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Analysis of the Contribution of Dredged Material to Sediment and Contaminant Fluxes in Long Island Sound

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Is the disposal of dredged sediment within an estuary a quantitatively significant source of physical disturbance and contamination? One way to address this management question is to scale the impacts of disposal relative to sedimentation from other sources. This paper compares the contribution of dredged material activities at open water containment sites in Long Island Sound to the overall sediment budget.

Three questions are addressed in this paper: (1) Is the fraction of disposed sediment that may be dispersed outside of the boundaries of disposal sites quantitatively significant relative to inputs of sediments from non-disposal activities such as land runoff, industrial discharges, and waste water treatment plants? (2) Are disposal sites quantitatively significant sources for the redistribution of particle-bound contaminants? (3) Can disposal losses be measured accurately with existing technology, and what are future data requirements?

The analysis provided here found that the answers to these questions are as follows: (1) The quantity of dredged material leaving aquatic containment sites is small when compared to non-disposal inputs from runoff, industrial effluents, and waste water treatment plants. (2) Disposal mounds are not significant sources of contaminants for the Sound outside the boundaries of designated dredged material containment sites. Monitoring for ecosystem effects should therefore be focused on individual mounds within disposal sites. Food chain contamination and transport is a greater potential issue than sediment transport. (3) Current technology is sufficient to make reasonably accurate estimates of mass balance for dredging-disposal activities; but these candidate technologies have never been brought together to perform an "ideal" mass balance study. Future data requirements include means of obtaining accurate sediment wet weight/volume conversions to dry mass. Independent measurements are required of mound and foundation consolidation, lateral creep, and erosion in order to understand underlying processes that control changes in mound height during termination of disposal activities.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

EXECUTIVE SUMMARY

Is the disposal of dredged sediment within an estuary a quantitatively significant source of physical disturbance and contamination? One way to address this management question is to scale the impacts of disposal relative to sedimentation from other sources. This paper compares the contribution of dredged material activities at open water containment sites in Long Island Sound to the overall sediment budget.

Three questions are addressed in this paper:

- Is the fraction of disposed sediment that may be dispersed outside of the boundaries of disposal sites quantitatively significant relative to inputs of sediments from non-disposal activities such as land runoff, industrial discharges, and waste water treatment plants?
- Are disposal sites quantitatively significant sources for the redistribution of particle-bound contaminants?
- Can disposal losses be measured accurately with existing technology, and what are future data requirements?

Dredged material dispersed from aquatic disposal sites can enter the ambient Sound in three ways: 1.) plume dispersion during release of sediment from barges, 2.) current scouring of the apex of disposal mounds during the first month or so following termination of disposal activities, and 3.) long-term losses related to the passage of hurricanes.

Long Island Sound receives, on average, 4.1 x 10^8 kg/yr (dry weight) of dredged material, representing about half of all sediments disposed within New England (L.I. Sound to Rockland Maine). This annual disposal into the Sound is less than half of the sedimentation rate derived from non-disposal sources (9.3 x 10^8 kg/yr).

Dispersal losses from plume dispersion and initial mound scouring comprise only 6% of the total annual dredged material released into the Sound and are about 3% of the annual non-disposal sediment input. Hurricanes are the single most important agents of dispersal. Hurricanes pass through New England about once every 7 years (14/century). Dispersal of dredged material from disposal mounds by a single hurricane scouring event may equal a maximum of about 16% of the annual dredged material input and 7% of the annual non-disposal input of sediment to the Sound.

Contaminants such as petroleum hydrocarbons (PHCs) entering the open Sound from dispersed dredged material are less than 3% of the PHCs entering the Sound from other sources, and particle-bound metals are estimated to be less than 1% of the total input for mercury, zinc, arsenic, lead, and copper. One cannot find gradients in sediment contaminants extending from disposal sites to the ambient seafloor because dispersed dredged material is diluted by the ambient suspended particle field, natural sedimentation, and bioturbational mixing of dispersed sediment into the ambient sediment column.

Returning to the initial questions:

- The quantity of dredged material leaving aquatic containment sites is small when compared to non-disposal inputs from runoff, industrial effluents, and waste water treatment plants.

- Disposal mounds are not significant sources of contaminants for the Sound outside the boundaries of designated dredged material containment sites. Monitoring for ecosystem effects should therefore be focused on individual mounds within disposal sites. Food chain contamination and transport is a greater potential issue than sediment transport.

- Siting criteria for locating aquatic containment sites should include factors that limit the exposure of dredged material mounds to hurricane scour (e.g., wind fetch, water depth, and kinetic energy).

- Current technology is sufficient to make reasonably accurate estimates of mass balance for dredging-disposal activities, but these candidate technologies have never been brought together to perform an "ideal" mass balance study. Future data requirements include means of obtaining accurate sediment wet weight/volume conversions to dry mass. Independent measurements are required of mound and foundation consolidation, lateral creep, and erosion in order to understand underlying processes that control changes in mound height during the first few months following termination of disposal activities.

In light of this review, the main focus of dredged material management should be on ensuring that disposal operations are controlled so that materials are confined to a footprint located entirely within the designated disposal boundary. Because potential ecological impacts are largely limited to individual disposal mounds, these mounds should be the units of surveillance. The major fisheries issue is related to prevention of food chain contamination from those species foraging on disposal mounds. The utility of monitoring outside of designated disposal areas is to compare the response of the biology and chemistry of disposal mounds to large scale events (e.g., regional hypoxia, spills, or hurricane impacts). The New England experience has been that system-wide events tend to affect disposal sites more than disposal sites affect the ambient system.

ACKNOWLEDGEMENT

I wish to thank Mr. Donald Cobb for preparing Table 6-4 and associated text.

1.0 PROBLEM STATEMENT

Due to the long commercial history of New England harbors, their waters have received industrial and municipal effluent over an extended period of time. For example, high trace metal sediment loads can be traced back to the Civil War (McCaffrey and Thompson, 1980). Because many of the bottom sediments in these harbors have associated contaminants, dredging and disposal activities must be managed closely. In order to minimize the loss of dredged material to the aquatic environment at large, the U.S. Army Corps of Engineers (COE), New England Division (NED) has developed a containment strategy for managing dredged material disposal at most of the New England sites. We have deliberately excluded the Long Island Sound Cornfield Shoals disposal site from our calculation, because this is managed as a dispersal site for sandy or fine grained sediment suitable for unconfined disposal. The DAMOS (Disposal Area Monitoring System) Program has evolved to minimize adverse effects of dredging and sediment disposal on coastal New England habitats. Under the DAMOS Program, dredged material is placed on the seafloor by methods that produce discrete mounds in specially-selected, low-energy containment sites. These sites are monitored periodically to evaluate the temporal and spatial stability of the dredged material deposits. Any erosion or movement of sediment away from the disposal sites presumably could be associated with loss of sediment-bound contaminants to the marine environment.

It is the purpose of this paper to identify potential losses of dredged material from disposal mounds to the "far-field system", and to compare these losses quantitatively to non-dredging related inputs of sediment. Three main questions will be addressed:

- Are the losses of sediments from disposal operations and disposal mounds significant in terms of other sources of sediment?
- Are disposal sites quantitatively important as point sources for the redistribution of particle-bound contaminants?
- Can these losses be measured accurately with existing technology, and what are the future data requirements?

Universal generalizations about dredged material effects are difficult to make because of the wide range of dredging methods, disposal methods, and ambient sedimentation processes. For this reason, this analysis is focused on current dredging and disposal practices within the New England Division as described in Section 2.0. Given these disposal methods, each operational phase of disposal is evaluated in Section 3.0 for potential dredged material loss to the overall system. In Section 4.0, data are presented to calculate these loss rates.

Non-dredging related sedimentation processes in New England estuaries and embayments are outlined in Section 5.0.

