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Sewage Sludge and Dredge-Spoil Derived Pollutant Transport and Accumulation in the Vicinity of the Nearshore Dumpsites

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Recent Sediment and Contaminant Distributions in the Hudson Shelf Valley

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ABSTRACT

Net sediment accumulation rates were determined in the vicinity of the nearshore dumpsites (Area 1) through measurements of radionuclide tracers in sediment core sections. The highest rates of accumulation (a few cm/y) were found along the axis of the Hudson Shelf Valley up to several kilometers down valley from the dredge spoil and former sewage-sludge disposal sites. Observed levels of PCBs, chlordane and DDT-derived compounds in surface sediment samples were highest in cores characterized by fine-particle deposition. Contaminant levels were much lower in samples of recent sediment from the Hudson Shelf Valley at mid-shelf (Area 2) and on the continental slope (Area 3), reflecting minimal influence of the nearshore disposals. Analyses of samples from the continental slope indicated that DDT contamination of recent sediments from Areas 2 & 3 reflected regional inputs of unaltered DDT derived from atmospheric deposition. Evidence of the atmospheric DDT signal, a high ratio of pp'-DDT to pp'-DDD, was also found in some surface suspended particle samples from Area 1, near the dumpsites. This indicates that analyses of DDT-derived compounds can provide useful information on the behavior and fate of particle-associated contaminants in the nearshore environment. A few samples were analyzed for 2,3,7,8-TCDD. The highest concentrations, a few hundred parts per trillion, were found in the Hudson Shelf Valley between the sludge and dredge spoil dumpsites and were probably derived from disposal of material dredged from the lower Passaic River and Newark Bay, the site of a major incident of 2,3,7,8-TCDD contamination.

Introduction

This study was designed to provide information on the distribution, fate and sources of particle-associated pollutants in the vicinity of the nearshore dumpsites through the application of a multi-tracer approach. Both sediment core (Table 1) and suspended particle samples were analyzed. The tracers employed included radionuclides (Cs-137 and K-40) and persistent chlorinated hydrocarbons (PCBs, DDT-derived compounds, chlordane and dioxin).

The study area (Figure 1) receives multiple, potentially significant inputs of contaminants from a number of sources. These include discharge from the Hudson, Raritan, Passaic and Hackensack Rivers (Hudson-Raritan discharge), disposal of dredged material from the lower Hudson River, Newark Bay, Raritan Bay, and contiguous waters (the NY Harbor complex) and past disposal of sewage sludge from New York City and New Jersey (Stanford and Young 1988). Construction and demolition wastes, often referred to as cellar dirt, have also been dumped in the study area. Loadings of contaminants associated with this activity are believed to be negligible compared to the other sources (Stanford and Young 1988). For many contaminants, the sources are closely related. For example, lower levels of DDT in sewage resulting from the ban on domestic use in 1972, would lower not only the levels in sewage sludge, but also levels in wastewater discharge, a major source of contaminants to the NY Harbor complex (Mueller et al. 1982). This would result in lower levels of DDT in Hudson-Raritan discharge and in the recent sediments dredged from the harbor and disposed of in the study area. Such considerations make it very difficult to quantify the relative importance of these sources on the basis of contaminant analyses. Only in the case of DDT-derived compounds and dioxins was some distinction of sources possible. A specific indicator of sewage sludge derived material in sediments of the Hudson Shelf Valley, the abundance of Clostridium perfringens spores, is discussed in detail elsewhere in this volume (Davis et al. 1992; O'Reilly et al. 1992).

Accumulation of particle-reactive contaminants would be greatest in areas of recent fine-grained sediment deposition. Such areas are relatively uncommon on the continental shelf off the northeast coast of the United States where sandy surface sediments are the rule (Schlee 1973; Biscaye et al. 1978). These considerations led us to focus our sediment core sampling on specific areas along the axis of the Hudson Shelf Valley where the surface sediments were known to be fine-grained.

It is common to establish the "recent" nature of fine-grained sediment accumulation through the use of radionuclide tracers with known sources and input histories (Alderton 1985). Cs-137 has been shown to be a useful particle tracer in freshwater, estuarine, and coastal systems (Olsen et al. 1989; Mulholland et al. 1992). The major sources of Cs-137 to natural waters include global fallout derived from atmospheric testing of large nuclear weapons and effluent from nuclear reactors. Sediment cores from areas of continuous, rapid net particle accumulation (on the order of 1 cm/y or more) can often be dated based on their depth profile of Cs-137 activity (Olsen et al. 1981). In profiles that reflect the delivery of fallout-derived Cs-137 to the sediment column, the initial appearance of that radionuclide corresponds to approximately 1952, the beginning of large-scale atmospheric nuclear weapons testing. Maximum levels of Cs-137 would correspond to the fallout maximum of the mid 1960s (Hardy 1977). Such detailed chronological information cannot be derived from sediment cores from the vicinity of the nearshore dumpsites because of the mixing inherent in the process of dredged material disposal, a major source of fine-grained particles to this area. For this study, the presence of Cs-137 in a sediment core section has been interpreted simply as an indicator of a post-1950 component in that sample. In cores with high net accumulation rates of fine particles, the Cs-137 penetration depth, i.e. the depth to which Cs-137 activity can be detected, would correspond to the amount of deposition since the early 1950s.

In areas of lower net sediment accumulation, it becomes more likely that biological mixing of the sediments will be an important factor in determining the Cs-137 penetration depth, (Goldberg and Koide 1962; Guinasso and Schink 1975; Robbins and Edgington 1975; Olsen et al. 1981). Biological mixing will produce lower Cs-137 activities via dilution of recent deposition with sediments that accumulated prior to 1952. Similarly, lower concentrations of particle-associated contaminants would result.

Sediments with higher proportions of sand-sized particles would also be expected to have lower Cs-137 activities and particle-associated contaminant levels than their finer-grained analogs (O'Connor 1988). Two processes that could increase the fraction of coarser particles in a sediment sample are post-depositional winnowing of fine particles and biological mixing of recent fine-particle deposition into older coarser sediments. In either case, this sediment type would be characterized by lower activities of K-40, a natural radioactive tracer of the distribution of stable potassium. Since potassium is enriched in clay minerals relative to quartz sands, the activity of K-40 in a sediment sample provides a useful, first-order indication of grain-size distribution.

Based on the preceeding discussion, our sediment core data were analyzed in terms of depth of Cs-137 penetration, average Cs-137 activity, average K-40 activity and contaminant concentration. The radionuclide data proved to be a useful indicator of the extent and degree of influence of Hudson-Raritan discharge and sewage sludge and dredge spoil disposal on contaminant levels in recent sediments of the study area.

Samples of suspended particles were collected to characterize Hudson-Raritan discharge and to investigate the possibility of particle resuspension from the disposal sites. Evidence was found for a significant atmospheric source of DDT-derived compounds characterized by a high ratio of pp'-DDT to pp'-DDD. pp'-DDT is the dominant isomer in technical DDT and is degraded to pp'-DDD under anaerobic conditions. Additional evidence for a continuing atmospheric source of DDT was found in our samples from the shelf break region and in a study of DDT accumulation in bogs (Rapaport et al. 1985). The ratio of pp'-DDT to pp'-DDD on particles was used to distinguish atmospheric deposition from the other inputs of DDT-derived compounds to our study area. This ratio could be further exploited as a tracer of particle and associated contaminant dynamics in the coastal system.

Methods

Sediment samples were collected by gravity or piston coring. Cores were sectioned at 1 to 8 cm intervals and dried at 35°C under a flow of air filtered through Florisil to minimize atmospheric contamination. Core sections were ground with a mortar and pestle and stored in air-tight aluminum cans. Radionuclide analysis was accomplished via non-destructive gamma counting, employing lithium-drifted germanium and intrinsic germanium detectors and multi-channel analyzers.

Suspended particle samples were collected with the large volume *in situ* filtering system (LVFS) developed by Dr. James Bishop of the Lamont-Doherty Geological Observatory (Bishop et al. 1985). The filters used were 25.4-cm-diameter quartz fiber (Whatman QMA) that were pre-combusted at 400°C for at least 42 hours. Sediment trap samples were collected as part of the SEEP-I experiment in traps deployed on moorings described in Biscaye et al. (1988).

Subsamples of sediment core sections and individual filters were soxhlet extracted, cleaned and analyzed for PCBs, DDT-derived compounds and chlordane by electron capture gas chromatography (Bopp et al. 1981, 1982). Dioxin analyses employed isotopic spikes, chromatographic clean up and high resolution gas chromatography/high resolution mass spectrometry as described previously (Tong et al. 1990). All contaminant concentrations and radionuclide activities are reported on a dry weight basis.

Sediment cores were obtained from three general areas. The first (Area 1) was in the immediate vicinity of the dumpsites. Specific coring locations were chosen on the basis of surface sediment textures determined during the NOAA Broadscale Survey. Our desire to obtain fine-grained sediments led to the collection of cores at stations NY5, NY6, A41 and A56 (Figure 1). NOAA field observations of sediment types at these sites ranged from very soft soupy mud (A41 and A56), to medium soft sludgy mud (NY6), to compact mud (NY5). Our cores from station A56, in the axis of the Hudson Shelf Valley, about 6 km south of the dumpsites, were dominated by a fairly homogeneous fine-grained mud throughout their entire length. This observation prompted our collection of cores at five additional sites along the axis of the valley up to about 18 km down-valley from A56 (HSV1 - HSV5).

The second coring area (Area 2) was located about 45 km down-valley from A56 (Figure 1). It was chosen on the basis of grain size maps prepared by one of the authors (Biscaye) which indicated that it was one of the few mid-shelf areas in this general region with fine-grained surface sediments (40-60% < 63 microns). Cores were collected from stations HSV6 and HSV7 from within this surface textural regime.

Sediment cores were also collected from the continental slope (Area 3), an area known for its fine-grained surface sediments. Coring sites HSV8 and HSV9 were on the axis of the Hudson Canyon about 150 km down-valley from A56. In addition, results from core EN-123 BC-E6 will also be discussed. This core was collected on the continental slope about 200 km northeast of the Hudson Canyon as part of the SEEP program. It has been described in detail in a previous publication (Anderson et al. 1988). The locations of all sediment coring sites are given in Table 1.

Results

Radionuclide Activities in Sediment Cores

Radionuclide data on the cores are presented in Table II and Appendix 1. The cores have been listed on the basis of location starting from the head of the Husdon Shelf Valley (NY5 & NY6) and proceeding down-valley to the Hudson Canyon (HSV8 & HSV9).

Available grain-size information supports our assumption that K-40 levels in our samples provide a first-order indication of particle-size distributions. Average K-40 levels were highest (>18,000 pCi/kg) in Area 3 cores from the Hudson Canyon (HSV8 & 9, Table II) where previous studies found that 80-100% of the surface sediments were <63 microns (Schlee 1973; Biscaye et al. 1978). Much lower average K-40 levels (<12,000 pCi/kg) were found in cores from Area 2 (HSV6 & 7, Table II) where 40-60% of the surface sediments were <63 microns. Additional measurements relating grain size to K-40 activities in sediments from our study area would be quite useful.

