NOAA Technical Memorandum NOS OMA 15

IMPACT OF AND RECOVERY FROM SEWAGE SLUDGE DUMPING AT THE PHILADELPHIA DUMPSITE

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April 1985

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National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

NOTICE

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Michael Devine and Duane Simpson

ABSTRACT. This report reviews the results of studies of the Philadelphia Sewage Sludge dumpsite carried out between 1973 and 1984 by NOAA, EPA, and other organizations. The site, located on the continental shelf east of the Maryland coast, was used for the disposal of sewage sludge from Philadelphia between 1973 and 1980. Studies were carried out before, during and after dumping.

A substantial number of studies were undertaken during dumping to attempt to identify and quantify impact. These included measurements of metals and total organic carbon in sediments and biota, analyses of impacts on the benthos, and microbial studies. Although several of these approaches lead to an indication of impact, many of the results were ambiguous. More focused studies in recent years have developed useful indications of impact and recovery. These include investigations of microbial contamination of sediments, pathogenic amoebae in sediments, viruses in sediments and organisms, and gill contamination and heavy metal levels in rock crabs. Many of those approaches represent advances over conventional indicator bacterial accounts for assessing possible threats to human health. Overall, results indicate a much lower level of degradation at the Philadelphia site than in nearshore areas in the New York and Los Angeles regions. All pollution indicators have declined rapidly in the four years since dumping has stopped.

1. INTRODUCTION AND BACKGROUND

1.1 NOAA's Role in the Problem

The introduction of treated and untreated sewage into the marine environment represents one of the primary sources of pollution to coastal and nearshore waters. Much of this material enters the ocean indirectly through riverine transport and runoff. However, each day nearly four billion gallons (15×10^6 m^3) of sewage and effluents and six million gallons of sewage sludges are disposed directly into the nation's marine coastal waters (NOAA, 1982). These wastes are generated by some 220 publicly owned coastal treatment plants that serve an estimated 80 million people, nearly one-third of the total United States population. By the year 2000, U.S. coastal communities are expected to discharge to marine waters some six to seven billion gallons per day of sewage effluents and an as-yet-to-be-determined amount of sewage sludges.

Proper marine disposal of sewage sludge potentially provides a cost-effective method for protecting residents of the U.S. coastal zone from sewage-borne disease and epidemics. It may also serve to minimize the ecological and public health effects that would occur in coastal rivers, streams, lakes, and ground water reservoirs if the wastes were disposed onshore. However, despite the partial protection afforded by treatment and dilution, marine sewage effluent and sludge disposal has caused local and regional changes in water quality and marine life. Furthermore, ocean disposal may itself represent a threat if improperly carried out. Sludge disposal has not been directly implicated in any disease outbreaks or in degraded water quality in beaches. Problems at beaches in the New York Bight region, for example, are attributable to direct discharge of sewage into embayments. Sludge does degrade well-defined areas of the ocean bottom when disposed in sufficient quantities, and areas around sludge dumpsites are invariably closed to shell-fishing. There is also uncertainty about possible long-range effects that have yet to be convincingly documented. It is not yet established at what level and concentration of input marine waste disposal itself becomes a hazard to human health, nor is it known how long pathogens survive in marine sediments.

Sewage effluents and sludges represent a possible hazard to human health, because they harbor numerous agents of human disease, including viruses, enteric bacteria, and pathogenic amoebae, as well as a wide variety of chemical contaminants. The direct hazard from effluent and sludges is not great at present, because of effective treatment and disposal methods. Yet it must be remembered that food-borne hazards of microbial origin do constitute a direct threat to human health. Confirmed cases of food poisoning in the United States amount to only a few thousand annually, but that is because of poor reporting: the total number of cases is estimated as much higher (Goyal, 1984). A significant fraction of these incidents are caused by seafood, in particular contaminated shellfish. The role of sewage in human illness involving shellfish is not clear, but it is known that conventional wastewater treatment is inadequate for removal of viruses (Goyal, 1984). The documented incidence of food-borne disease is on the increase, however, and several hundred cases were reported in 1982 in New York and New England alone. The sewage disposal problem is clearly one of the most important issues in marine pollution assessment.

Ocean dumping of sewage sludge was carried out at the Philadelphia site on the mid-Atlantic continental shelf between 1973 and 1980. At this site, approximately 4.11×10^6 metric tons of waste were dumped, representing only a small fraction of the sludge and effluents entering U.S. coastal waters. It is, however, of great importance in the context of the national sewage waste disposal problem to understand the fate and effects resulting from this approach to sludge disposal.