Most of the data utilized are from investigations in Long Island Sound, arguably the best studied estuary in New England. On average, Long Island Sound also receives more than half of all the dredged material disposed annually at open-water containment sites in New England. While much of the data are derived from Long Island Sound, many physical and biological attributes of the Sound can be extrapolated to other New England embayments and coastal locations.

Documented or estimated losses of material from disposal operations and disposal sites are compared with non-disposal-related inputs in Section 6.0. Finally, the original three questions outlined in the Problem Statement are addressed in Section 7.0.

To avoid confusion, the following terms are defined: a dredged material disposal site is a circumscribed area with clearly defined boundaries. Typically, a disposal site contains several disposal mounds, each composed of dredged material from several dredging projects. Loss or "dispersion" of disposed material is defined here as dredged material that moves outside of the specified disposal site boundaries into the ambient environment.

2.0 CURRENT NED DREDGING AND DISPOSAL PRACTICES

Prior to initiating dredging of an existing or new navigation channel or docking facility, background data on sediment quality usually are obtained from long cores or surface grabs in the area to be dredged. Management decisions about possible disposal options are based, in part, on the concentrations of organic and inorganic chemical contaminants in the sediment. Management options normally include: no dredging, aquatic disposal with no capping, aquatic disposal with capping, dilution at a dispersal site, near-shore disposal, or upland disposal. Most dredged material in the New England region is directed to aquatic disposal sites.

Normally, levels of chemical contaminants in dredged material disposed at open-water containment sites are relatively low. Based on results of chemical testing, these sediments are determined beforehand to be suitable for unconfined disposal. Such material does not need to be isolated by "capping" with cleaner sediments once it is placed at the disposal site. Projects with some elevated levels of contaminants may involve "de facto" capping as a conservative management approach. De facto capping is the result of dredging operations that begin within the most contaminated areas of harbors. These are usually the inner-most areas near outfalls and off-loading facilities. As dredging moves into cleaner reaches of a channel (usually the outer and sandier regions of a harbor), progressively cleaner material is removed and subsequently deposited over the contaminated inner harbor sediment at the disposal site. Not all of the dredged materials may come from the same harbor. De facto capping may also involve scheduling individual projects in separate harbors. The temporal window for de facto capping is October to March to allow sufficient time (2 months) for mound coverage by cleaner projects before dredging operations cease temporarily (see below).

Dredging operations begin only after a decision is made by the Corps regarding a disposal strategy. Most dredging in New England is done by bucket or clam-shell type grabs. Clamshell dredging has been shown to have a very localized effect, with turbidity levels falling off to ambient not far from the dredging site (Bokuniewicz and Gordon, 1980). About 2% of the volume of dredged material is estimated to be resuspended by the dredge or by barge overflow (Gordon, 1973; Tavolaro, 1984). The turbidity levels around dredging operations tend to converge with ambient levels within a few hundred meters or less (Martin and Yentsch, 1973; Cronin et al., 1976; Yagi et al., 1977; Barnard, 1978; and Bohlen et al., 1979).

Furthermore, the State of Connecticut requires that dredging cease during the late spring and summer months in Long Island Sound to avoid potentially adverse effects on benthic and pelagic organisms during critical spawning and migration periods. This is done as a conservative, cautionary measure, even though there is little evidence to support any actual harm to spawning or migrating animals during this time (Lunz et al., 1984). The disposal season typically runs from October 1st to May 31st.

Depending on the project size, excavated sediment is placed into pocket barges ranging in capacity between 400 and 2000 cubic yards (300-1500 cubic meters). Once filled, a barge is towed to the designated disposal site and positioned adjacent to a taut-wire-moored buoy marking the disposal point. A COE certified inspector is present onboard the tow boat to assure that disposal takes place at the buoy. The material dredged from several projects may contribute to the formation of a single disposal mound. To avoid having any single disposal mound become too shallow from accumulated sediment, the disposal buoy may be moved to a different part of the disposal site at the beginning of, or during, the disposal season. Therefore, several disposal mounds may occur within a disposal site.

A pocket barge discharges its contents by opening doors located on the bottom of the hull. Large barges (e.g., 1500 cubic meters) may consist of eight separate compartments (pockets); complete discharge of all pockets usually is accomplished within 10 minutes. Assuming a typical barge load of 1500 cubic meters of dredged material, and an estimated annual disposal volume of 150,000 to 200,000 cubic meters per site, over 100 separate discharge events may take place at the buoy during a disposal season.

An estimated total of 1.25×10^6 cubic meters of dredged material is disposed annually at the eight designated NED containment sites, giving an average volume per site of 156,000 cubic meters (Table 2-1). This is equivalent to a dry weight of 9.9×10^7 kg/yr. This value is based on an average volume to dry mass conversion factor of 0.64 gm/cc, based on observations reported by Suszkowski (1978) for in situ sediments and later utilized by Tavolaro (1984; Figure 2-1). The 9.9×10^7 kg/yr value has been reduced by 3% to 9.4×10^7 kg/yr based on observations that there is typically a 3% reduction in dry weight mass upon introduction of dredged materials into barges (Tavolaro, 1984). Most of the disposed sediment in Long Island Sound consists of organic silts and clays. Sandy muds dominate projects in Maine (Cape Arundel, Portland, and Rockland Disposal Sites).

Table 2-1

Volume and in situ Dry Mass Estimates for Disposed Material at the Eight Active NED Containment Disposal Sites. Data Source is SAIC (1988). Volume to Dry Mass Conversion (0.64 gm dry wt/cm^3) from Tavolaro (1984; see Figure 2-1). The Dry Weight of Disposed Material Has Been Reduced by 3% Based on the Loss of Mass in Sediments in Barges Relative to in situ Mass (Tavolaro, 1984).

SITE	SIZE	DEPTH (m)	AVERAGE ANNUAL DISPOSAL VOLUME (Cubic Meters)	DRY WEIGHT OF DISPOSED MATERIAL (Kg)
Western Long Island Sound (WLIS)	1 nautical mile square	29-34	150,000	9.3 x 10^7
Central Long Island Sound (CLIS)	2x1 nautical mile	17-23	350,000	2.1 x 10^8
New London (NLON)	1 nautical mile square	14-25	150,000	9.3 x 10^7
		Subtotal for L.I.S.	= 650,000	4.1 x 10^8
Buzzards Bay	500 yard dia. circle	9-11	21,000	1.3 x 10^7
Mass Bay (MBDS)	2 nautical mi. dia. circle	58-92	300,000	1.8 x 10^8
Cape Arundel (CADS)	500 yard dia. circle	35-42	4,000	2.5 x 10^6
Portland	1 nautical mile square	41-62	200,000	1.3 x 10^8
Rockland	0.5 nautical mile square	55-75	70,000	4.3 x 10^7
		Totals	= 1.25 x 10^6/yr	7.5 x 10^8/yr
		Average per site	= 1.56 x 10^5/yr	9.4 x 10^7/yr