Cs-137 penetration depths were greatest in Area 1 along the axis of the shelf valley, reaching a maximum of 2 meters in a piston core from site A56. The average Cs-137 and K-40 values at sites A41, A56 and HSV1 are similar to those found in cores from areas of fine-grained sediment deposition in the NY Harbor complex (Table 2). These factors indicate that the sedimentary regime is characterized by fine particle accumulation. The rapid rate of recent net fine particle accumulation at A56 was confirmed by the presence of significant Be-7 in the 0-2 cm sections of several of the cores from this site. Be-7 is a cosmic-ray produced radionuclide with a half life of only 53 days which means that its presence in a sediment core section is an indicator of deposition within about a year of core collection.

Cores from the remaining sites in Area 1 -- those down-valley from HSV1 and NY5 & NY6 -- have lower average values of both Cs-137 and K-40. This could be the result of post-depositional winnowing of fine-grained sediments or biological mixing of recent, fine-grained deposition into older, coarser sediments. Lower average Cs-137 and K-40 levels were also seen in the cores from the mid-shelf, Area 2. The consistent variation of average Cs-137 levels with average K-40 levels throughout Areas 1 & 2 (Figure 2) requires only two components -- recent fine particles (high in Cs-137 and K-40) and sands (low in Cs-137 and K-40).

Cores from Area 3, the continental slope, fall significantly off the K-40/Cs-137 trend defined by Area 1 & 2 cores, at much higher ratios of average K-40 to Cs-137 activities. At the site of core EN-123 BC-E6, the sedimentary regime has been described (Anderson et al. 1988) as consisting of low rates (on the order of one centimeter per hundred years) of recent fine particle accumulation. Profiles with depth of natural and fallout-derived radionuclides in the sediments were interpreted as resulting from biological mixing which typically occurs to a depth of several centimeters. Over this interval, the recent fines were mixed with much older, fine-grained sediments, diluting the average Cs-137 activity while retaining the high levels of K-40. Two other factors could also have played a role in lowering the Cs-137 to K-40 activity ratio in our Area 3 cores compared to Area 1 & 2 and NY Harbor cores. These are the relatively low efficiency of Cs-137 sorption onto particles from ocean water and the possible desorption of Cs-137 from particles into ocean water. Mulholland and Olsen (1992) have proposed that the the former was responsible for lower Cs-137 activities observed on marine particles compared to particles derived from a riverine drainage basin. They also concluded that desorption of Cs-137 from the riverine particles upon transport into seawater was not significant because most of the Cs-137 was at non-exchangable interlayer sites on clay minerals.

Data on cores from three sites in the New York Harbor complex are also plotted on Figure 2. These particular cores were chosen on the basis of their Cs-137 profiles which, in all cases indicated continuous deposition since the early 1950s (Bopp and Simpson 1984, 1989; Bopp et al. 1991). Core -1.7 was collected in 1979 from the Hudson River, 1.7 statute miles down channel from the southern tip of Manhattan Island. NB 13 was taken in Newark Bay in 1985 and RB 17 was from Raritan Bay in 1980. The three cores plot within the field defined by cores from Areas 1 & 2, suggesting a Hudson-Raritan influence (either dredge spoil disposal or discharge) on Area 1 & 2 sediments. The rapid rate of net sediment accumulation over the past three decades at some of our Area 1 sampling sites (for example, the two meters of recent sediment observed in piston core 2 at site A56; Table 2), would be consistent with dredge spoil translocation. We would have difficulty arguing that such high net accumulation rates could be supported by natural discharge of particles from the Hudson-Raritan Estuary.

Chlorinated Hydrocarbon Contaminants

Several core top sections were analyzed for chlorinated hydrocarbon contaminants including PCBs, DDT-derived compounds and chlordane (Table 3). As expected, the highest levels of contamination were found in the cores from Area 1 that had the highest average Cs-137 and K-40 levels (sites A41, A56 and HSV1). The sections of the core from site A41 that contained measurable Cs-137 were composited and analyzed. This sample (A41, 0-20cm, Table 2) should represent an average of the sediment deposited at this site since the early 1950s. Total PCB, pp'-DDD and γ-chlordane levels were siginficantly higher than in the 0-2 cm section from the same core. This core section would represent the most recent deposition at this site. These results indicate a recent decline in the levels of these contaminants in sediments being deposited in Area 1. Similar improvements have been reported for sediments deposited in the lower Hudson River and were interpreted as the result of domestic restrictions on the use of all of these substances during the 1970s and, for PCBs, as a result of reduced transport from the upper Hudson (Bopp and Simpson 1989). These factors would also lower the inputs of these contaminants to Area 1 with dredged material and sewage sludge disposal and Hudson-Raritan discharge. This would explain the recent decline in chlorinated hydrocarbon levels in sediments that was indicated by our results from site A41.

Down-valley from the sites of highest surface sediment contamination there is a decrease in contaminant levels at Area 1, sites HSV2 through HSV5, that generally follows the drop in the average Cs-137 & K-40 levels. This indicates a decreasing contribution of contaminated fine-particles.

In the uppermost section of cores from the mid-shelf sites of Area 2, total PCBs and γ-chlordane were not detected at 10 and 0.1 ppb levels respectively. This decrease in contaminant concentrations relative to levels observed at sites HSV4 and HSV5 is greater than would have been predicted from the average Cs-137 or K-40 activities in the cores. For example, the decrease in average Cs-137 levels is at most a factor of two (Table 2) while the total PCB level drops by at least a factor of five and γ-chlordane by at least a factor of three (Table 3). This indicates that the fine-grained particles accumulating in Area 2 are significantly less contaminated with chlorinated hydrocarbons than those accumulating in Area 1.

Sediment core data from Area 3, the continental slope, show similar evidence of a less contaminated, recent, fine-grained component, i.e., non-detectable levels of PCBs and γ-chlordane in samples containing Cs-137.

Interpretation of the levels of DDT-derived compounds in sediments from Areas 2 & 3 provides a means of characterizing this component. In areas of low net accumulation, but significant biological mixing, the Cs-137 activity in individual sediment core sections should correlate with the levels of DDT-derived compounds. Consider, for example, a core with net fine-particle accumulation rate of 0.01 cm/y. The entire history of DDT and Cs-137 accumulation would be contained in the last half centimeter of sediment that was deposited. Biological mixing to depths on the order of a few centimeters would obscure any detailed differences in the Cs-137 and DDT input functions. Mixing would be the major determinant of the depth profiles of these substances and, at sampling intervals of one to two centimeters, a very good correlation would be expected between the activity of Cs-137 and levels of DDT-derived compounds. The picture is complicated slightly by DDT geochemistry. Under anaerobic conditions, pp'-DDT can be converted to pp'-DDD (Guenzi and Beard 1968). This can be taken into account by seeking a correlation between Cs-137 activity and the sum of pp'-DDT and pp'-DDD concentrations. Data from the upper six centimeters of core EN-123 BC-E6 and the surface sections of HSV 6,7 & 8 are presented in Figure 3. A ratio of approximately 1 ppb (pp'-DDT + pp'-DDD) per 60 pCi/kg Cs-137 is consistent with these data on recent deposits in Areas 2 & 3. Our surface sediment samples from near the dumpsites had much higher ratios, i.e. enhanced relative concentrations of DDT-derived compounds, which we interpret as an indicator of sources related to dredge spoil and sewage sludge disposal and Hudson-Raritan discharge. The most likely dominant source of DDT-derived compounds to Areas 2 & 3 is atmospheric deposition. Further evidence for the importance of atmospheric inputs of DDT to Area 3, the continental slope, is presented below.

DDT-Derived Compounds on Particles from the Continental Slope

The profile of levels of DDT-derived compounds in core EN-123 BC-E6 has been described previously (Anderson et al. 1988). This core, from 1640 m depth on the continental slope, is particularly valuable because of its well defined and carefully sampled aerobic zone which provided a record of DDT deposition unaltered by anaerobic conversion to DDD. The net particle accumulation rate in the core was estimated to be on the order of 0.01 cm/y. As a result of biological mixing, DDT-derived compounds were found to a depth of about 7 cm in the core. In situ conversion of DDT to DDD was observed at depths below 4 cm. Iron and manganese pore water chemistry indicated that the onset of anaerobic conditions occurred at about this level (Buesseler 1986). The total historical deposition of DDT-derived compounds at this site was computed to be 48 ug/m^2 for pp'-DDT, 13 ug/m^2 for pp'-DDE, and 1.8 ug/m^2 for pp'-DDD. Such dominance of the parent compound, pp'-DDT, has been shown to be characteristic of atmospheric inputs (Rapaport et al. 1985). Concentration data from EN-123 BC-E6 indicates that such inputs can supply parts per billion levels of DDT-derived compounds to recent sediments.

Other possible inputs to our study area, including Hudson-Raritan discharge and dredge spoil and sewage sludge disposal, would be vastly different, and would be characterized by pp'-DDT to pp'-DDD ratios less than unity, as discussed below.

Assuming that most of the atmospheric input of DDT recorded by core EN-123 BC-E6 occurred over the approximately twenty years of major domestic use, that period would be characterized by average yearly atmospheric pp'-DDT fluxes of about 2.4 ug/m^{2}y. This value falls within the range of peak atmospheric inputs estimated from dated cores from peat bogs in central and eastern North America (Rapaport et al. 1985). That study also indicated a continuing atmospheric input estimated for the early 1980s at 10-20% of peak inputs. Since the use of DDT was banned in the U.S. and Canada in 1972, the source of the early 1980s deposition was suggested to be DDT use in Mexico and Central America (Rapaport et al. 1985).

An indication of the recent delivery of DDT to the continental slope can be obtained by analyzing data from sediment trap samples collected in 1984 as part of the SEEP program (Biscaye et al. 1988). The results presented in Table 4 are from two moorings on the continental slope, one at 1250 m water depth and the other at 2300 m. The traps were deployed for 175 days, from 23 April to 15 October 1984. Typically, only a few hundred milligrams of sample were available which made ppb level DDT-derived compound analysis quite challenging. Measured pp'-DDT fluxes ranged from 0.07 to 0.27 ug/m^{2}y (n=7) with an average of 0.18 ug/m^{2}y. This estimate of mid 1980s flux is about an order of magnitude lower than the flux during major domestic DDT use that was inferred from the data for core EN-123 BC-E6 (2.4 ug/m^{2}y). This decrease in pp'-DDT flux is in reasonable agreement with the peat core data cited above.

Fluxes of excess Pb-210 in the trap samples appear to vary directly with pp'-DDT flux (Figure 4). We attribute this to similar sources and behaviors of the two substances. The excess Pb-210 originates from decay of gaseous Rn-222 in the atmosphere and, similar to DDT, Pb-210 is quite particle reactive in natural water systems. The average Pb-210 flux in these trap samples was about 1 dpm/cm^{2}y, similar to the long term steady state average flux that would be expected for core EN-123 BC-E6 based on other cores taken along the SEEP transect (Biscaye et al. 1988). This suggests that these trap samples, on average, provide a good representation of recent accumulation at coring site EN-123 BC-E6.