Following intensive field efforts by the EPA between 1973 and 1979, NOAA's Ocean Dumping Program assumed the major responsibility for the Philadelphia studies in 1979. The NOAA-supported field and laboratory programs carried out between 1979 and 1983 refined the EPA effort to measure impact, studied recovery trends, and compared the site with both cleaner and more degraded locations. The key EPA personnel working at the site from 1973-1979 continued their efforts from 1979-1981 with NOAA support under an interagency agreement with EPA.

The discontinued Philadelphia sewage sludge site represents a case study of the impact of sludge disposal on a marine environment that had not been affected by any other substantial pollution source. The cessation of dumping in November 1980 has provided a unique opportunity for examining the extent to which recovery takes place in such an environment; although, as will be seen in subsequent sections of this report, environmental recovery is sometimes difficult to quantify scientifically because not all of the impacts at the site are clear and unambiguous and because midshelf environments exhibit high spatial and temporal variability. For these reasons, the NOAA studies have focused on areas where impacts are most directly attributable to sludge: pathogens and other key contaminants in sediments and benthic organisms.

1.2 Dumping History and Environmental Setting

The Philadelphia sewage sludge dumpsite is a 172 km^2 area located about 70 km east of Ocean City, Maryland, centered at roughly 38°23'N, 74°15'W (Figure 1). It was used for the disposal of sewage sludge from Philadelphia, Pennsylvania, and Camden, New Jersey, between May 1973 and November 1980. For a short period in 1974 and 1975, the Modern Transportation Company dumped relatively small amounts of sludge from some northern New Jersey communities.

Regulation of dumping at the site was administered by the Environmental Protection Agency Region III Office in Philadelphia. The site replaced a site near the mouth of Delaware Bay which had been used between 1961 and 1973. The 1973-1980 site, in fact, was designated only as an interim dumpsite; it has always been intended that alternatives to ocean dumping be developed. A comprehensive regulatory history of dumping at the site is provided by Muir (1983). Figure 2 shows the amounts of sludge dumped between 1973 and 1980, and Table 1 shows the loadings of various waste constituents from Philadelphia and Camden.

The environmental setting of the dumpsite is typical of the middle Atlantic continental shelf. The site lies over waters 40-60 m deep. The ocean bottom is composed primarily of medium to fine sands, with a silt-clay fraction of less than one percent. It exhibits a gently rolling topography of low parallel ridges separated by shallow depressions. This ridge-and-swale system runs NE-SW, with amplitudes of 2-14 m and wave lengths of 2-6 km (Swift et al., 1974).

The mean oceanographic structure of the area is summarized by Lear and O'Malley (1983a). The hydrographic structure is vertically isothermal in winter and has a well-developed thermocline at 16-20 m under summer conditions. Salinities and temperatures below the thermocline are characteristic of "cold-pool" waters (Ingham, 1982).

The mean circulation in the area is characterized by ellipsoidal tidal currents with velocities around 12 cm/sec. Near-surface drogue studies in the region show a southwest movement at about 25 cm/sec in the winter; net movement in the summer is unclear, with some drogues tending to move north and northeast (Klemas et al., 1977). Net bottom currents deduced from seabed drifter studies are to the south or southwest at around 2 cm/sec (Ingham, 1982).

The near-bottom tidal currents are of sufficient magnitude to transport surficial sediments. Quantitatively, however, sediment transport in the ocean appears to be dominated by strong, infrequent storm-induced events (Ingham, 1982). Swift et al. (1976) show the importance of storm events with near-bottom currents greater than 50 cm/sec for 12 hours or more in causing large sediment transports.

A 1973 predumping survey of the area by the EPA showed no apparent aberrances in the parameters measured (Lear et al., 1977). The hydrographic structure was typical for known spring conditions. Water quality determinations for nutrients, dissolved oxygen, and pH were well within limits expected for a nonstressed, temperate mid-shelf environment. Zooplankton and phytoplankton populations were typical of temperate coastal waters. Coliform and fecal coliform bacteria were not present in significant quantities in the water or the sediments sampled. There was no evidence of fin rot or external diseases of the vertebrates collected. The benthic community was diverse and abundant and was characteristic of a clean, firm, sandy mid-shelf habitat.