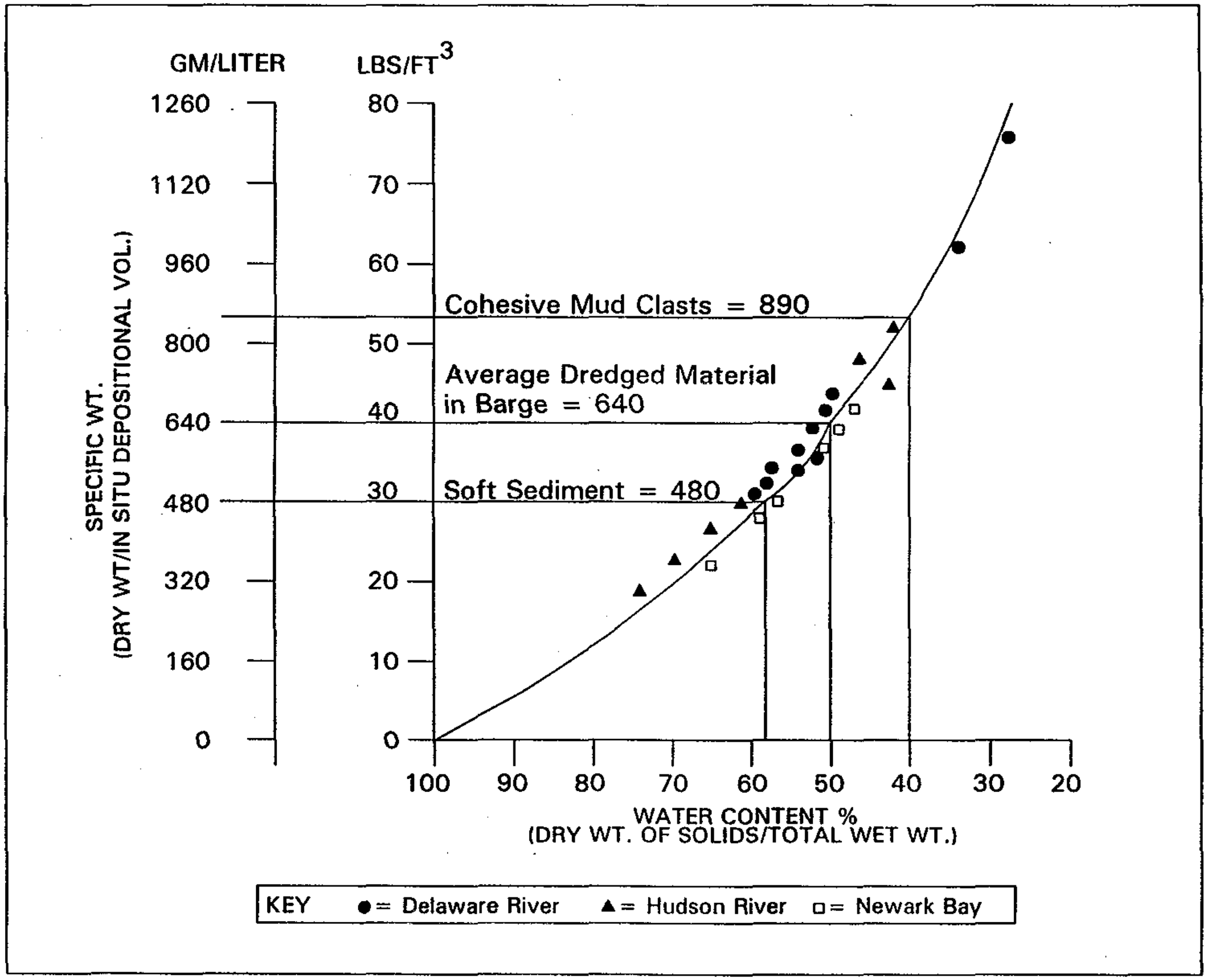

Figure 2-1. Water content versus dry density of dredged material (from Suszkowski (1978) as presented in Tavolaro (1984)).

3.0 POTENTIAL LOSSES OF DISPOSED MATERIALS

The following discussion about potential losses of disposed materials is based on the assumption that a project is carried out using current NED dredging and disposal practices (Section 2.0). Only potential losses during and after barge discharge at the disposal site will be considered. The plume of excavated material generated at dredging sites is beyond the scope of this paper. Also, the following descriptions are appropriate for a single disposal mound (i.e., once a disposal season ends, no further disposal takes place at that mound for several years).

3.1 Barge Discharge at the Disposal Site

There are three major phases which affect the behavior of dredged material once the pockets of a barge have been opened adjacent to the taut-wire-moored buoy (SAIC, unpubl.). During the convective descent phase, the majority of the dredged material is transported to the bottom under the influence of gravity as a concentrated cloud, which descends at a high fall velocity (roughly 1 m/sec). During the dynamic collapse phase, the vertical momentum present during the convective descent phase is transferred to horizontal spreading of the material following impact with the bottom. In Long Island Sound, these processes typically result in the formation of distinct dredged material mounds with thin flank deposits. In the passive dispersion phase, fine materials that remain suspended in the water column following the loss of momentum from the disposal operation are dispersed laterally as a suspended plume which may be tracked for several hours. The potential for far-field dispersion of fines is related partially to the drift of this turbid plume.

3.2 "Remolding" of the Disposal Mound

The term "remolding" is used here to describe early (up to 6 months) post depositional changes in the shape, volume, surface topography, and texture of a disposal mound as the deposited mass of sediment adjusts to its new environment. During and immediately after cessation of disposal, the dredged material mound settles and compacts; interclast space is compressed; water is squeezed out of the deposit; and topographic roughness of the surface is decreased and "smoothed" by bioturbation and near-bottom flow. Currents accelerate as they diverge over and around the mound, and the mound apex commonly becomes coarse-grained as fines are washed away progressively until the mound is armored by only coarse materials. If a mound has been capped by sand, the sand layer will compress the underlying finer grained sediment. The sand layer may sink into the underlying layers or creep down the flanks of the mound. In extreme cases, these latter two processes can cause a breach in a sand cap (Bokuniewicz and Liu, 1981).

Colonizing megafauna (crabs, lobsters, stomatopods, or fish) burrow into the surface or use large interclast spaces for refuge. Burrowing and foraging activities may result in the production of sub-rounded aggregates (clasts) of mud which roll down the sides of the mound. This "bio-erosion" also contributes to reduction in surface topography; it results in surface smoothing. In some cases, a capped mound may be penetrated by deep burrowing megafauna.

Colonizing macrofauna (polychaetes, bivalves, or amphipods) pelletize the surface, and the polychaetes or amphipods may form dense tube aggregations. Bioturbational pumping by such organisms initially ventilates the upper 1-2 cm of the sediment, exchanging pore waters with overlying water.

3.3 Long-Term Exposure

Once the mound remolding phase is completed, the compacted, smoothed, and texturally-armored deposit may be subject to further erosion only during the passage of severe storms or hurricanes. As long-term faunal succession progresses, the depth of both particle and fluid bioturbation increases. Deeply buried sediment may be moved to the surface through biological activity. If the mound is capped, this latter factor may be of special concern, especially if the cap is too thin to prevent substantial penetration of larger infauna into the underlying layer. Most biological mixing in the Sound is limited to the upper 20 cm, with the most rapid biogenic mixing taking place in the upper 12 cm (Aller and Cochran, 1976).

4.0 DISPOSAL LOSS ESTIMATES

In the following evaluation, losses of dredged material are calculated for the barge discharge phase, the mound "remolding" phase, and for the high-energy phase associated with the passage of a hurricane. Disposal losses are defined here as the weight of solids and associated contaminants that move outside the designated disposal site boundaries and into the "open system". Such losses may be estimated through direct measurements of disposal plume dispersion following release of the material from the barge, by measuring the loss of sediment from the disposal mound surface over time, or by mapping the progressive migration of the deposited material on the seafloor. Loss of material also may be deduced by performing mass balance calculations, which involve documenting the differences between the mass of dredged material in the barges and the mass of material deposited at the disposal site.

4.1 Losses Related to Barge Discharge at the Disposal Site

Immediately following discharge of dredged material from a barge at the disposal site, large cohesive clasts are transported rapidly (on the order of 1 m/sec) to the bottom directly below the barge. Small particles entrained in the down-welling density current strike the bottom and spread laterally a few tens to hundreds of meters, forming thin flank deposits. The volume of material which ends up in the central mound can be determined through high resolution acoustics, while the thin flank deposits can be detected using sediment-profile photography. In most of the monitoring surveys performed under the DAMOS program, the volume of material detected on the bottom by precision bathymetry and REMOTS® sediment-profile photography is less than the volume of disposed material estimated from barge records. However, this discrepancy is attributed to compaction of the material on the bottom and to the significant amount of interstitial water in the barges (Tavolaro, 1984) rather than to loss of dredged material outside the disposal site boundaries. The general conclusion is that most of the solids are transported to the bottom as cohesive clasts or as part of the density current, forming the central mound and flank deposits. These are retained within a well-circumscribed "footprint" and are not transported more than a few hundred meters from the disposal point (see review by Poindexter-Rollings, 1990).