The data from core EN-123 BC-E6 implied a total flux of pp'-DDT (48 ug/m^2) about 25 times greater than that of pp'-DDD (1.8ug/m^2). The trap data (Table 4) indicates only about a factor of three excess of pp'-DDT in the more recent flux. In absolute terms, the total pp'-DDD flux requires an average yearly flux on the order of 0.05 ug/m^{2}y since the beginning of significant domestic DDT use in about 1950. This long term flux estimate for pp'-DDD falls within the range of values determined for the mid 1980s flux from the sediment trap samples (0.03 to

0.10 ug/m^2y, Table 4). This suggests that the pp'-DDD flux is an indicator of non-atmospheric input which has not experienced a major (order of magnitude) change over the past three or four decades. The cross-shelf transport of contaminants derived from river discharge or dredge spoil and sewage sludge disposal is a likely source. While DDT-derived compounds may provide an indicator of cross-shelf contaminant transport, it should be noted that such transport does not appear to be the dominant mid 1980s source of these compounds to the slope environment. The excess of pp'-DDT over pp'-DDD in the trap samples indicates that atmospheric inputs continue to be most important.

It is possible that there was some anaerobic conversion of pp'-DDT to pp'-DDD within the traps. In an effort to guard against this, the traps were initially poisoned with a 10% sodium azide solution in filtered seawater to which sodium chloride was added to increase its density to minimize mixing with the overlying water. This treatment was at least somewhat successful in that it prevented the foul H_2S odor and almost complete loss of pp'-DDT observed in some unpoisoned traps (Table 4), however, some conversion of pp'-DDT to pp'-DDD in our samples cannot be ruled out. Even a worst case scenario, however, would not drastically alter our general interpretations of the data. If all of the pp'-DDD were produced from pp'-DDT within the traps, our estimate of recent pp'-DDT flux would increase by less than a factor of two and the argument that the principal input of DDT-derived compounds to the slope environment is derived from the atmosphere would be strengthened. If (pp'-DDT + pp'-DDD) levels were used to determine the flux of pp'-DDT to the traps, the correlation with Pb-210 fluxes (Figure 4) would still be very good. We hope to address the concern about conversion of pp'-DDT to pp'-DDD during trap deployment by analyzing samples of fresh suspended particles from the shelf and slope that would be collected by *in situ* filtration.

Sources of DDT-Derived Compounds to Nearshore Particles

Data related to the pp'-DDT to pp'-DDD ratio in Hudson-Raritan discharge, sediments dredged from the NY Harbor complex, and NY City sewage sludge are presented in Table 5. We interpret the suspended matter samples as representative of Hudson-Raritan discharge. NY City sewage sludge is represented by a single sample from the Ward's Island treatment plant collected in the mid 1970s. Data on samples of raw sewage and primary treated effluent from the Yonkers, NY sewage treatment plant are also included. These data can be used to investigate the possible sources of DDT-derived compounds to the sediment cores from Area 1 and to our suspended particle samples.

From the data in Table 3, we estimate that the surface sediment samples from our Area 1 cores had an average pp'-DDT to pp'-DDD ratio of about 0.5. It is tempting to cite the much lower average pp'-DDT to pp'-DDD ratio in cores -1.7, NB 13 and RB17 (Table 5) as evidence that atmospheric inputs contribute significantly to the DDT-derived compounds in Area 1 sediments and that dredge spoil disposal was not the dominant source of contaminants to our Area 1 cores. We believe, however, that this argument is seriously flawed. Sediment samples from the NY Harbor complex waters bordering Staten Island had the highest levels of pp'-DDT that we have observed in NY Harbor sediments and a relatively high ratio of pp'-DDT to pp'-DDD (core KvK1, Table 5). In the case of the Kill van Kull, which forms the northern border of Staten Island, sections of a core that records deposition from approximately the mid 1970s to 1985 had an average pp'-DDD level of 580 ppb and an average pp'-DDT of 500 ppb (Bopp and Simpson 1991). Comparable results have been obtained from sediment core samples from the Arthur Kill, on the western boundary of Staten Island (Bopp, unpublished data). To put this in perspective, sediment deposited along the main axis of the Hudson near the site of core -1.7 from approximately the mid 1970s to 1986 had an average pp'-DDD level of approximately 50 ppb (core -1.65, CN1923, Bopp and Simpson 1989) and an average pp'-DDT level of approximately 5 ppb (Bopp, unpublished data). We have found no published information that indicates the source of the relatively high levels of DDT-derived compounds in recent Kill van Kull and Arthur Kill sediments.

From the above discussion, it is evident that even a small component of sediment similar to that found in the Kill van Kull core would significantly increase the ratio of pp'-DDT to pp'-DDD in material dredged from the NY Harbor complex. Data from the

Army Corps of Engineers indicates that in 1986, projects in the Arthur Kill and Kill van Kull contributed about 14% of the volume of material disposed of at the dredge spoil dumpsite (U.S. Army Corps of Engineers, New York District, Mud Dump Activity Listout, 1 December 1990). This indicates that the pp'-DDT to pp'-DDD ratio in the surface sediment samples from our Area 1 cores does not require a significant atmospheric input nor does it rule out the possibility that dredged material disposal is the dominant source of these compounds to the sediments.

Strong evidence for atmospheric inputs of DDT-derived compounds to Area 1 was found in the pp'-DDT to pp'-DDD ratios in our suspended particle samples. The fact that major inputs of DDT-derived compounds to Area 1 with dredge spoil and sewage sludge disposal and Hudson-Raritan discharge did not totally obscure the atmospheric signal underscores the power of the pp'-DDT to pp'-DDD ratio as a tracer in the coastal environment.

Data from suspended particle samples collected in Area 1 is presented in Table 6. Figure 5 shows station locations and all of the pp'-DDT to pp'-DDD ratio data. The majority of the data is easily interpreted. At the G1 station, near Sandy Hook buoy G1, the ratio is consistent with Hudson-Raritan discharge. It is likely that this source continues to be the major influence at site SB (at the bell buoy off Shrewsbury Rocks) which is located within the plume of discharge from the Hudson-Raritan which follows the New Jersey coast (Ingham 1989). Further south along the coast, as the plume is diluted by mixing, there is evidence of an additional source of DDT-derived compounds. At sites LB 3 & 5 (Long Branch) the pp'-DDT to pp'-DDD ratio increases to greater than one as a result of higher levels of pp'-DDT. Near the dumpsites at stations A44 & A54, the pp'-DDT to pp'-DDD ratios in the deep suspended particle samples are similar to those in near-surface sediments from our Area 1 cores (Table 3). We interpret this as an indication of resuspension. The pp'-DDT to pp'-DDD ratios would also be consistent with a Hudson-Raritan discharge source, however, the great difference between deep and surface samples makes this unlikely. Surface suspended particle samples at sites A54 & A56 had the highest levels of pp'-DDT and ratios of pp'-DDT to pp'-DDD much greater than one (Table 6). It should be noted that all of the samples used to characterize Hudson-Raritan discharge, dredge spoil disposal and sewage sludge disposal had pp'-DDT to pp'-DDD ratios of less than one (Table 5) and so an additional source is indicated.

As mentioned above, a most likely source of enhanced pp'-DDT is atmospheric input. The ratios of pp'-DDT to pp'-DDD in the surface suspended particle samples from sites A54 & A56 were similar to those observed in sediment trap samples from the continental slope (Table 4). It should be noted, however, that the level of pp'-DDT (Table 6) on these suspended particle samples was much higher than in the trap material. The surface suspended particles at A56 and A54 had about 20 ppb pp'-DDT while the trap samples averaged about 2.5 ppb. This could reflect differences in sample type (traps collect the larger, sinking particles), location and collection period or perhaps in pp'-DDT sources. Analysis of suspended particle samples from the continental slope environment would help to limit these possibilities.

For Area 1, our data indicate that the contaminant regime in surface waters can be vastly different than that found near the bottom. The pp'-DDT to pp'-DDD ratio on particles appears to have significant potential in the nearshore environment as a tracer of water masses and the fate of particle-associated contaminants. Specific application to onshore transport of pollutants and deposition in coastal embayments and estuaries as discussed by Olsen et al. (1989) is indicated. At this point, however, it must be remembered that our interpretations are based on a limited number of samples and that other possible sources of pp'-DDT have not been ruled out. While the collection and analysis of additional samples is necessary, the potential for increasing our understanding of pollutant behavior in this important environment indicates that such an effort is warranted.

2,3,7,8-TCDD on Particles from Area 1

A major incident of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) contamination in sediments of Newark Bay has been described recently (Bopp et al. 1991). It was estimated that sediments deposited in the bay over the past four decades averaged between 600 and 1200 parts per trillion (ppt) 2,3,7,8-TCDD. This study indicated that discharges from an industrial chemical manufacturing plant on the lower Passaic River (a major tributary of Newark Bay) could account for much of the 2,3,7,8-TCDD contamination in the New York Harbor complex. Major inputs of 2,3,7,8-TCDD to Area 1 associated with Hudson-Raritan discharge and Newark Bay dredge spoil disposal would be expected. The data in Table 7 confirms the presence of significant levels of 2,3,7,8 TCDD on particles from Area 1.

Based on our analyses, it appears possible that levels of 2,3,7,8-TCDD could provide a specific indicator of the dredged material disposal source to the sediments of Area 1. The 120 part per trillion level in the 1987 sample of suspended matter from near Sandy Hook at the mouth of the Hudson-Raritan estuary is an indicator of mid 1980s input from discharge. Samples of mid 1980s particles from the vicinity of the dumpsites included the deep suspended matter sample from site A56 which contained <33 ppt 2,3,7,8-TCDD and the 0-2 cm section of core A56 #4 which contained 40 ppt. This sediment core section was among those mentioned above that contained detectable levels of Be-7 indicating deposition within about a year prior to collection (1987). The concentration of 400 parts per trillion 2,3,7,8-TCDD found in the composite sample from site A41 indicates that past inputs were significantly greater, an observation supported by the Newark Bay sediment data and chemical production records of the industrial facility (Bopp et al. 1991). Most interesting was the low level of 2,3,7,8-TCDD in the 72-80 cm sample from piston core P1 at site A56. In this particular core, Cs-137 penetrated to 88 cm (Table 2). The 72-80 cm sample contained a significant recent component (115±16 pCi/kg of Cs-137). This core section represents an attempt to sample sediment from approximately the late 1950s. Bopp et al. (1991) indicates that, compared to the mid 1980s, the period between the mid 1950s and early 1960s would be characterized by much higher levels of 2,3,7,8-TCDD contamination, both in sediments depositing in Newark Bay and the lower Passaic River and in Hudson-Raritan discharge derived from the bay. It would be difficult to explain the low level of 2,3,7,8-TCDD in the sample under consideration if Hudson-Raritan discharge were the major contributor to the contamination observed in our cores from Area 1. Our observations are consistent with dredged material disposal being a major source. Prior to 1970, material dredged from Newark Bay was disposed of primarily in upland sites adjacent to the bay (Suszkowski 1978). Only since 1970 has the dumpsite located in our study area been the dominant repository for Newark Bay dredged materials (Suszkowski 1978; HydroQual, Inc. 1989). If A56 P1 (72-80 cm) does indeed represent dredged material dating from approximately the late 1950s, it would not have a large Newark Bay component and would be expected to contain a relatively low level of 2,3,7,8-TCDD, consistent with value reported (Table 7). At present, this interpretation is quite speculative due to the limited amount of applicable data.