2. IMPACT STUDIES, 1973-1979

2.1 Overview of the Program

A wide variety of studies were carried out at the Philadelphia dumpsite between 1973 and 1979 by the EPA, universities, and private corporations. Lear et al. (1981) and Lear and O'Malley (1983a) provide a summary of the EPA work, while Oostdam (1983) summarizes much of the university effort, and Guarino et al. (1977, 1979) discuss work carried out on behalf of the City of Philadelphia by Raytheon Corporation, universities, and other organizations.

EPA monitoring at the sludge site began in 1973. Initial sampling was done over a 6,860 km^2 grid. In addition, in 1975 a more intensive near-field grid, 1.8 x 5.6 km, was established adjacent to and south of the sewage sludge release area to investigate apparent accumulations of sludge and departures from ambient conditions. In 1978 additional stations were added based on the mesoscale topography to sample more definitively the contrasting ridge-and-swale habitats. Depths of stations varied from 38 to 63 m. Two to four cruises per year were made to the site between 1973 and 1979.

The assessment included physical oceanographic characterizations, barge plume studies, hydraulic models, bathymetry, sedimentological studies, faunal surveys, analyses of metal concentrations in sediments and animals, population dynamics assessments, and pathological comparisons of animals near and remote from the sludge site (Lear et al., 1981). With the 1973 predumping survey serving as a baseline, this assessment of impact focused on four main areas: direct accumulation of sludge matter on the sea bottom, contaminant accumulation in sediments and biota, benthic community variations, and microbial effects.

The university studies reported on by Oostdam (1983) consider short-, intermediate-, and long-term effects, and include work at the old dumpsite near the mouth of Delaware Bay, which was used as a dumpsite from 1961 to 1973. Short-term effects are considered to be those lasting from minutes to hours, intermediate-term effects are those from several hours to a year, and long-term effects are those lasting on the order of years. Studies carried out for the City of Philadelphia included determination of metal concentrations in sediments and benthic organisms.

2.2 Sludge Dynamics and Accumulation

By 1975, according to Lear et al. (1977) sludge discharged at the Philadelphia site appeared (by distinguishing between "dark," presumably contaminated sediments and "clear" sand) to have collected on the ocean bottom, mostly in regions to the southeast, south, and southwest of the dumping locations, rather than within the boundary of the site. Bottom-drifter studies in the area indicate prevailing net water movement in those directions, and tidal and wind-induced currents were apparently of sufficient strength to sweep most released sludge outside the boundaries of the release site. Although the actual mechanisms of sludge dispersal, as well as the overall spatial distribution of the sludge beds in the region, were not well established, the sludge appeared to collect in multiple, separate deposits in the shallow topographic depressions running through the area.

Oostdam (1983), however, reports on short- and medium-term observations, which were much less conclusive. Short-term effects observed in a June 1974 field experiment were those that would be expected from the disposal of a large amount of particle-laden material in relatively shallow water. The sludge plume moved rapidly downward, with particulates settling out over several hours. The surface slick was followed for about 8 hours. It moved about 25 cm sec^{-1}, which was about 2 percent of the wind speed. Some elevated concentrations of metals were observed, and other expected chemical transformations occurred. Light transmissometry was irregularly but substantially decreased, and plankton and nekton in the water column were disturbed by the impeded light transmission. Short-term bottom distributions of sludge and direct impacts on the bottom were not observed.

For the intermediate-term observations , disposal of sludge beyond the boundaries of the dumpsite was examined by observing the seafloor using underwater television, scuba divers, and submersibles. Bottom samples were also collected at and near the dumpsites. Brownish floc found below a previous day's barge transect was similar to that found elsewhere on the shelf during a period of quiet weather and did not contain any fibers typical of sludge. Oostdam asserts that although indirect evidence of sludge was found by other investigators in the form of elevated trace metal concentrations in surficial layers and high TOC and fibrous material in floc, material on the seafloor could not be conclusively identified as sewage sludge based on direct evidence.

Bisagni (1983) considered the potential area of influence (PAI) of sludge dumped at the Philadelphia Site a function of initial dispersion by currents. Bisagni extends his initial PAI as much as 200 km from the site, based on the hypothesis that fine sludge fractions can remain suspended above the seasonal thermocline for 10 days. Seaward, the PAI is extended 50 km beyond the shelf break, because of intermittent intrusions of oceanic water from this region into the site. Quantitative analysis of post-depositional resuspension and transport is not given, although analysis of storms would predict transport to the south and southwest.