The question remains regarding the off-site dispersion of the finest fractions of the dredged material, which remain suspended as a turbid water plume. These fines have low settling velocities and therefore may have the highest potential for far-field dispersal.

The best direct measurements of dispersion by plume transport have been made at the Rockland Disposal Site (SAIC, 1988). Plumes associated with discharge events of less than 2000 cubic meters of sediment were not detected outside the 0.5 nautical mile disposal site boundary, and generally were limited to a net transport distance of approximately 500 meters. A larger disposal event (approximately 2800 cubic meters) did result in off-site plume transport. During this latter event, initial suspended solid concentrations at the point of disposal were 1492 mg/ℓ. After one hour, the plume had traveled 1000 meters, and concentrations had dropped to 110 mg/ℓ (a 93% decrease in initial suspended solids). After two hours, the plume had moved 1700 meters (1000 meters beyond the disposal site boundary), and suspended solids dropped to 13 mg/ℓ (a 99% decrease in initial turbidity).

The Rockland study showed that during disposal up to 6% of the dredged material (dry mass) can remain suspended in the water column as a turbid plume. However, it was calculated that this mass of material would be exposed to current velocities capable of transporting it out of the disposal site only 13% of the time, or approximately 1.6 hours of each tidal cycle. We will assume in our subsequent calculations that the entire 6% of the material (dry mass) which remains in suspension as a turbid plume has the potential for off-site transport. This is clearly a maximum estimate because the potential for transport is a function of the size of the discharge event, the particle settling velocities, and the ambient flow field. This 6% estimate is comparable to the 4% loss estimate made by Tavolaro (1984) for plume dispersion at the New York Mud Dump.

The dry weight of dredged material disposed annually in Long Island Sound is 4.1×10^8 kilograms (Table 2-1). Six percent of this mass yields a maximum plume dispersion loss estimate of 2.46×10^7 kg/yr (Table 4-1).

4.2 The "Remolding" Phase

The "remolding" phase involves compaction, local erosion, and redistribution of cohesive mud clasts which make up the central mound. Compaction does not result in significant transport of solids. Pore water migration is involved in this process, but this phenomenon is not considered in this discussion of sedimentation effects. Scouring of the mound apex usually results in an armored surface. The break-up of large mud clasts into smaller clasts by bioturbation and current activity produces some local displacement of the clasts. Diver observations and REMOTS® sediment-profile photography have shown rounded mud clasts occupying local depressions on the central mound or being transported down the flanks of the mound. None of these clasts have been found beyond the flanks of the mound.

Over a period of several months, the apex of the mound (usually within a radius of approximately 25 meters or an area of approximately 2000 square meters) becomes coarser grained as fines are winnowed away. This process is self-limiting because the coarse residue of sand, shells, and gravel eventually reaches an equilibrium distribution with respect to the critical erosion velocity. It is difficult to make generalizations about how much fine-grained material is lost during this localized erosion, because this loss will

Table 4-1

Estimates of Off-Site Losses of Dredged Material to Long Island Sound. See Text for Explanation.

LOSS DUE TO:	DRY MASS	FOOTNOTE
PLUME DISPERSION	2.46 x 10^7 kg/year	1
SCOURING OF MOUND APEX DURING REMOLDING PHASE	2.67 X 10^5 kg/mound	2
HURRICANE	6.5 x 10^7 kg/hurricane	3

Notes: 1 - Dry mass/vol. conversion= 0.64 gm/cm³ (average dredged material)

2 - Dry mass/vol. conversion= 0.89 gm/cm³ (cohesive mud clasts)

3 - Dry mass/vol. conversion= 0.48 gm/cm³ (bioturbated surface sediment)

(All conversions from Tavolaro (1984); see Figure 2-1)

depend on how rapidly the equilibrium grain-size distribution is attained. This, in turn, is a function of the concentration of coarse-grained material within sediments occupying the mound apex. With sand-capped mounds, the equilibrium condition is reached very rapidly. With silt or clay caps or uncapped mounds, this condition may be attained only after considerable erosion. Measurements of the amount of winnowing required to armor a sediment surface have not been made, and so our estimates of erosion are approximate at the present time.

However, a limit may be placed on this erosion because large negative changes in the height of disposal mounds have not been observed in repeated bathymetric surveys under the DAMOS program. The resolution (i.e., the ability to detect vertical changes in the surface of a mound) of these surveys is on the order of 10 to 20 cm, depending on the water depth. Negative changes in mound height can be related to mound compaction, consolidation, lateral creep, and surface erosion. Morton (1980) found that the greatest changes in mound elevation (greater than 15 cm) occurred within a few days of disposal. Although this is considered the period of mound consolidation, it is not possible to separate the non-erosive from the erosive factors because they never have been measured separately. However, it is possible to conclude that the combined effects apparently are limited to a change in mound height of 10 to 20 cm.

In the absence of further data, we make a maximum estimate and assume that 15 cm of surface sediment are lost due to erosion during armoring of the mound apex. To further maximize this "worst-case scenario" estimate, assume that a typical mound apex in Long Island Sound is composed of large, cohesive mud clasts and covers an area of 2000 square meters (i.e., it has a radius of 25 meters). The subsequent calculation results in an estimated 300 cubic meters of fine-grained material lost to the open Sound from a typical mound apex during the remolding phase. Using a dry mass-to-volume conversion of 0.89 gm/cm^3 for cohesive mud clasts (from Figure 2-1), this is equivalent to a dry mass of 2.67×10^5 kg per mound (Table 4-1). It is assumed that once material is washed from a mound, and the apex becomes armored, further losses from the mound apex approach zero. The total quantity of material lost to the open Sound will then depend on the number of new mounds constructed each year. In Long Island Sound, it is assumed that this number will be three (one new mound at each disposal site).

4.3 Long-Term Losses

Hurricane Gloria passed directly over Long Island Sound on 27 September 1985. Bathymetric surveys of the Long Island Sound disposal sites immediately following this storm indicated no significant loss of dredged material, except for the apparent loss of 15,000 cubic meters of sediment from Cap Site 1. Because dredged material had been deposited at this mound only four months prior to the hurricane, this apparent loss of sediment was primarily attributed to compaction (Fredette, et al., 1988). In support of this inference, REMOTS® sediment-profile photographs showed remnants of the oxidized bioturbated surface were still present at Cap Site 1, suggesting that only about 1 cm of sediment was lost. This value is comparable to erosive losses measured by REMOTS® at five other Central Long Island Sound (CLIS) disposal mounds following the hurricane (Table 4-2). The interval of erosion in most cases corresponded to the intensively-bioturbated layer of near-surface sediment. It is reasonable to assume that the eroded sediment was mixed with ambient resuspended sediment and transported away from the disposal mounds.

As of 1989, there was a total of 18 disposal mounds among the three disposal sites in Long Island Sound. If we assume that the average disposal mound "footprint" covers a radius of 400 meters (again a maximum estimate for worst-case scenario predictions), then a cumulative area of 9×10^6 square meters in Long Island Sound is covered by dredged material. A 1.5 cm thick layer of this material eroded and transported outside the disposal sites during a hurricane is equivalent to a total volume of 135,717 cubic meters. Using a dry mass-to-volume conversion factor of 0.48 gm/cm^3 for bioturbated surface sediment (Figure 2-1) yields a total of 6.5×10^7 kg (dry weight)

Table 4-2

Estimates of Surface Erosion at CLIS Caused by Hurricane Gloria.
Data based on Pre- and Post-Storm REMOTS® Surveys
(from Fredette et al., 1988).