Conclusions

The conclusions of this study can be summarized as follows:

1) High rates of fine particle and associated pollutant accumulation were found along the axis of the Hudson Shelf Valley from the vicinity of the dredge spoil and former sewage sludge dumpsites to sites several kilometers down-valley. The high rates of net particle accumulation, data on 2,3,7,8-TCDD, and trends in Cs-137 and K-40 activities in sediments are consistent with the major source of accumulating particles being the translocation of material dredged from the NY Harbor complex and dumped at the dredge spoil disposal site. Other studies (Davis et al. 1992) indicate that sewage sludge derived material has also been deposited at these sites. Any estimate of total recent particle and contaminant deposition down-valley from the dumpsites would require additional sediment cores from transects across the axis of the Hudson Shelf Valley to complement our along-axis samples.

2) Cs-137 and K-40 activities and contaminant analyses in sediment core sections indicate that fine particles that have accumulated in a mid-shelf region (Area 2) and on the continental slope (Area 3) over the past four decades are relatively uncontaminated. Analyses of DDT-derived compounds

in these samples indicate a dominantly atmospheric source. Cumulative and mid 1980s fluxes of DDT-derived compounds calculated from sediment trap and core data are consistent with other estimates of regional atmospheric inputs (Rapaport et al. 1985).

3) The pp'-DDT to pp'-DDD ratio on particles is a useful tracer of atmospheric inputs and processes associated with particle-reactive pollutant behavior in the continental slope and coastal environments. Indications of atmospheric inputs have been found on suspended particles collected within a few kilometers of the Hudson-Raritan discharge and the dredge material and former sewage sludge disposal sites. Further exploitation of this tracer is recommended.

4) Based on four samples, there appears to be significant 2,3,7,8-TCDD contamination on particles from Area 1 that is probably related to industrial discharges to the lower Passaic River. Analysis of additional samples should be undertaken to test this provisional conclusion.

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Citations

ALDERTON, D. H. M.
1985. Sediments. In Historical Monitoring, p. 1-95. Monitoring and Assessment Research Center, MARC Report Number 31.

ANDERSON, R. F., R. F. BOPP, K. O. BUESSELER, and P. E. BISCAYE.
1988. Mixing of particles and organic constituents in sediments from the continental shelf and slope off Cape Cod: SEEP-I results. Continental Shelf Research 8:625-651.

BISCAYE, P. E., C. R. OLSEN, and G. MATHIEU.
1978. Suspended particulates and natural radionuclides as tracers of pollutant transports in continental shelf waters of the eastern U.S.A. In First American-Soviet symposium on chemical pollution in the marine environment, Odessa U.S.S.R. (K. K. Turekian, and A. I. Siminov, compilers), p. 125-147. EPA-600/9-78-038.

BISCAYE, P. E., R. F. ANDERSON, and B. L. DECK.
1988. Fluxes of particles and constituents to the eastern United States continental slope and rise: SEEP-I. Continental Shelf Research 8:855-904.

BISHOP, J. K. B., D. SCHUPACK, R. M. SHERRELL, and M. CONTE.
1985. A multiple-unit large-volume in situ filtration system for sampling oceanic particulate matter in mesoscale environments. In Mapping strategies in chemical oceanography (A. Zirino, ed.), p. 155-175. American

Chemical Society, Advances in Chemistry 209.

BOPP, R. F., M. L. GROSS, H. TONG, H. J. SIMPSON, S. J. MONSON, B. L. DECK, AND F. C. MOSER.

1991. A major incident of dioxin contamination: sediments of New Jersey estuaries. Environ. Sci. Technol. 25:951-956.

BOPP, R. F., and H. J. SIMPSON

1984. Persistent chlorinated hydrocarbon contaminants in the New York Harbor complex. Hudson River Foundation, First Year Final Report for Contract HUD 1183-A38.

1989. Contamination of the Hudson River: the sediment record. In Contaminated marine sediments: assessment and remediation, p. 401-416. National Academy Press, Washington DC.

1991. Sediment sampling and radionuclide and chlorinated hydrocarbon analysis in Newark Bay and the Hackensack and Passaic Rivers. State of New Jersey Department of Environmental Protection, Final Report for Contract P24096.

BOPP, R. F., H. J. SIMPSON, C. R. OLSEN, and N. KOSTYK.

1981. Polychlorinated biphenyls in the sediments of the tidal Hudson River, New York. Environ. Sci. Technol. 15:210-216.

BOPP, R. F., H. J. SIMPSON, C. R. OLSEN, R. M. TRIER, and N. KOSTYK.

1982. Chlorinated hydrocarbons and radionuclide chronologies in sediments of the Hudson River and estuary, New York. Environ. Sci. Technol. 16:666-676.

BUESSELER, K. O.

1986. The geochemistry of Pu-239 and Pu-240 in the pore waters and sediments of the N. W. Atlantic shelf, slope and rise. Ph.D. Diss., WHOI/MIT Joint Program in Chemical Oceanography.

DAVIS, W. R., W. S. BOOTHMAN, R. McKINNEY, and W. D. WATKINS.

1992. Response of the Hudson Shelf Valley sewage sludge-sediment reservoir to cessation of disposal at the 12-mile dumpsite. This volume.

DEARTH, M. A., and R. A. HITES.

1991. Complete analysis of technical chlordane using negative ion mass spectrometry. Environ. Sci. Technol. 25:245-254.

GOLDBERG, E. D., and M. KIODE.

1962. Geochronological studies of deep sea sediments by the ionium-thorium method. Geochim. Cosmochim. Acta 26:417-450.

GUENZI, W. D., and W. E. BEARD.

1968. Anaerobic conversion of DDT to DDD in soil and aerobic stability of DDT in soil. Soil Science Society of Amer. Proc. 32:522-524.

GUINASSO, N. L., and D. R. SCHINK.

1975. Quantitative estimates of biological mixing rates in abyssal sediments. J. Geophys. Res. 80:3032-3043.

HARDY, E. P.

1977. Final tabulation of monthly Sr-90 fallout data, 1954-1976. U.S. Dep. Energy, Environmental Quarterly, HASL-329.

HYDROQUAL, INC.

1989. Assessment of pollutant inputs to New York Bight. Job

Number DYNM0100, HydroQual, Inc., Mahwah, NJ.

INGHAM, M. C.

1989. Physical oceanography of the New York Bight -- A review. In Response of the habitat and biota of the inner New York Bight to abatement of sewage sludge dumping: Second annual progress report -- 1988, p. 4-11. U.S. Dep. Commer., NOAA Tech. Mem. NMFS-F/NEC-67.

MUELLER, J. A., T. A. GERRISH, and M. C. CASEY.

1982. Contaminant inputs to the Hudson-Raritan Estuary. U.S. Dep. Commer., NOAA Tech. Mem. OMPA-21, 191 p.

MULHOLLAND, P. J., and C. R. OLSEN.

1992. Marine origin of Savannah River Estuary sediments: evidence from radioactive and stable isotope tracers. Estuarine, Coastal Shelf Sci. 34:95-107.

O'CONNOR, T. P.

1988. A summary of selected data on chemical contaminants in sediments collected during 1984, 1985, 1986, and 1987. U.S. Dep. Commer., NOAA Tech. Mem. NOS OMA 44.

OLSEN, C. R., H. J. SIMPSON, T. -H. PENG, R. F. BOPP, and R. M. TRIER.

1981. Sediment mixing and accumulation rate effects on radionuclide profiles in Hudson Estuary sediments. J. Geophys. Res. 86:11,020-11,028.

OLSEN, C. R., M. THEIN, I. L. LARSEN, P. D. LOWRY, P. J. MULHOLLAND, N. H. CUTSHALL, J. T. BYRD, and H. L. WINDOM.

1989. Plutonium, lead-210, and carbon isotopes in the

Savannah Estuary: riverborne versus marine sources. Environ. Sci. Technol. 23:1475-1481.

O'REILLY, J. E., I. Katz and A. J. DRAXLER.
1992. Changes in the abundance and distribution of Clostridium Perfringens, a microbial indicator, related to the cessation of sewage dumping in the New York Bight. This volume.

RAPAPORT, R. A., N. R. URBAN, P. D. CAPEL, J. E. BAKER, B. B. LOONEY, S. J. EISENREICH, and E. GORHAM.
1985. "New" DDT inputs to North America: atmospheric deposition. Chemosphere 14:1167-1173.

ROBBINS, J. A., and D. N. EDGINGTON.
1975. Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137. Geochim. Cosmochim. Acta 39:285-304.

SCHLEE, J.
1973. Atlantic continental shelf and slope of the United States-sediment texture of the northeastern part. U.S. Dep. of Interior, U.S. Geological Survey Professional Paper 529-L.

STANFORD, H. M., and D. R. YOUNG.
1988. Pollutant loadings to the New York Bight apex. Oceans '88 Conference Record, Mar. Technol. Soc., Washington DC.

SUSZKOWSKI, D. J.
1978. Sedimentology of Newark Bay, New Jersey; an urban estuary. Ph.D. Diss., University of Delaware, Newark DE.

TONG, H. Y., S. J. MONSON, M. L. GROSS, R. F. BOPP, H. J. SIMPSON, B. L. DECK, and F. C. MOSER.

1990. Analysis of dated sediment samples from the Newark Bay area for selected PCDD/Fs. Chemosphere 20:1497-1502.

WEBB, R. G., and A. C. McCALL.

1973. Quantitative PCB standards for electron capture gas chromatography. J. Chrom. Sci. II:366-373.

Table 1.

Sediment Core Locations.

Station	Water Depth (m)	Latitude	Longitude
Area 1			
NY5	35	40° 24.9'N	73° 47.6'W
NY6	30	40° 25.0'N	73° 45.6'W
A41	40	40° 23.4'N	73° 46.8'W
A56	55	40° 19.0'N	73° 47.4'W
HSV1	60	40° 16.9'N	73° 47.2'W
HSV2	60	40° 15.4'N	73° 46.8'W
HSV3	60	40° 13.9'N	73° 45.9'W
HSV4	50	40° 12.0'N	73° 45.4'W
HSV5	60	40° 10.3'N	73° 42.0'W
Area 2			
HSV6	80	40° 02.3'N	73° 26.4'W
HSV7	80	40° 00.9'N	73° 20.4'W
Area 3			
HSV8	480	39° 29.7'N	72° 20.1'W
HSV9	980	39° 28.4'N	72° 15.2 W
EN-123 BC-E6	1640	39° 45.8'N	70° 55.4'W

Table 2.
Radionuclide Data on Sediment Cores

Core[a]	Date of collection	Cs-137[b] penetration (cm)	Average Cs-137[c] (pCi/kg)	Average K-40 (pCi/kg)
AREA 1				
NY5 #1	10/30/87	16	54	10,700
NY6 #1	10/30/87	12	38	8,500
A41 #1	10/30/87	20	290	13,900
A56 #3	09/01/87	>47[d]	240	13,400
#4	09/01/87	>48	240	13,400
#5	09/26/88	>40	260	14,300
#6	10/04/89	>40	220	14,600
P1	09/26/88	>80	240	14,700
P2	10/04/89	200	220	14,100
HSV1 #1	06/27/88	>19	330	15,740
#2	06/27/88	>16	400	16,330
HSV2 #2	06/27/88	>21	140	13,300
#3	10/04/89	20	59	11,700
HSV3 #1	06/27/88	>21	110	12,400
HSV4 #2	11/17/88	20	50	11,100
HSV5 #1	11/17/88	24	44	10,400
AREA 2				
HSV6 #1	11/17/88	6	37	11,000
#2	11/17/88	6	25	11,500
HSV7 #1	11/17/88	20	27	10,200

Table 2. (continued)

AREA 3				
HSV8 #1	11/17/88	6	85	18,700
HSV9 #1	11/17/88	0	0	18,500
EN-123 BC-E6	10/25/84	4[e]	95	14,500

[a] P indicates piston cores. All others were gravity cores except EN-123 BC-E6 which was a subcore of a box core.