Overall, it appears that dumped sludge was distributed over a wide area after deposition and may well have been intermixed with the top few centimeters of the local sandy substrate (Clarke et al., 1982) to the extent that it could not readily be located and identified. No short- or long-term sludge budget can presently be given.

2.3 Metals and Total Organic Carbon in Sediments and Biota

Philadelphia sludge contains large quantities of a number of metals, several of which are known to have detrimental biological effects in elevated concentrations. The EPA program analyzed sludge samples from Philadelphia and Camden for thirteen metals. In the field, however, studies generally covered a suite of five metals considered to be significant identifiers of sludge: chromium, copper, nickel, lead, and zinc. Some analyses of zirconium, cadmium, and manganese were also made. A reference or control grid was established just north of the dumpsite. This area was of approximately the same topographic character. Results of the studies are shown in Tables 2-6 and in Figure 3. There was an increase in levels of some metals at the dumpsite as compared to the control area (Table 4). The increase, however, is not consistent and did not become larger over time (Figure 3). The concentrations of metals in the area of the dumpsite were higher than typical levels of metals in sediments in the midshelf environment. However, higher metal levels in sediments have been reported on the continental shelf (Harris 1977).

According to Table 4 of Lear and O'Malley (1983a), the means of lead, copper, chromium, and zinc concentrations were all greater in the dumpsite grid than in the reference grid. However, the highest metal values observed in the grid stations fall within the range of means for metal concentrations in sediments associated with "clean" areas along the mid-Atlantic Bight according to Guarino et al. (1979). According to these authors, concentrations of these metals do not appear to be unusual compared with those at other areas (Table 5). Lead was considered to be of particular significance for monitoring for contamination by ocean dumping (Lear and O'Malley, 1983b). As with other metals, however, the data on lead (Table 6) show variations from cruise to cruise without an indication of loading over time. There is no pattern to metal concentrations in sediments at the Philadelphia dumpsite that can be considered conclusively indicative of sludge accumulation.

The presence of elevated levels of total organic carbon (TOC) is a possible, but not conclusive indicator of the presence of sewage sludge. The distribution of TOC in sediments was determined by Lear et al. (1981) in both the far-field and near-field sampling schemes. Ambient concentrations of TOC, as estimated by mean, standard deviation, and range in the far-field grid, were on the order of 300-800 mg/kg dry weight. However, in the intensive grid area associated with sewage sludge dumping, concentrations of 1000-4500 mg/kg dry weight were encountered at certain locations. Detailed comparison between a dumpsite grid and a reference grid showed that mean TOC concentration in the dumpsite grid was 1330 mg/kg, while that in the reference grid averaged 830 mg/kg.

Lear and O'Malley (1983a) report apparent evidence of sewage sludge dumping at one station on the southern edge of the dumpsite. Here the dry-weight sediment concentrations of lead, copper, and total organic carbon were 6.3, 2.7, and 2690 mg kg^{-1}, respectively. These concentrations are not particularly high relative to other sediments on the shelf, but were statistically higher than those at both the other 22 dumpsite-grid and the 21 reference-grid stations. Another station, located about 1.5 km southeast of the one on the dumpsite edge, also showed elevated concentrations of lead, copper, and organic carbon. These two stations were within topographic swales. Sediment from a station on a ridge between them did not display elemental or organic carbon enrichment. Also, within the swale running through the dumpsite there was a station with elevated organic carbon (not higher lead or copper) and another with a high copper concentration.

The mahogany clam (<u>Arctica islandica</u>) and the sea scallop (<u>Placopecten magellanicus</u>) were examined for accumulations of heavy metals. Although Lear and O'Malley (1983a) report high concentrations of cadmium and zinc in tissues from mahogany clams and elevated concentrations of copper, silver, nickel, and cadmium in the tissues of sea scallops, the concentrations found are not necessarily indicative of accumulation due to dumping (Guarino et al., 1979; see also Table 7).

Oostdam (1983) also reports that long-term concentrations of zinc, nickel, and lead may have increased due to dumping, but that values are near or below the minimums found in British coastal areas impacted by sewage sludge. Cadmium concentrations in the viscera and muscles of sea scallops were inconclusive. Other studies at the interim and old dumpsites also were not conclusive in showing effects of dumping. Overall, Oostdam asserts that the lack of consistent increase with time of trace element levels in sediments and biota and the lack of correlation between changes in trace element levels and changes in dumping input cast considerable doubt on statements about progressive deterioration at the dumpsite.