	MEAN DEPTH OF RPD (cm)		
MOUND	PRE STORM	POST STORM	CHANGE IN RPD DEPTH (cm)
FVP	2.65	2.21	- 0.4
STNH-N	3.97	1.97	- 2.0
STNH-S	4.08	2.07	- 2.0
CS-1	4.02	2.97	- 1.0
CS-2	3.98	2.56	- 1.4
MQR	4.58	2.58	- 2.0

of disposed sediment lost to the open Sound per hurricane (Table 4-1).

It is clear that hurricanes potentially can be important sources of turbulence, causing the dispersion of surface sediment from mounds. The long-term losses can be estimated if we know the frequency of hurricanes per century. Such a data base exists for New England over the period 1900-1957 (Dunn and Miller, 1960). A hurricane is defined in this context as having a sustained wind of ≥ 74 mph (Beaufort wind force 12). Eight such wind events affected New England over the 57 year period. This equals an extrapolated frequency of 14 hurricanes per century. If we apply the loss estimates from Table 4-1 to the time-span of 100 years (Table 4-3), we note that 27% of the total mass of dispersed sediment can be accounted for by hurricanes and the balance by plume dispersion and day-to-day scouring of the mound apex by non-hurricane turbulence. However, compared to the total mass of sediment entering the Sound from other sources, the losses from disposal mounds account for only 3.5% when averaged over the long term.

Table 4-3

Long-Term Losses from Disposal Mounds Averaged over 100 Years. This table assumes an average of 14 hurricane events per century in the New England region (Dunn and Miller, 1960). Yearly values (kg / dry weight) are taken from Table 5-1. Percentage values in the last column are the contribution of plume dispersion, mound erosion, and hurricane scour relative to the total sediment mass (100%) dispersed from disposal sites (averaged over a century).

	Mass of Loss (dry kg)		
Source of Loss	**Non-Hurricane Year**	**Hurricane Year** (14 hurricanes per century)	**Total for Century**
Plume Dispersion and Mound Scour	2.5×10^7	2.5×10^7	25.0×10^8 (73.3%)
Hurricane Scour	0	6.5×10^7	9.1×10^8 (26.7%)

Total Mass Dispersed from Disposal Sites per Century:	34.1×10^8 (100%)
Total Mass Entering the Sound from Other Sources per Century:	93.0×10^9
Contribution from Disposal Sites to Total Mass Input to Sound per Century	3.5%

5.0 NON-DISPOSAL RELATED SEDIMENTATION PROCESSES

This section will describe ambient sedimentation processes in New England estuaries and embayments. This information will be used to compare to, and evaluate the effects of, dredged material disposal in Section 6.0. Most of the data can be drawn from Long Island Sound because this estuary has been the subject of intensive sedimentological and geochemical study.

For Long Island Sound, the two natural sedimentation processes of interest are the inputs of "new" sediment to the Long Island Sound system and the resuspension and redistribution of sediment already there. These two processes are discussed separately in the following sections.

5.1 Inputs of "New" Sediment

As stated in Section 2.0, most dredged material consists of very fine sand to silt and clay. For this reason, the background or ambient sedimentation rates of very fine-grained and organic-rich (8-9% organic matter) sediment is of primary interest in the present exercise. The major source of "new" fine-grained sediment to Long Island Sound is riverine inputs. This amounts to about 4.7 x 10^8 kg/yr (Gordon, 1980).

Between 1982 and 1984, Farrow et al. (1986) estimated that 8.7 x 10^8 kg/yr of sediment entered the Sound from riverine input, agricultural runoff, urban runoff, and discharges from sewage treatment plants. The difference between the Gordon (1980) and Farrow et al. (1986) estimates is that Gordon did not consider urban runoff. Another source is the selective washing of fines from bluffs composed of glacial till and morainal deposits in the eastern part of the Sound. This may add an additional 0.5 x 10^8 kg/yr (Bokuniewicz and Tanski, 1983). Additional areas of shoreline erosion and minor riverine inputs may add another 0.5 x 10^8 kg/yr to the system (Bokuniewicz and Gordon, 1980). About 0.4 x 10^8 kg/yr (80%) of these shoreline sediments never reaches the open Sound but is trapped in fringing marshes (Bokuniewicz, 1988).

The net annual input of fine-grained sediment to the open Sound is estimated to range between 5.3 x 10^8 kg/yr (Gordon's estimate) and 9.3 x 10^8 kg/yr (Farrow et al. estimate). Because urban runoff appears to be such a significant fraction of this sedimentation load, we will use the Farrow et al. estimate in subsequent mass calculations. The total area of the Sound is 3200 km^2, and 56% of this area (1792 km^2) is composed of fine-grained sediment (Bokuniewicz and Gordon, 1980). The yearly input of fine-grained sediment is equivalent to an annual sedimentation rate of 0.05 $gm/cm^2/yr$ within the muddy facies. Long-term sedimentation rates, as determined by profiles of ^{210}Pb near the Central Long Island Disposal Site, also yield a sedimentation rate of 0.05 $gm/cm^2/yr$. Radiocarbon dating at this same site yielded an accumulation rate of 0.077 $gm/cm^2/yr$ (Benoit et al., 1979). Therefore, the net sedimentation rate in the central mud basin of Long Island Sound falls within 0.05 to 0.08 gm/cm^2/yr. Slightly higher rates (0.1 gm/cm^2/yr) may occur to the west of Mattituck Sill and Stratford Shoal (Bokuniewicz, 1988). These estimates are similar to those presented in a review of sediment fluxes in Long Island Sound prepared by Kim and Bokuniewicz (1991).

5.2 Resuspension and Redistribution of Sediments

Measurements of suspended sediment concentrations over the muddy parts of Long Island Sound (the central and western basins) show a near-bottom turbidity maximum. This near-bottom turbidity layer develops in the lower 6-9 meters of the water column and contains a higher concentration of suspended particulates than mid-water or surface water. This layer should not be confused with the well-known estuarine turbidity (flocculation) zone that occurs at the head of some estuaries or the nepheloid layer in the deep sea. Rather, this benthic turbidity zone or BTZ (Rhoads et al., 1984) is formed by tidal flow. At peak flood and ebb velocities, turbulence resuspends surface sediment forming a turbid layer of water that rises a few meters off the bottom. The suspended particles consist of organic-mineral aggregates with settling velocities of 0.01 to 0.04 cm/sec as inferred from transmissometry measurements made in the field (Rhoads et al., 1984). Bokuniewicz (1988) estimated a settling velocity of 0.05 cm/sec for similar particles caught in sediment traps deployed off Shoreham, NY in the central Long Island Sound basin. This turbidity zone extends over an area of at least 1000 km^2 (Rhoads et al., 1984). All three dredged material containment sites in Long Island Sound are located within areas associated with the BTZ.

The source of the organic-mineral aggregates in the BTZ is tidal resuspension of the upper 1-3 millimeters of the bottom. In the region of the Central Long Island Sound Disposal Site, peak turbidity is observed 1 hr before slack low water or about 1.5 hours after the peak ebb tidal current (Rhoads et al., 1984). On a seasonal basis, maximum turbidity levels are observed during spring and early summer (May, June, and July) and in the fall, when suspended loads range from 10-40 mg/ℓ. Summer loads commonly fall below 10 mg/ℓ (Rhoads et al., 1984). These ranges compare favorably with other Long Island Sound studies cited by Bokuniewicz (1988). According to Bokuniewicz's summary, average near-bottom values are approximately 7 mg/ℓ, and average surface values are approximately 2 mg/ℓ. Bokuniewicz estimates that a value of 5 mg/ℓ might be reasonable for the Sound as a whole (including sandy facies). Based on the 5 mg/ℓ value, the total amount of material in suspension would be 2.5 x 10^8 kg or about 27% of the annual supply of "new" fine-grained material. The trapping efficiency of the Sound is 100% (Bokuniewicz, 1988); therefore, this resuspended material is retained and dispersed laterally throughout the central and western basins. It also may enter harbors via estuarine bottom flow. During the summer, much of this sediment is confined below the pycnocline, but, during unstratified periods, it may reach upper levels in the water column (Benninger, 1976).