[b] Cs-137 penetration is defined as the bottom of the deepest core section that contained Cs-137 at a level at least two standard deviations greater than zero. Using this two sigma statistical counting error criterion, our minimum detectable Cs-137 activities were typically 15 to 30 pCi/kg. Data on individual core sections is reported in Appendix 1.

[c] Cs-137 and K-40 activities are mass weighted averages from the top section of the cores to the Cs-137 penetration depths. The only exception is core HSV9 #1 which had no detectable Cs-137. The K-40 activity reported for this core is the mass weighted average of the 0-1, 1-2 and 2-3 cm sections.

[d] > values indicate that Cs-137 was detected in the bottom section of the core except in the case of core A56 P1 where radionuclide profiles indicated that a section of the core top was missing. While this is not uncommon in piston cores, our gravity cores all had undisturbed sediment-water interfaces.

[e] Based on analyses of DDT-derived compounds, mixing in this core can be detected to a depth of about 7 cm, however, the Cs-137 activity was within two standard deviations of zero by the 4-5 cm section (24 pCi/kg with a standard deviation of 17 pCi/kg).

Table 3.

Contaminant Levels in Surface Sediment Core Sections

Core	Depth (cm)	γ-chlordane[a] (ppb)	pp'-DDD (ppb)	pp'-DDT (ppb)	$\frac{pp'\text{-DDT}}{pp'\text{-DDD}}$	PCBs[b] (ppb)
AREA 1						
NY5 #1	0-2	7	22	5.0	0.23	(400)[c]
NY6 #1	0-2	14	18	29	1.61	(400)[c]
A41 #1	0-2	19	38	10	0.26	(950)[c]
	0-20[d]	24	117	75	0.64	1650
A56 #3	0-2	9	25	19	0.76	820
#4	0-2	13	25	5.4	0.22	(750)[c]
HSV1 #1	0-2	14	115	41	0.36	820
HSV2 #2	0-2	4	14	25	1.79	290
HSV3 #1	0-2	3	7	1.4	0.20	200
HSV4 #2	0-2	0.3	1.1	<0.2	<0.2	50
HSV5 #1	0-2	0.9	2.0	<0.4	<0.2	60
AREA 2						
HSV6 #1	0-2	<0.1	0.5	<0.2	<0.4	<10
HSV7 #1	0-2	<0.1	0.5	<0.2	<0.4	<10

AREA 3

HSV8	0-1	<0.1	1.3	<0.2	<0.2	<10
EN 123 BC-E6[e]	0-1	<0.1	0.11	2.95	27	<5

[a] Technical chlordane is a mixture containing over 100 compounds. γ-chlordane, one of two major isomers, comprises about 15% of technical formulations (Dearth and Hites 1991).

[b] Based on quantification of 22 components resolved by packed-column gas chromatography (tri- through decachlorobiphenyl) (Webb and McCall 1973).

[c] Chromatograms contained significant interference from unidentified peaks. Concentration estimates are given in parentheses.

[d] This sample is a mass weighted average of the sections of this core that contained dteectable activity of Cs-137. It represents an average of the sediments deposited at this site since the early 1950s. The 0-2 cm sample from this core should represent more recent deposition.

[e] The profiles of DDT-derived compounds with depth in this core were reported and modeled by Anderson et al. (1988).

Table 4.

DDT and DDD in SEEP Sediment Trap Samples[a]

Mooring #/ Trap #	Trap depth/ Water depth (m)	pp'-DDT		pp'-DDD		$\frac{pp'\text{-DDT}}{pp'\text{-DDD}}$
		conc.[b] (ppb)	flux[c] ($ug/m^2/y$)	conc. (ppb)	flux ($ug/m^2/y$)	
Poisoned Traps[d]						
5/5	167/1250	2.5±0.3	0.15	1.5±0.2	0.089	1.7±0.3
5/13	872/1250	2.9±0.4	0.21	1.2±0.1	0.090	2.4±0.4
5/14	1217/1250	1.9±0.2	0.27	0.68±0.06	0.10	2.8±0.4
6/8	468/2300	2.3±0.5	0.067	1.1±0.2	0.032	2.1±0.6
6/9	868/2300	3.1±0.4	0.17	1.3±0.2	0.070	4.1±0.8
6/12	1768/2300	2.8±0.4	0.18	0.69±0.08	0.044	6.3±1.1
6/17	2263/2300	2.4±0.3	0.18	0.38±0.05	0.028	
Unpoisoned Traps[e]						
4/3	158/500	1.3±0.4		2.6±0.3		
4/20	498/500	0.1±0.1		1.3±0.1		

[a] All samples were from the summer SEEP deployment described in detail

in Biscaye et al. (1988).

[b] Error estimates are based on the reproducibility of blanks and the precision of replicate analyses (about ±10%) as reported by Bopp et al. (1982).

[c] Flux calculations were based on the total mass fluxes, contaminant concentrations, trap openings (729 cm^2) and deployment times (175 days).

[d] Traps were poisoned with a 10% solution of sodium azide in filtered seawater to which sodium chloride was added. The sodium azide was used to inhibit biological activity in the traps, including the conversion of pp'-DDT to pp'-DDD. The sodium chloride was added to increase the density of the trap solution to minimize mixing with the overlying water.

[e] Because of the likelihood of conversion of pp'-DDT to pp'-DDD in the unpoisoned traps during deployment and uncertainty about the sampling period represented by the trap 20 sample, no flux calculations or computations of the pp'-DDT to pp'-DDD ratio were made for these samples.

Table 5.

Ratio of pp'-DDT to pp'-DDD in Selected Samples

Sample	pp'-DDT / pp'-DDD
Suspended Particles[a]	
NY Harbor, Hudson R. (GFF1060, 1981)	0.22
Newark Bay (F1049, 1985)	0.22
Newark Bay (F1054, 1985)	0.11
Newark Bay (F1077, 1986)	0.22
Newark Bay (F1091, 1986)	0.16
Arthur Kill (GFF1057, 1981)	0.19
Arthur Kill (F1089, 1986)	0.44
Kill van Kull (F1090, 1986)	0.25
Raritan Bay (GFF1055, 1981)	0.63
Sediment Cores from the NY Harbor Complex[b]	
-1.7 (CN1472, NY Harbor, Hudson R.)	0.05
NB13 (CN1964, Newark Bay)	0.18
RB17 (CN1533, Raritan Bay)	0.16
KvK1 (CN1959, Kill van Kull)	0.87
Sewage Samples	
Secondary sludge from the NYC treatment plant on Ward's Island	0.2

Table 5. (continued)

Raw sewage from the Yonkers, NY[c] sewage treatment plant	0.3
Primary treated effluent from the Yonkers, NY sewage treatment plant	0.2

[a] Suspended particle samples are identified by the Lamont control numbers given in parentheses.

[b] The ratio reported is the average pp'-DDT level in the core sections divided by the average pp'-DDD level. Sediment cores are identified by Lamont control numbers given in parentheses. Control Numbers of cores collected for this study are given in Appendix 1.

[c] The city of Yonkers is located on the east bank of the Hudson and is bordered on the south by NYC.

Table 6.
Large Volume Filter Samples

Station[a]	Suspended Matter (mg/l)	pp'-DDT[b] (ppb)	pp'-DDD (ppb)	pp'-DDT / pp'-DDD
August 24, 1987				
G1 (S), F1099	2.7	4.8±0.7	25±3	0.19±0.03
A54 (S), F1097	0.16	24±3	7.2±1.5	3.3±0.8
A54 (D), F1098	1.4	5.2±0.6	14±2	0.36±0.06
LB3 (S), F1094	0.41	14±2	10±1	1.4±0.3
LB5 (S), F1095	0.19	15±2	11±2	1.4±0.3
A56 (S), F1096	0.15	17±3	6.3±2.0	2.7±1.0
October 31, 1987				
G1 (S), F1103	1.5	5.8±0.7	18±2	0.33±0.05
A44 (D), F1102	0.80	6.9±1.0	9.9±1.1	0.70±0.13
SB (D), F1100	1.3	8.7±1.1	22±2	0.40±0.07
A54 (D), F1101	1.0	c	c	0.23
June 27, 1988				
G1 (S), F1105	1.3	16±2	36±4	0.43±0.07
G1 (D), F1106	1.4	9.6±1.1	25±3	0.38±0.06
SB (S), F1107	0.87	9.3±1.4	31±3	0.30±0.06

Table 6. (continued)

[a] Station locations are shown on Figure 5. A44, A54 and A56 are NOAA Broadscale designations. LB3 & 5 are along the NOAA Long Branch transect. G1 is green buoy #1 off Sandy Hook and SB is the bell buoy off Shrewsbury Rocks. (S) indicates surface samples collected at a depth of about 2 meters; (D) are deep samples collected at about 5 meters above bottom. F designations are Lamont control numbers used for sample identification.

[b] Error estimates are based on the reproducibility of blanks and the precision of replicate analyses (about ±10%) as reported by Bopp et al. (1982).

[c] Individual concentrations are not reported due to an uncertainty in the total extraction volume.

Table 7.

2,3,7,8-Tetrachlorodibenzo-p-dioxin Concentrations in Area 1 Samples

Sample	**2,3,7,8-TCDD (ppt)**
Core Sections	
A41 #1, 0-20 cm	400
A56 #4, 0-2 cm	41
A56 P1, 72-80 cm	ND(18)[a]
Suspended Matter	
G1 (S), F1099	120
A54 (D), F1098	ND(33)

[a] ND indicates not detected and is followed by the detection limit in parentheses.