2.4 Impacts on the Benthos

In general, even when elevated levels of contaminants are found in biota, they often cannot be directly linked to any effect. The most important indications of impact to look for in benthic organisms are direct effects on health, mortality, and reproduction, and variations in community structure. Any significant level of disease or significant alteration in the structure of the bottom community would indicate an impact of dumping; whether it is significant for the regional coastal ecosystem is then a matter of judgment.

The mahogany clam occupies the entire study area and is particularly common in bottom communities inhabiting waters between 36-54 m deep. Over the duration of the site survey, the apparent rate of recent mortality of this animal increased significantly in several sections of the zone contaminated by sewage, and the increased rate of death did not appear to be a seasonal phenomenon (Lear et al., 1978). Mortality here was measured in terms of increasing frequencies of appearance of recently dead pairs of clams with intact hinge ligaments collected at stations that were sampled repeatedly over the duration of the field survey. Evidence of a high incidence of recent mortality among the clams appeared at two collecting stations inside the boundaries of the dumpsite as well as at two stations outside the site, one of which is located 37 km east of the dumping location. In all cases, the incidents could be linked indirectly with dumping by high local sediment concentrations of metals. Distributions of dead shells were widespread and patchy, however, due to natural variability, and therefore cannot be considered as conclusive. Moreover, the finding of the shells was sporadic over time and did not increase with continued dumping.

Demersal disorders similar to those known from fish collected at sludge discharge sites in the New York and Southern California bights were not detected in fish from the Philadelphia disposal area. However, pathological disorders did appear in bottom-dwelling crabs from the vicinity of the Philadelphia dumping area. These disorders included necrotic lesions of the exoskeleton and melanistic accumulations in the gills (Lear et al., 1981; Grieg et al., 1982). The incidence of the disorders seemed to be higher in areas contaminated by metals and sewage than in cleaner waters surrounding the polluted area, but a definite link between the disorders and dumping could not be established.

The benthic infaunal community is the most vulnerable to sludge dumping due to its lack of mobility. This community, however, is subject to wide variations in natural factors. Distributions of certain benthic species are influenced by the mesoscale topography, with some species characteristic of ridge habitats and others characteristic of the finer, more stable substrates found in swales, and gradations between (Boesch, 1982). Areas in the New York Bight affected by sewage sludge were found to be "devoid of normal benthic population" (Pearce, 1972). This was not shown to be the case in the Philadelphia site.

Comparisons of standard indices of species' diversity, as well as number of taxa per station and average density of organisms, indicate no major differences in community structure when all stations in each grid are considered together (Lear and O'Malley, 1983a). Of the stations sampled, an indicater polychaete (Capitella capitata) was found at only one swale station in the dumpsite. This organism is one of the most characteristic of marine pollution-tolerant species (Word et al., 1977). The occurrence of this organism and the unexpected absences of the normal species in the same location suggest that changes to benthic conditions characteristic of marine pollution have occurred at this site (Lear and O'Malley, 1983a). However, this alteration of the benthic macrofauna is only minor, and even if sewage sludge disposal is responsible for such community fluctuations, the observed effects do not seem to exceed natural environmental variability and are soon observed to be negated by other natural influences, e.g., storm disturbances and reproductive cycles (Reid, 1983). The information available indicates that any effects of sludge dumping on the benthic macrofauna populations near the Philadelphia dumpsite have been small relative to effects seen in two other well-studied sewage disposal areas--the New York and Southern California bights.

2.5 Microbial Studies

Studies made to estimate total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS) bacteria in surficial sediments from the area of an open-ocean wastewater sludge disposal site were important as health indicators to the shellfish industry in the area. The analysis for shellfish contamination was accomplished by the U.S. Public Health Service, Food and Drug Administration (FDA). The FDA considers a water column level of 70 MPN (most probable number) of total coliform bacteria for 100 ml water, or a 14 MPN for 100 ml fecal coliform level, to indicate a serious enough health risk to require the closure of an area to shellfishing. However, unlike water column concentrations, there is no established hazard concentration for coliform bacteria in bottom sediments, even though much of the contamination of shellfish by pathogens probably results from the uptake of microorganisms from sediments (Melnick, personal communication).