The flux of particles across the sediment-water interface caused by suspension and redeposition greatly exceeds the long-term sedimentation rate. Sediment trap studies have shown that 7.5 $gm/cm^2/month$ are trapped during the summer and 3.6 $gm/cm^2/month$ during the winter (McCall, 1977). The monthly mean corresponds to an annual resuspension and redeposition rate of 56 gm/cm^2. This value has been supported by subsequent sediment trap work in Long Island Sound (Bokuniewicz, 1988). There are some uncertainties associated with these kinds of measurements related to the trapping efficiencies of the containers used in such studies. Because these efficiencies are not reported, the performance of the traps is unknown (undertrapping or overtrapping). For a first-order estimate of fluxes these data are probably accurate to within ± 10%.

Extrapolating McCall's sediment trap data to the muddy facies in the Sound, it is estimated that 1.4×10^9 kilograms are resuspended with each tidal cycle, and, cumulatively, 1×10^{12} kg are resuspended annually. This cumulative rate is 1000 times greater than the long term sedimentation rate calculated for Long Island Sound. These resuspension or "re-sedimentation" rates rival the inputs of new sediments to active deltas. Although the net sedimentation rates in estuaries are very low compared to deltas, the cumulative tidal fluxing of surface sediment in estuaries rivals deltaic sedimentation.

It is clear that only a small fraction of the 9.3×10^8 kilograms of fine-grained sediment introduced into the Sound each year is actually bound into the permanent deposit (i.e., removed from the resuspension cycle). The short-term retention efficiency of the estuarine seafloor in Long Island Sound therefore may be only 0.1%; the balance is involved in resuspension cycles.

Storm energy may result in transient resuspension events that produce significant redistributions of sediment within Long Island Sound. For example, the passage of Hurricane Gloria directly over the CLIS Disposal Site in September 1985 resulted in the creation of a 5 to 6 cm thick sand layer over muds just north of the northern edge of the CLIS boundary. This sandy unit was probably generated by intensive reworking and resuspension of nearshore sands off New Haven Harbor. Outwelling of water and entrained sand from the harbor and nearshore areas following relaxation of the wind seiche was the likely transport mechanism (Fredette et al., 1988).

6.0 COMPARISONS OF DISPOSAL AND NON-DISPOSAL INPUTS OF SEDIMENT AND PARTICLE-ASSOCIATED CONTAMINANTS

Bokuniewicz (1988) used data from the New England River Basin Commission (1981) to estimate the total quantity of material moved by dredges in Long Island Sound. Estimates made from 362 dredging projects over a 10 year period (1970-1980) yielded an average annual dredging activity of 12 x 10^8 kg. On a shorter time scale, the annual dredging activity at the three currently active disposal sites is 4.1 x 10^8 kg (Table 2-1). These estimates are respectively 1.3 to 0.4 times the annual input of new sediment to the Sound from non-dredging sources (9.3 x 10^8 kg) as calculated by Bokuniewicz (1988) and Kim and Bokuniewicz (1991).

6.1 Off-site Loss of Sediment

As stated in Section 4.0, most of the dredged material remains where it is deposited at the three active Long Island Sound containment disposal sites. It is of interest to determine what percentage of the total input of dredged material to Long Island Sound may be lost from the disposal sites. It is also of interest to determine how much dredged material moves off-site compared to the total input of sediment to Long Island Sound from non-dredging sources. In addressing these questions, we will use the worst-case off-site losses of dredged material as shown in Table 4-1, the total dredged material input to Long Island Sound of 4.1 x 10^8 kg/yr from Table 2-1, and the total non-disposal sediment input of 9.3 x 10^8 kg/yr determined in Section 6.1.

The maximum loss of dredged material to the open Sound from plume dispersion was 2.46 x 10^7 kg, representing 6.0% of the total annual dredged material input and 2.6% of the annual non-disposal sediment input. In Section 5.2, it was calculated that a dry mass of 2.67 x 10^5 kg/yr was lost by scouring of the top of each new mound, and three mounds (one at each of the three disposal sites) usually are active during the disposal season. This means that a total of 8 x 10^5 kg of sediment may be lost to the open system each year from this source, representing 0.06% of the annual dredged material input and 0.03% of the non-dredged input. Finally, the loss of sediment from disposal sites to the Sound from hurricanes (6.5 x 10^7 kg/hurricane) represents 15.8% of the annual dredged material input and 7% of the non-dredging input of sediment in years in which they occur. A summary of these losses is given in Table 6-1. If we average these losses over a period of one century, the mass of sediment dispersed from disposal sites is only 3 to 4% of the sediment entering the Sound from other sources per century, and the hurricane contribution to this dispersal is about 1% of the non-disposal input of sediment per century (Table 4-3).

6.2 Off-site Loss of Particle-Bound Contaminants

To determine the total particle-associated contaminant loss from the three disposal sites to the open system in Long

Table 6-1

Dredged Material Lost from Disposal Sites to Long Island Sound as a Percentage of the Total Dredged Material Input and the Total Non-Disposal Sediment Input. Refer to Table 4-1 for the Mass Values used to Derive these Estimates.

OFF-SITE LOSS FROM:	PERCENTAGE OF TOTAL ANNUAL DREDGED MATERIAL INPUT	PERCENTAGEOFTOTAL ANNUAL NON-DISPOSAL SEDIMENT INPUT
Plume Dispersion	6.0%	2.6%
Scouring of the Mound Apex (3 active mounds/yr)	0.06%	0.03%
Hurricanes	15.8%	7.0%
Annual total in years without hurricanes =	6.1%	2.6%
Annual total in years with hurricanes =	21.9%	9.6%
Mound loss due to hurricanes per century =	ca. 27%	ca. 1.0%

Island Sound, a series of calculations was performed. First, the total annual input of each contaminant to each site was estimated. The most accurate way to do this would have been to measure the contaminant concentrations in the dredged material being transported to each site (i.e., in the barges). Unfortunately, such measurements have not been made routinely. Contaminant concentrations have been determined in the material prior to dredging; however, using these measurements probably would lead to an overestimation of the ultimate input of contaminants to the disposal sites. These overestimates occur because surface material is mixed and diluted with underlying relic sediments during dredging and subsequent barge loading, resulting in a decrease of total dredged material contaminant concentration.

Contaminant concentrations in dredged material at the disposal sites also are measured routinely as part of DAMOS monitoring. These measurements usually are made for surface sediments (top 2-10 cm of disposal mounds) and potentially could underestimate the concentrations in the barges. Given enough time, natural resuspension and sedimentation would act to dilute the upper layers of disposal mounds with ambient sediment. However, the initial post disposal DAMOS sampling usually is performed within 2 months following cessation of disposal, before such dilution becomes significant. Therefore, it is assumed that the concentrations measured at the site during initial post disposal surveys closely approximate the concentrations in the barges. Continuing with the first part of our calculation, the contaminant's known concentration in dredged material at each site (Table 6-2) was multiplied by the total annual dry weight input of dredged material to each site (last column in Table 2-1). The resulting values were used to determine the total annual dry weight input of each contaminant (Table 6-3 and column A of Table 6-4).