Figure Captions

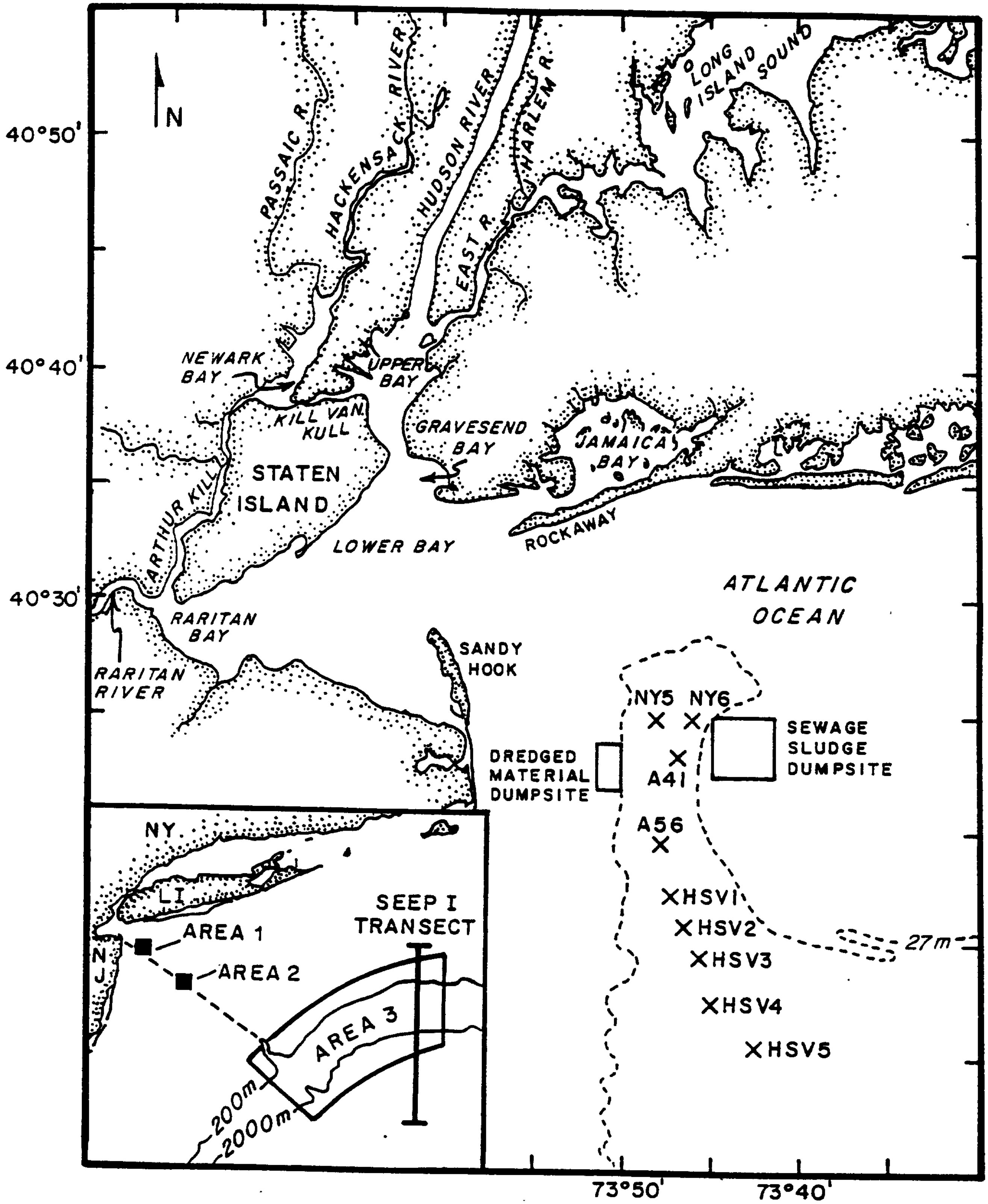
Figure 1. Map of our sampling sites in Area 1. The axis of the Hudson Shelf Valley falls within the area bordered by the 27 meter contour line. The cellar dirt dumpsite is located between the dredge spoil and former sewage sludge dumpsites. Approximate locations of sediment coring sites in Area 1 are indicated by the x's. The insert shows the general locations of Areas 2 & 3. Area 2 includes coring sites HSV6 & HSV7. Sites HSV8 and HSV9 are in Area 3, on the axis of the Hudson Canyon. Coring site EN-123 BC-E6 and the sediment trap moorings were located along the SEEP I transect. Latitudes and longitudes of all coring sites are listed in Table 1.

Figure 2. Average K-40 versus average Cs-137 activities in our sediment cores. Area 3 cores have the highest ratios of K-40 to Cs-137 activity. The cores from Areas 1 & 2 and NY Harbor all follow the same general trend. Statistical counting errors for K-40 levels in individual core sections are on the order of ±1 pCi/kg (see Appendix). This limits any attempt to distinguish between Area 1 & 2 cores and NY Harbor cores on the basis of this data.

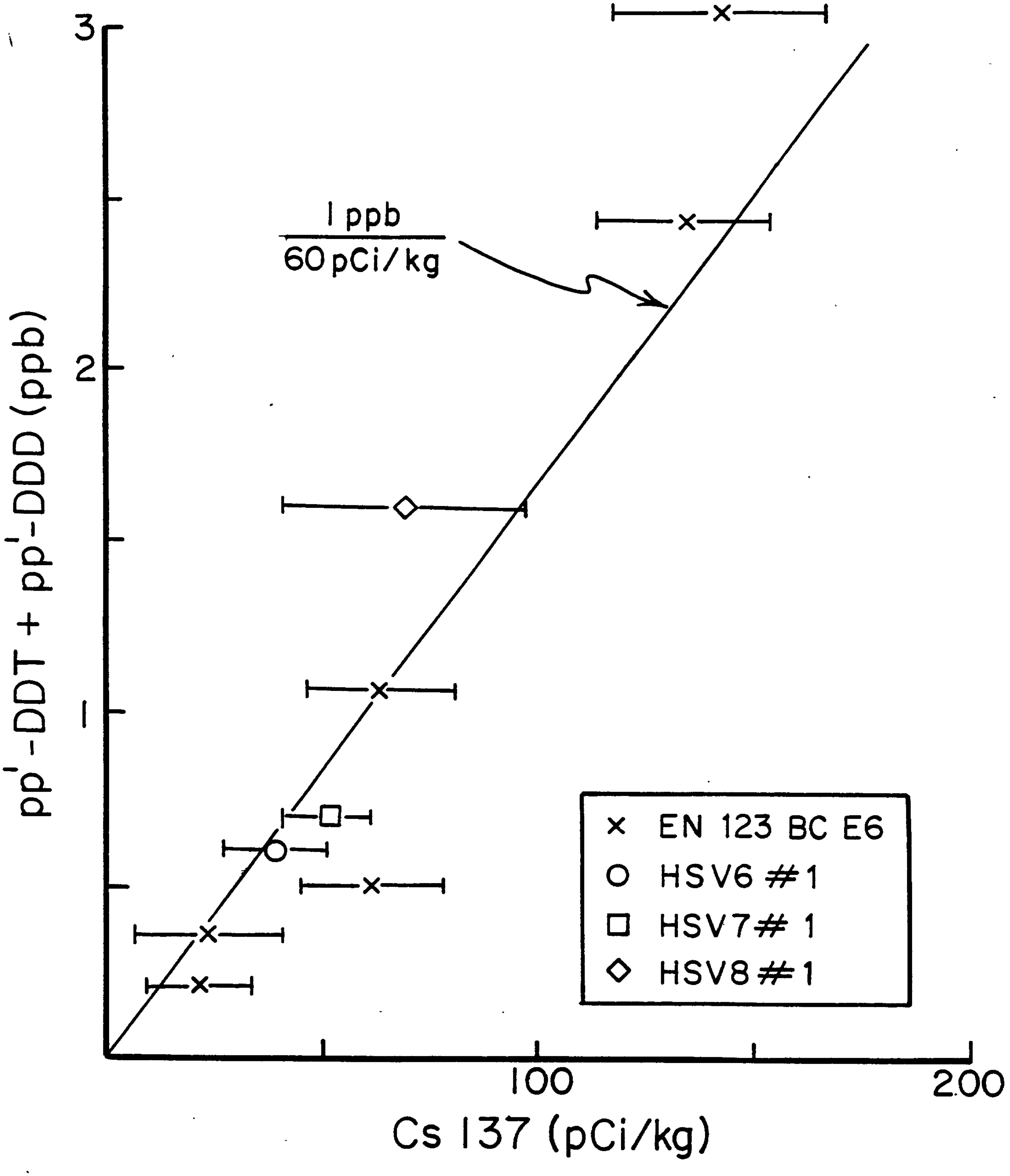
Figure 3. pp'-DDT + pp'-DDD concentrations versus Cs-137 activities in sections of sediment cores from Areas 2 & 3. The Cs-137 data are plotted with error bars of ± one standard deviation based on counting statistics.

Figure 4. pp'-DDT flux versus Pb-210 flux derived from the sediment trap samples listed in Table 4.

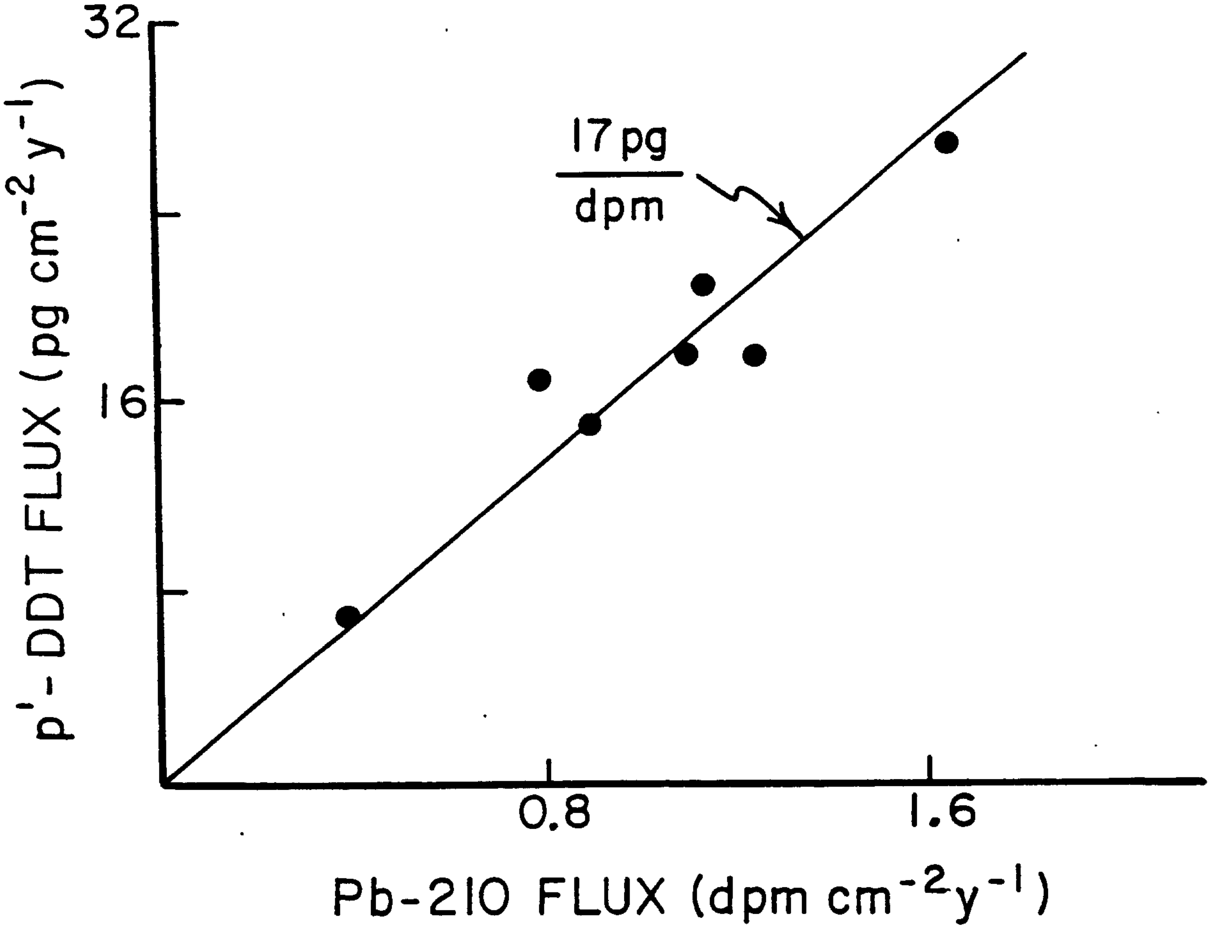
Figure 5. pp'-DDT to pp'-DDD ratio on suspended particle samples from Area 1. (S) indicates surface samples collected at a depth of approximately 2 meters. (D) indicates deep samples collected at approximately 5 meters above bottom.



