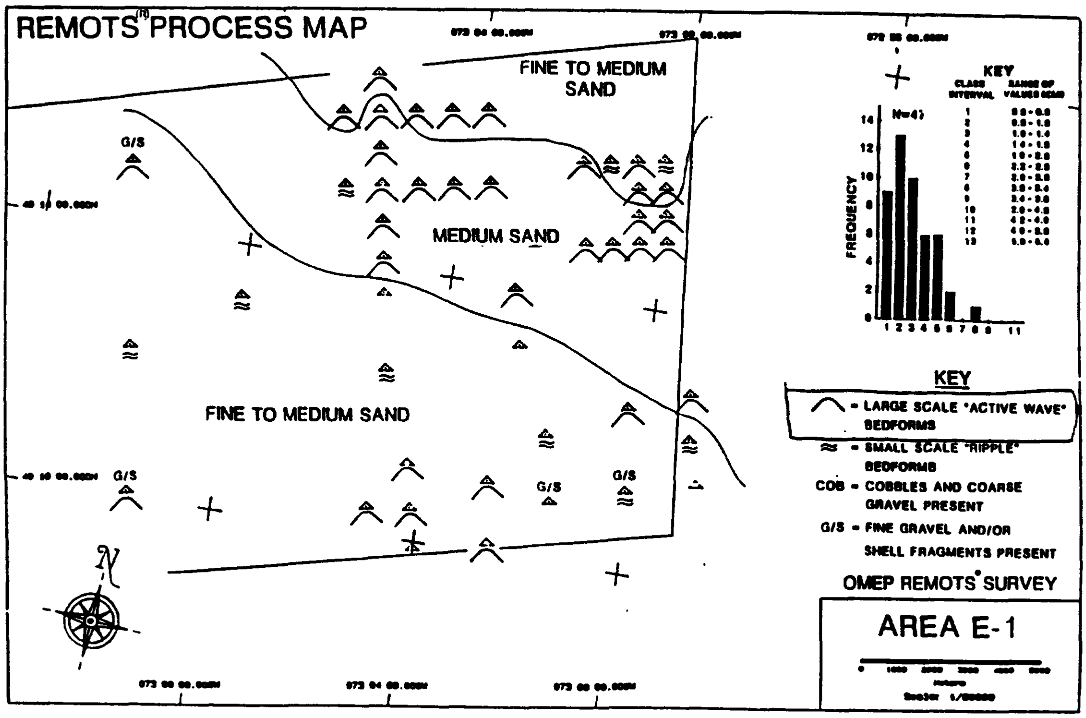

Figure 9: REMOTS© process map at the location E1 (see Figure 1 for location. Large scale bedforms are present over much of the site, indicating that fine and medium sand moves as bedload transport during typical winter storms. From Battelle (1989a).

	Cs sand	Med sand	Fine sand	V fn sand	Cs silt
C2	43	52	55	61	65
E1	12	18	21	28	37

Table 4: Percent of time wave-generated bottom shear velocities exceed threshold of movement of bottom sediments for several size classes.

60 m. As previously mentioned, strong bottom currents have been observed at the shelf break (around 200 m), suggesting that the outer shelf should be avoided for sediment containment.

Comparing the sites C2 and E1, it is clear that the increased water depth of E1 results in a greatly reduced frequency of sediment movement due to the reduced action of waves (Table 4). The table suggests, however, that even at E1, material finer than coarse silt will move more than 37 percent of the time. Since the stress required to keep this fine grained material in suspension is low, there is a potential for large amounts of material to leave E1 unless the site is capped with coarse-grained material. Although March–July observations by SAIC did not show evidence of sediment resuspension at E1 (SAIC, 1990b), observations during more energetic winter storms in deeper water at ME (see Figure 2 for location) revealed large resuspension events and ripple formation (Butman and Moody, 1983). In addition, if the disposal material is finer than the naturally occurring fine and medium sands at E1, observations of resuspension at E1 are likely to underestimate the amount of dredged material that would be transported.

Table 4 also shows that coarse grained material is subject to movement by moderate storms, but since it is much less likely to move as suspended load (Table 1), it is likely to protect fine-grained underlying material as long as the cap is thicker than the height of the active bedforms that form in the capping material during typical storms. REMOTS© observations in March 1989 at E1 indicate that these active wave bedforms have heights of order 10 cm (Battelle, 1989a). An effective cap, therefore, must be at least several tens of cm thick.

8 Summary

The movement of material from a dredged material disposal site on the shelf can be minimized by: (1) avoiding the regions of shallow water where surface waves frequently move material; (2) avoiding the shelf break region where strong bottom currents frequently move material, and; (3) capping the site with a thick layer of coarse grained material. Once disposal has commenced, the site should be monitored periodically to ensure the integrity of the cap, as biological organisms or extreme storm events such as hurricanes may have unforeseen consequences.

It is important to note that while deeper water is more desirable from the standpoint of sediment resuspension, deeper water is less desirable from the standpoint of water column dispersion. The results of the U.S. Army Corps of Engineers DIFID model show that since the current regime is similar over much of the Bight, deeper water sites are in general significantly more dispersive than shallow water sites (U.S. Army Corps of Engineers, 1989). Selection of a dredged material disposal site on physical grounds requires estimating the relative importance of dispersion and resuspension as well as recognizing their opposing impact with varying water depth.

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