The second step in the calculation was to determine how much of this total annual particle-associated contaminant input was lost from the disposal sites through plume dispersion, mound scouring, and erosion due to hurricanes. Of the total annual input of dredged material, 6.0% is lost be dispersion, 0.06% is lost be scouring, and 15.8% is lost during hurricane years (Table 6-1). These same percentages can be applied to the total annual inputs of particle-bound contaminants in the dredged material (resulting values shown in columns B, C, and D in Table 6-4). The total estimated annual loss of contaminants from the disposal sites to the open Sound (column E in Table 6-4) represents the worst case (e.g., a year with a hurricane passing over the Sound). The last column (H in Table 6-4) shows the estimated annual loss of contaminants when the hurricane effects are averaged on a yearly basis.

For each contaminant, the annual loss from the disposal sites then can be expressed as a percentage of its total annual input to Long Island Sound from other sources (column F in Table 6-4). The total annual input of each contaminant is taken from the National Oceanographic and Atmospheric Administration (NOAA) National Coastal Pollutant Discharge Inventory for Long Island Sound for the period 1982-1984 (Table 6-5; from Farrow et al., 1986). The worst-case contribution of mercury, zinc, and arsenic from disposal sites during hurricane years is less than 1% of the total inputs, while the inputs of lead and copper are less than 2%. The dominant source of the metals is waste water treatment plants and upstream sources; most of the petroleum hydrocarbon (PHC) input is from water treatment plants and urban runoff (Table 6-6). Because the significant atmospheric input of lead (Benninger, 1978) was not considered in the NOAA inventory, the values in Table 6-5 represent an underestimate of the total loading for this metal.

Dredged material typically has a high iron content, so the disposal contribution of Fe to the open Sound potentially can amount to about 9% of the total annual input during hurricane years (Table 6-4). This contribution is not considered to be of

Table 6-2

Average Contaminant Concentrations in Dredged Material at Long Island Sound Disposal Sites. Data from SAIC (1990a, b, c).

	WLIS	CLIS	NLON
Hg (ppm)	0.164	0.296	0.127
Pb (ppm)	60.8	47.2	28.4
Zn (ppm)	175	128	-
As (ppm)	4.78	6.28	6.10
Fe (ppm)	28400	24500	14600
Cu (ppm)	84.4	59.3	17.4
PHCs (ppm)	450	217	-
PCBs (ppb)	101	-	-

(-) Data Not Available

ecological concern because iron per se is not considered a biological contaminant. Reduced iron can chelate and co-precipitate other metals, and with the exception of manganese, it is largely responsible for fixing metals as insoluble sulphides (McCaffrey and Thompson, 1980). These bound metals may not be readily available to biota (Scott, 1989).

Estimates of polychlorinated biphenyls (PCBs) input are difficult to make because the NOAA inventory lacks data for many of the potential input categories. As with metal contaminants, it is likely that disposed dredged material represents a similarly small, but measurable, source of PCBs.

The specific sedimentation rate in muddy areas of Long Island Sound is estimated to be 0.03 gm/cm^2/yr (Bokuniewicz, 1988). If we assume a worst-case scenario, where plume dispersal, mound apex scouring, and hurricane scouring add 22% dry mass to the non-disposal source of sediment input (Table 6-1), the specific sedimentation rate may be increased by 0.007 gm/cm^2/yr. This is well within the error or uncertainty associated with making such sedimentation rate estimates. This small incremental quantity will be diluted further by bioturbational mixing of particles into the bottom to depths of 10 cm or more.

Table 6-3

Annual Contaminant Inputs (in Short Tons)
to Long Island Sound Disposal Sites.

	WLIS	CLIS	NLON	TOTAL
Hg	0.018	0.072	0.013	0.103
Pb	6.44	11.5	3.01	20.9
Zn	18.5	31.1	na	49.6*
As	0.506	1.52	0.646	2.67
Fe	3010	5940	1540	10500
Cu	8.93	14.3	1.84	25.1
PHCs	47.6	52.7	na	100*
PCBs	0.011	na	na	0.011*

na = Data Not Available
* = Incomplete Total Due To Missing Data

6.3 Ambient Resuspension

As stated in Section 5.0, fine-grained sediment entering the Sound is not bound immediately into the permanent deposit but rather participates in resuspension cycles. This resuspension and temporary redeposition occur at a rate 1000 times the rate of long-term accumulation. This means that any fine-grained sediment leaving disposal sites will be mixed thoroughly and diluted with the ambient suspended sediment which is 27% (2.5 x 10^8 kg) of the annual input of new sediment. Suspended material is estimated to have a residence time in such resuspension cycles of 6 months (Bokuniewicz, 1988). This means that material lost from disposal sites will be diluted by a factor of 1 part ambient suspended sediment to 1 part dispersed dredged material sediment at a maximum, or by 1 part ambient to 0.3 parts dredged material at a minimum.

When this ambient resuspended sediment settles to the bottom during slack water, some of it will cover the disposal mounds, particularly if there are "lee-side" effects where particles are captured in eddies. A small fraction of this material will be incorporated into the mound (with the noted exception of the scoured mound apex). Over time, this phenomenon will result in dilution of the upper layers of the disposal mound by ambient sediment. This process was used to explain a temporal decrease in sediment contaminant concentrations observed in the upper 2 cm of the FVP disposal mound at CLIS. Ten months after this mound was created, only 2% of the bulk surface sediments (0-2 cm interval) retained the unique Black Rock Harbor chemical signature (Scott et al., 1987). This was attributed to dilution of the FVP sediment with ambient material.

This dilution effect is important to consider, because storm-induced scouring of dredged material mounds has been shown to involve only the upper 2 cm of sediment. While we have estimated that this may amount to 7% of the annual input of non-disposal related sediment, the dispersed material may have contaminant concentrations which are lower than those of the underlying material (i.e., especially if the mound is capped).

Because of the high resuspension rates in the muddy subtidal areas of Long Island Sound where the disposal sites are located, the turbidity generated by disposal plumes or scour of disposal mounds cannot be recognized from the natural background turbidity of 50 to 40 mg/ℓ. It has been shown in Section 4.0 that turbidity levels in plumes reach background levels in a short period of time. Because of the high mixing and dilution effects that take place with fine-grained sediments, no strong benthic gradients in sediment quality are expected to exist beyond the edges of disposal mounds. This factor should be kept in mind when designing a benthic monitoring program.

Table 6-4

Maximum Estimated Off-Site Loss of Particle-Bound Contaminatns from Disposal Sites in Long Island Sound Compared with Total Inputs. All Values are in Short Tons, except Column F.

	A. Total Annual Input from Dredged Material Disposal	B. Plume Dispersion Loss (6.0%)	C. Mound Remolding Loss (0.06%)	D. Hurricane Scouring Loss (15.8%)	E. Maximum Loss Estimate (B+C+D)	F. Maximum Loss Estimate as a Percentage of Total Annual Input to LIS[a]	G. Average Yearly Loss[b]	H. Average Loss Estimate as a Percentage of Total Annual Input to LIS
Hg	0.103	6.2×10^{-3}	6.2×10^{-5}	0.016	0.022	0%	2.3×10^{-3}	0%
Pb	20.9	1.25	0.013	3.30	4.57	1.7%	0.46	0.65%
Zn	49.6[c]	2.98	0.030	7.84	10.85	1.0%	1.10	0.40%
As	2.67	0.16	0.002	0.42	0.58	0.9%	0.06	0.33%
Fe	10500	630	6.3	1659	2295	8.8%	232	3.52%
Cu	25.1	1.51	0.015	3.97	5.49	1.3%	0.56	0.51%
PHCs	100[c]	6.0	0.06	15.8	21.86	6.9%	2.21	2.75%
PCBs	0.011[c]	6.6×10^{-4}	6.6×10^{-6}	1.7×10^{-3}	2.4×10^{-3}	-[c]		

[a] Calculated as follows:

$$\frac{\text{Maximum Loss Estimate x 100}}{\text{Maximum Loss Estimate + Other Inputs (from Table 6-5)}}$$

[b] Contribution of hurricane scour loss averaged on an annual basis

[c] Incomplete total due to missing data

Table 6-5
Annual Pollutant Discharges to Long Island Sound and
Percent of Annual Discharge by Analysis Area,
circa 1982-1984. From Farrow et al. (1986).