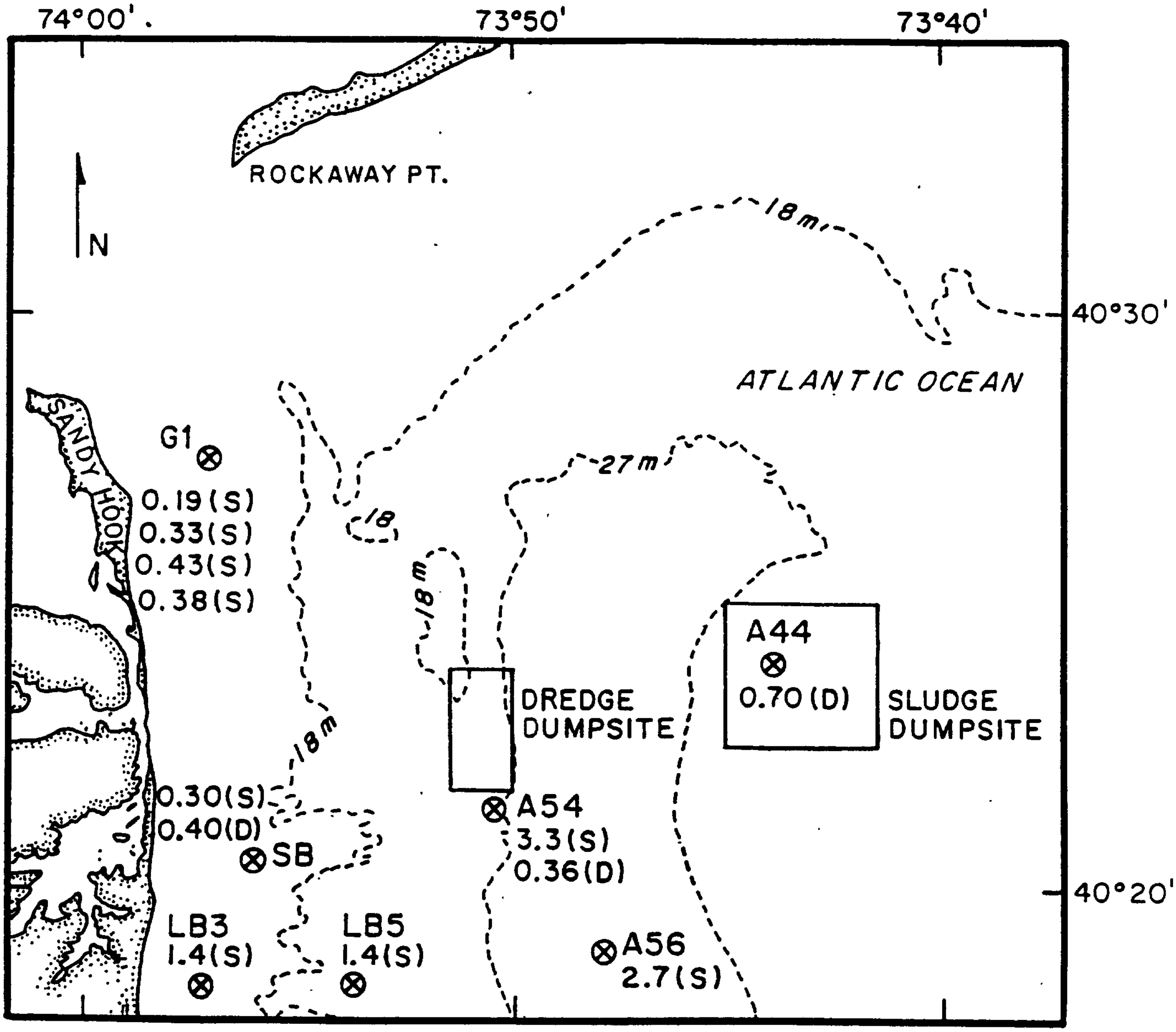
Bopp etal. Fig 1



Bopp et al. Fig. 3



Bopp et al. Fig 4.



Bopp et al. Fig 5

Appendix: Radionuclide Data on Sediment Core Sections[a]

LOCATION	DEPTH (cm)	WEIGHT (g)	Cs-137 (pCi/kg)	Be-7 (pCi/kg)	K-40 (pCi/g)
AREA 1					
NY5 #1	0-2	51.2	49±14	167±103	10.9±0.9
CN 2032	2-4	51.1	75±14	-26±104	10.8±0.6
10/30/87	4-6	62.4	66±16		10.7±0.6
	6-8	67.9	56±15		10.2±0.6
	8-12	129.6	73±8		10.7±0.6
	12-16	133.2	21±7		10.9±0.6
	16-20	130.3	11±6		11.3±0.6
	20-24	130.9	0±6		10.7±0.6
NY5 #2	0-0.5	15.0	50±20	178±209	11.6±0.7
CN 2033					
10/30/87					
NY 6 #1	0-2	40.0	54±12	195±95	8.6±0.5
CN 2030	2-4	67.5	37±7	7±60	8.3±0.4
10/30/87	4-6	70.0	47±10		8.1±0.4
	6-8	66.7	37±14		8.7±0.5
	8-12	145.1	29±9		8.7±0.5
	12-14	66.9	8±7		9.0±0.5
NY6 #2	0-0.5	7.4	55±31	335±341	10.2±0.7
CN 2031	0.5-1.0	8.5	75±30	-33±338	10.7±0.7
A25 #1	0-2	26.3	418±31	127±143	16.7±0.9
CN 2034	2-4	31.3	536±35	276±149	17.8±1.0
10/30/87	4-6	31.0	230±22	21±123	15.3±0.8
	6-8	26.1	370±33		15.7±0.9
	6-8[b]	26.1	403±32		17.5±1.0
	6-8[b]	26.1	362±25		18.1±1.0
	6-8[b]	26.1	318±30		17.8±1.0
	8-12	51.2	419±29		17.6±1.0
	8-12[b]	51.2	420±29		17.2±0.9
	12-16	56.6	320±25		17.3±0.9
	16-20	55.9	163+18		17.4±0.9
	16-20[b]	55.9	192±20		17.6 1.0
	20-24	61.4	198±19		18.2±1.0
	24-28	57.9	234±23		18.9±1.0
	28-32	66.4	126±12		15.6±0.8
	28-32[b]	66.4	127±15		15.5±0.8
	32-33	29.1	220±18		13.2±0.7
A25 #2	0-0.5	11.8	201±31	33±261	14.9±0.9
CN 2035					
10/30/87					

A25 P[c]	0-4	77.6	27±7	-11±61	10.6±0.6
CN 2075	4-8	57.8	23±9		9.0±0.5
10/4/89	8-12	55.0	45±10		9.5±0.5
	12-16	55.8	21±10		10.1±0.6
	16-24	60.6	192±14		14.1±0.7
	24-32	58.2	180±15		12.5±0.7
	32-40	90.4	39±7		7.6±0.4
	40-48	60.9	321±19		12.7±0.7
A41 #1	0-2	22.8	129±18	70±123	12.5±0.7
CN 2028	2-4	28.6	227±21	-77±120	12.9±0.7
10/30/87	4-6	19.0	387±37	17±369	14.5±0.9
	6-8	17.3	394±34		16.1±0.9
	6-8[b]	17.3	420±46		15.4±1.0
	6-8[b]	17.3	351±34		15.7±0.9
	8-12	39.3	342±28		13.2±0.8
	12-16	40.8	361±30		14.0±0.8
	16-20	51.0	180±18		14.6±0.8
	20-24	80.4	13±11		12.8±0.7
	24-28	58.4	10±13		15.8±0.9
	28-32	51.5	-10±11		16.9±0.9
	32-36	60.8	-5±9		15.8±0.8
	36-40	99.4	17±11		11.7±0.6
	40-44	118.0	-7±9		11.5±0.6
	44-47	111.8	4±7		11.2±0.6
A41 #2	0-0.5	4.4	162±60	-369±759	13.9±1.1
CN 2029					
10/30/87					
A56 #1	0-2	16.3	151±25	386±205	13.0±0.8
CN 2024	2-4	18.3	214±34	109±240	13.7±0.9
9/1/87	4-6	20.1	256±36	-55±236	14.3±0.9
	6-8	21.6	229±29		12.9±0.8
	8-12	36.8	158±18		12.0±0.7
	40-42	18.2	196±26		14.6±0.9
A56 #2	0-2	16.2	157±20	1008±179	14.3±0.8
CN 2025	2-4	13.9	191±29	65±244	15.6±0.9
9/1/87	4-6	14.6	173±20	-12±211	14.1±0.8
	6-8	15.4	206±28		13.9±0.8
	40-42	17.5	228±35		12.9±0.9
A56 #3	0-2	15.3	180±38	610±239	13.8±0.8
CN 2026	2-4	18.8	334±34	-200±252	14.0±0.9
9/1/87	4-6	20.0	188±30	-11±253	13.3±0.9
	6-8	18.8	217±29		13.1±0.8
	8-12	32.7	304±25		16.2±0.9
	12-16	32.2	278±25		13.5±0.8
	16-20	40.1	280±19		12.8±0.7
	20-24	32.7	267±25		11.8±0.7
	24-28	30.4	408±30		12.0±0.7