Pollutant	Upper East River	Western Narrows	Central and Eastern Sound	Total
Flow (BG)	836 (9.3)[a]	116 (1.3)	8,030 (89.4)	8,990
Conventional				
BOD (100 tons)	137 (12.5)	52 (4.7)	912 (82.8)	1,100
TSS (100 tons)	288 (3.3)	329 (3.8)	8,120 (92.9)	8,730
Nutrients				
TN (100 tons)	131 (26.1)	15 (3.0)	355 (70.9)	502
TP (100 tons)	8 (10.8)	10 (13.5)	56 (75.7)	75
Heavy Metals				
As (tons)	18 (27.2)	4 (6.1)	44 (66.7)	66
Cd (tons)	1 (2.5)	3 (7.5)	36 (90.0)	40
Cr (tons)	23 (9.7)	7 (2.9)	208 (87.4)	238
Cu (tons)	110 (27.3)	11 (2.7)	283 (70.0)	404
Fe (tons)	1,110 (4.7)	568 (2.4)	22,100 (92.9)	23,800
Pb (tons)	29 (10.9)	14 (5.3)	223 (83.8)	266
Hg (lbs)	3,790 (23.5)	210 (1.3)	12,100 (75.2)	16,100
Zn (tons)	139 (13.6)	43 (4.2)	841 (82.2)	1,020
PHCs (100 tons)	127 (43.3)	27 (9.2)	139 (47.5)	293
Chlorinated HCs				
CHP (lbs)	1,292 (60.0)	142 (6.6)	716 (33.4)	2,150
PCB (lbs)	0 (0)	0 (0)	0 (0)	0
Pathogens				
FCB (c. x 10^{12})	58,000 (7.0)	27,200 (3.3)	741,000 (89.7)	826,000
Sludge (100 tons)	399 (64.5)	7 (1.1)	212 (34.3)	618

[a] = Value in parenthesis is percent of total annual discharge.

Table 6-6
Percent of Annual Pollutant Discharges to Long Island Sound by Source Category, circa 1982-1984.
From Farrow et al. (1986).

Pollutants	Total Annual Discharge	WWTPs	Industry	Power Plants	Runoff			Upstream Sources
					Urban	Crop	Forest	
Flow (BG)	8,990	4.2	0.5	26.6	3.1	0.6	0.9	64.1
Conventional								
BOD (100 tons)	1,100	24.2	5.2	-[a]	14.9	3.0	0.1	52.6
						50.0	3.7	17.2
TSS (100 tons)	8,730	3.4	0.3	<0.1	25.4			
Nutrients								
TN (100 tons)	502	37.6	2.1	<0.1	7.3	3.7	0.1	49.2
						0.5	<0.1	25.2
TP (100 tons)	75	66.2	0.1	0.1	7.9			
Heavy Metals								
As (tons)	66	51.7	<0.1	1.7	8.1	3.4	<0.1	35.1
Cd (tons)	40	28.2	<0.1	<0.1	5.1	<0.1	<0.1	66.7
Cr (tons)	238	18.9	4.2	0.4	7.1	8.0	0.4	61.0
Cu (tons)	404	31.9	3.4	5.2	7.2	1.2	0.2	50.9
Fe (tons)	23,800	4.9	<0.1	<0.1	15.7	34.8	2.2	42.4
Pb (tons)	266	14.7	2.3	<0.1	43.0	<0.1	<0.1	40.0
Hg (lbs)	16,100	25.4	0.6	0.1	7.3	<0.1	<0.1	66.6
Zn (tons)	1,020	22.6	2.9	1.6	12.8	1.9	0.1	58.2
PHCs (100 tons)	293	66.6	0.4	0.3	32.7	-	-	-
Chlorinated HCs								
CHP (lbs)	2,150	90.3	1.3	-	5.4	3.0	-	-
PCB (lbs)	0	-	0.0[b]	-	-	-	-	-
Pathogens								
FCB (c. x 10^{12})	826,000	1.0	<0.1	-	47.3	-	-	51.7
Sludge (100 tons)	618	100	-	-	-	-	-	-

[a] No estimates made for this pollutant for this source category.
[b] Zero discharge estimated for this pollutant for this source category.

7.0 SUMMARY AND CONCLUSIONS

In summary, we return to the questions presented in the Problem Statement (Section 1.0):

1.) Are the losses of sediment from disposal mounds significant in terms of natural sedimentation processes?

During a year without hurricanes, the worst-case loss of sediments from disposal sites to the ambient Long Island Sound environment is a very small percentage (approximately 3%) of the non-disposal sediment inputs. Off-site losses may reach higher percentages during hurricane years (up to 10%). These percentages are decreased if we average the losses over longer intervals of time. Hurricanes (sustained winds ≥ 74 mph) strike the New England coast about 14 times per century. Over a 100 year period, dispersal of disposal site sediment by hurricanes is only about 1% of the total sediment load entering Long Island Sound from other sources.

Disposal activities and loss of sediment from disposal sites are not important sources of turbidity and do not affect the sedimentation rate of the open system. Once dispersed, the dredged material is mixed and diluted with the ambient suspended particle load. This material may stay in suspension for up to 6 months and be transported large distances. The quantitatively small mass of dispersed dredged material is probably not measurable once it is incorporated into the bottom deposits. Further dilution by bioturbation with ambient sediments makes qualitative or quantitative recognition of this material very difficult.

2.) Are disposal sites important point sources of particle-bound contaminants?

Based on the NOAA Pollutant Discharge Inventory for Long Island Sound (Farrow et al., 1986), the major non-dredging related inputs of contaminants to the Sound are wastewater treatment plants, industrial effluent, power plants, urban runoff, cropland runoff, forestland runoff, and upstream sources. Compared with these sources, loss of heavy metals associated with disposed dredged materials is a minor input (approximately 2% or less of the total except for PHCs and iron). This assumes a worst-case condition (e.g., passage of a hurricane over the Sound). The relative contribution of PCBs from disposal sites could not be determined because the NOAA inventory is incomplete for this category of pollutant. However, the dominant source of PCBs is predicted to be related to non-dredging related inputs.

3). Can disposal losses be measured accurately with existing technology, and what are the future data requirements?

Existing monitoring and measurement technology is adequate for this purpose. However, no single mass balance study has yet included all of the tools necessary for accurate measurement. These tools include an accurate plume dispersion study for each disposal event (with water sampling to calibrate the acoustic record), precision bathymetric profiling, in situ geotechnical measurements to measure compaction and creep, a method to measure accurately surface scour, and REMOTS® photography for measurement of thin flank deposits.

The change in mound height over time, as reflected in repeated precision bathymetric surveys, represents a combination of compaction, lateral creep, and erosion. To date, the relative contribution of these processes has not been quantified. In situ geotechnical measurements must be made to determine the relative contribution of these various processes.

Mass balance calculations should be made on a dry weight mass basis rather than on the volumetric standard currently used. To determine the proper volume-to-mass conversions, density measurements should be made at the dredging site, within the barge, and at the disposal mound (central mound versus flank deposits).

There is a limited number of past studies which have attempted to quantify the loss of dredged material through plume dispersion. This transport mechanism deserves to be a major part of any future mass balance study. Plume study results subsequently may be used, if needed, for specific projects to schedule disposal events within specific flow condition "windows" which would result in a minimum dispersion radius.

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INDEX