A56 #3	28-32	29.9	338±28		14.6±0.8
(Cont'd.)	32-36	36.8	252±23		14.2±0.8
	36-40	53.0	148±13		13.1±0.7
	40-44	42.0	191±22		12.4±0.7
	44-47	36.4	77±15		13.2±0.7
A56 #4	0-2	15.2	186±21	636±193	14.2±0.8
CN 2027	2-4	15.8	249±29	-182±234	14.2±0.9
9/1/87	4-6	24.3	194±20		13.4±0.8
	6-8	27.3	139±17		13.5±0.7
	8-12	36.1	219±19		13.7±0.8
	12-16	34.8	225±23		12.6±0.8
	16-20	34.8	285±25		13.8±0.8
	20-24	30.1	365±30		13.4±0.8
	24-28	32.4	348±26		13.4±0.7
	28-32	34.2	260±20		14.8±0.8
	32-36	41.3	225±19		13.9±0.7
	36-40	35.4	209±17		13.8±0.7
	40-44	39.7	168±19		11.8±0.7
	44-48	44.5	123±17		12.8±0.7
A56 #5	0-2	17.9	174±23	302±191	15.4±0.9
CN 2053	2-4	16.7	173±21	-216±177	15.0±0.8
9/26/88	4-6	20.1	229±26		15.2±0.9
	6-8	23.1	203±20		14.2±0.8
	12-16	34.4	213±23		13.7±0.8
	16-20	31.6	279±26		15.2±0.9
	20-24	31.2	282±27		14.6±0.9
	24-28	37.5	233±23		14.3±0.8
	28-32	39.1	272±25		15.0±0.9
	32-36	34.4	274±26		13.5±0.8
	36-40	29.1	326±30		13.4±0.8
	40-43	27.6	371±30		13.4±0.8
A56 #6	0-2	14.8	137±24	702±174	14.9±0.9
CN 2076	2-4	17.5	133±23	268±206	12.1±0.7
10/4/89					
A56 P1[d]	0-4	20.7	279±29	-274±210	14.6±0.8
CN 2052	4-8	8.8	327±37		14.0±0.9
9/26/88	8-12	9.8	312±38		12.9±0.8
	12-16	9.5	422±42		14.6±0.9
	16-24	22.4	429±29		14.1±0.8
	24-32	20.6	300±27		16.4±0.9
	32-40	20.6	261±26		15.4±0.9
	40-48	25.3	207±20		15.6±0.8
	48-56	19.9	194±24		15.5±0.9
	56-64	25.3	184±21		13.5±0.8
	64-72	26.2	157±20		13.8±0.8
	72-80	31.6	115±16		15.0±0.8
	80-88	28.2	36±18		17.0±0.9
	88-96	34.4	28±16		16.8±0.9
	96-104	35.9	-13±13		16.5±0.9

A56 P1	104-112	34.3	18±16		16.7±0.9
(Cont'd.)	112-120	38.1	-16±13		15.7±0.9
	136-144	53.9	-4±10		14.0±0.7
	160-168	46.7	7±11		14.6±0.8
A56 P2	0-4	10.1	158±47		17.0±1.2
CN2077	4-8	12.8	188±43		13.3±1.0
10/4/89	8-12	19.8	110±28		13.2±0.8
	12-16	14.3	101±33		12.8±0.9
	16-24	22.6	215±29		13.0±0.8
	24-32	18.2	251±34		14.6±0.9
	32-40	19.8	229±29		15.5±0.9
	40-48	21.4	235±30		14.9±0.9
	48-56	23.5	290±30		14.8±0.9
	56-64	17.5	262±32		14.5±0.9
	64-72	23.3	304±23		14.6±0.8
	72-80	22.1	311±26		14.7±0.8
	80-88	16.1	315±28		13.7±0.8
	88-96	14.5	315±33		13.7±0.8
	96-104	18.2	314±28		13.2±0.8
	104-112	24.6	415±28		13.4±0.7
	112-120	25.7	386±28		15.1±0.8
	120-128	21.5	262±22		14.6±0.8
	128-136	20.6	206±23		14.0±0.8
	136-144	22.2	201±22		15.7±0.9
	144-152	22.0	170±22		15.3±0.9
	152-160	21.5	192±23		14.5±0.8
	160-168	28.8	162±18		13.1±0.7
	168-176	40.2	63±11		11.6±0.6
	176-184	26.7	182±21		13.8±0.8
	184-192	25.2	92±17		14.2±0.8
	192-200	31.0	143±17		14.2±0.8
	200-208	26.1	24±16		15.3±0.8
	208-216	33.2	22±12		15.6±0.8
	216-224	38.3	-6±13		15.6±0.8
	224-232	40.1	10±11		14.2±0.8
	232-240	31.3	-2±13		16.2±0.9
	240-248	30.7	-5±14		16.8±0.9
	248-256	52.0	3±11		14.0±0.8
HSV1 #1	0-2	24.5	202±18	180±140	14.7±0.8
CN 2042	2-4	19.7	394±31	-311±279	16.9±1.0
6/27/88	4-6	25.0	423±29		17.2±0.9
	6-8	24.8	382±25		17.0±0.9
	8-12	43.4	435±32		15.7±0.9
	12-16	57.7	314±23		15.0±0.8
	16-19	42.6	228±22		15.2±0.9
HSV1 #2	0-2	25.9	339±24	172±167	17.1±0.9
CN 2043	2-4	20.5	444±38	258±380	16.4±1.0
6/27/88	4-6	22.5	447±35		17.3±1.0
	6-8	21.5	453±35		16.0±0.9
	8-12	47.1	409±24		16.2±0.8

HSV1 #2 (Cont'd.)	12-16	48.7	360±28		15.7±0.9
HSV2 #1 CN 2040 6/27/88	0-2	26.9	130±16	86±126	13.8±0.7
	2-4	25.4	156±19	-181±217	15.0±0.8
HSV2 #2 CN 2041 6/27/88	0-2	23.0	132±17	159±159	15.1±0.8
	2-4	25.5	160±25	133±311	15.1±0.9
	4-6	25.9	189±20		14.9±0.8
	6-8	25.4	151±20		14.9±0.8
	8-12	62.1	202±18		13.7±0.8
	12-16	71.9	141±15		12.6±0.7
	16-18	39.6	56±11		12.2±0.7
	18-21	93.0	121±13		12.3±0.7
HSV2 #3 CN 2078 10/4/89	0-2	32.4	70±13		12.3±0.7
	0-2[b]	32.4	60±14	61±109	12.4±0.7
	2-4	37.9	67±13	-101±123	12.5±0.7
	2-4[b]	37.9	66±16		14.2±0.8
	4-6	40.6	106±17		13.7±0.8
	6-8	35.6	138±15		12.8±0.7
	8-12	70.6	155±14		13.0±0.7
	12-16	90.9	90±9		11.4±0.6
	16-20	108.1	58±8		10.9±0.6
	20-24	122.5	28±8		11.7±0.6
	24-28	124.0	16±6		10.4±0.5
	28-32	123.1	15±7		11.0±0.6
	32-36	126.8	4±7		11.6±0.6
HSV3 #1 CN 2038 6/27/88	0-2	23.7	105±16	417±132	14.7±0.8
	2-4	24.3	115±17	166±191	14.6±0.8
	4-6	29.9	145±21		13.7±0.8
	6-8	30.7	155±21		13.7±0.8
	8-12	66.3	116±18		11.5±0.7
	12-16	73.2	104±16		12.0±0.7
	16-19	67.6	98±15		12.2±0.7
	19-21	47.7	106±16		11.7±0.7
HSV3 #2 CN 2039 6/27/88	0-2	25.7	134±16	272±142	15.0±0.8
	2-4	27.0	147±19	-2±214	12.6±0.7
	4-6	28.7	134±16		14.7±0.8
	24-26	53.9	53±9		11.7±0.6
HSV4 #1 CN 2059 11/19/88	0-2	48.0	53±10	118±78	11.3±0.6
	2-4	56.2	57±9	-35±77	11.1±0.6
HSV4 #2 CN 2060 11/19/88	0-2	39.6	48±11	156±100	12.4±0.7
	2-4	41.1	77±11	54±98	12.3±0.7
	4-6	52.4	50±10		12.2±0.6
	6-8	55.0	72±11		12.4±0.7
	8-12	108.6	56±10		10.5±0.6

HSV4 #2	12-16	117.0	40±10		10.2±0.6
(Cont'd.)	16-20	119.2	36±11		10.4±0.6
	20-24	122.4	-9±9		10.0±0.5
HSV5 #1	0-2	43.9	53±13	-39±103	11.7±0.6
CN 2061	2-4	32.2	107±18	15±146	12.5±0.7
11/19/88	4-6	41.1	77±12		11.8±0.6
	6-8	54.5	68±10		11.2±0.6
	8-12	104.6	54±10		10.4±0.6
	12-16	113.8	36±7		10.4±0.5
	16-20	127.3	27±9		9.8±0.5
	20-24	131.2	20±7		9.5±0.5
	24-28	143.6	3±6		9.4±0.5
	28-28.5	31.1	15±13		11.9±0.7
HSV6 #1	0-2	50.6	40±12	5±97	10.8±0.6
CN 2062	2-4	59.2	50±10	-16±87	11.3±0.6
11/19/88	4-6	72.3	23±8		10.8±0.6
	6-8	71.1	12±8		10.7±0.6
	8-12	145.7	6±6		9.8±0.5
	12-16	134.6	-4±6		10.5±0.5
HSV6 #2	0-2	56.2	35±7	-32±73	12.0±0.6
CN 2063	2-4	60.0	20±9		11.6±0.6
11/19/88	4-6	74.0	22±7		11.1±0.6
	6-8	77.1	7±7		11.1±0.6
	8-12	149.8	-5±6		10.5±0.5
HSV7 #1	0-2	54.5	52±10	54±102	11.7±0.6
CN 2064	2-4	50.9	42±13		11.5±0.6
11/19/88	4-6	59.2	42±12		11.4±0.6
	6-8	66.0	42±11		11.2±0.6
	8-12	125.6	34±9		11.0±0.6
	12-16	142.7	16±6		10.9±0.6
	16-20	139.5	15±7		11.2±0.6
HSV8 #1	0-1	10.0	70±28	91±284	18.2±1.1
CN 2065	1-2	12.3	63±25	106±259	17.5±1.0
11/19/88	2-3	12.2	88±26	148±306	19.3±1.1
	3-4	11.8	124±28		20.1±1.1
	4-6	22.4	80±17		18.5±1.0
	6-8	24.9	-15±24		17.1±1.0
HSV9 #1	0-1	8.7	4±49	358±455	17.0±1.2
CN 2066	1-2	10.7	33±41	-298±396	18.4±1.2
11/19/88	2-3	9.8	0±31		20.4±1.2
NBS Std.[e]			2675±136		14.7±0.8
			2643±133		14.3±0.7
			2656±134		14.5±0.7

[a] Activities are reported with error bars of ± one standard devaition based on statistical counting errors.

[b] These are results of replicate analyses.

[c] Site A25 is on the dredge spoil disposal site. The realtively low Cs-137 and K-40 activities in the top 40 cm of A25 P probably result from emplacement of a sand cap at that site after our collection of cores A25 #1 & 2 (10/30/87) and prior to collection of the piston core (A25 P, 10/4/89). Capping with relatively clean sand is known to have been performed at times at this disposal site. This procedure is an attempt to stabilize contaminated dredge spoil deposits and isolate them from the overlying water.

[d] This piston core overpenetrated. Based on the other cores from this site, we estimate that the top 60-120 cm were lost.

[e] These results are for NBS standard reference material 4350 (river sediment). NBS reported activities are 2703±122 pCi/kg for Cs-137 and 14.6±1.3 pCi/g for K-40.