Laboratory procedures were adapted for shipboard from several standardized procedures for the MPN tests for TC and FC in sediments (O'Malley et al., 1982). Both TC and FC estimates ranged from 10 to 2400 MPN for 100 g sediment. Based on these results, the Shellfish Sanitation Branch of the U.S. Food and Drug Administration issued a "notice to harvesters" that closed a shellfishing area of the Atlantic Ocean 9.5 nautical miles in diameter centered at the middle of the Philadelphia dumpsite. This action was taken on December 10, 1976 (Forste and Rinaldo, 1977), almost two years after dumping began.

Results of the distribution of coliforms and fecal coliforms in sediments from cruises in April and September 1978 show elevated concentrations of sewage bacteria associated with the sewage sludge dumpsite, with occasional sporadic low background counts elsewhere. Negative results were generally found on the transects in the direction of possible landward sources.

2.6 Summary

Overall, despite the major measurement and analysis effort made between 1973 and 1979, results are inconclusive. Some unambiguous indicators of the presence of sludge were found, but effects could not be unambiguously demonstrated. Impacts could not be quantified and in fact appeared to be minor. This was due partly to difficulties in measurement and partly to limited understanding of the natural variations in parametric values along the coast. There were some indications of microbial contamination, but only a limited analysis of unambiguous bacteriological indicators of sludge were made. Documentation of impact and recovery would require focusing on a few measures that can be replicated over time and compared with similar measures from other shelf locations.

3. THE NOAA PROGRAM AT THE SITE, 1979–1983

3.1 Overview and Summary of Field Efforts

The NOAA studies began during the last year of dumping at the site and continued for three years after dumping stopped. One of the NOAA objectives was to continue the lines of research that had been productive during the EPA effort. For this reason studies of metals in sediments and organisms, examination of benthic organisms for dumping indicators, and measurements to determine other indicators in sediments were continued. However, it was felt that the main focus of the NOAA effort should be on microbial indicators of sludge such as bacteria, pathogenic amoebae, and viruses.

The nature of the problems of measurement and interpretation described in the previous chapter seems to indicate that it is probably not possible to develop quantitative measures of impact and recovery at the Philadelphia site. Nevertheless, the presence or absence of unambiguous indicators of sewage material after dumping stopped would indicate the extent of recovery, especially if compared with clean control sites on the one hand and the more degraded locations in the New York Bight on the other. Controlled sampling for these indicators was an essential part of the NOAA field effort.

Four cruises were carried out at the site in the 1980-1983 period. The first was in August 1980 during a period of continued but decreasing dumping; the second was in May 1981, about five months after dumping stopped, the third was in June 1982, about 18 months after the cessation of dumping, and the fourth was in June 1983. The objectives of all four cruises were related in that similar sampling strategies and established stations were used. The later cruises focused on looking for measures of recovery by comparing 1981-1983 data with those obtained during dumping.

The emphasis of the NOAA-supported studies has been to focus on the most likely indicators of impact and recovery:

1) microbial contamination of sediments
2) pathogenic amoebae in sediments
3) viruses in sediments and organisms
4) heavy metals and gill contamination in rock crabs
5) mortality and growth rings in clams as indicators of dumping impact.

In all cases, historical trends of impact and recovery and comparison with clean and more contaminated sites have been emphasized. The rationale, methodology, and results to date of each of these components are summarized in the sections below. In all cases, support from organizations other than the NOAA Ocean Dumping Program has contributed to the studies.

3.2 Microbial Contamination of Sediments

Sewage sludge contains high concentrations of microbial contaminants, and microbial contamination is a specific and readily measurable feature of any sedimentary area where sewage particulates are disposed. O'Malley et al. (1982) have estimated total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS) bacteria in surficial sediments from the area of the Philadelphia site during 1978-1980, a period of active but decreasing dumping. These measurements have continued in the postdumping period. Standard methods were used on sediments from the top surficial layer, with three separate subsamples from each station being processed immediately after collection. A total of 400 stations in the dumpsite region were sampled from 1978-1980.

The distribution of wastewater-indicator bacteria was examined as a function of distance from the center of the dumpsite. As shown in Table 8, the percentage of TC-, FC-, and FS-positive stations generally decreased away from the center of the site. However, a slightly elevated percentage of positive stations was noted 37 km northeast and southwest of the dumpsite center, indicating significant transport of dumped materials by seasonal and wind-induced currents. The table also shows the percent of stations that were positive for amoebae.

Distributions of TC were examined with respect to mesoscale topography. Statistical analysis showed that recovery of TC was greater in the deep flank-swale stations than in the ridge-shallow flank stations. It seems, therefore, that sludge materials tend to settle preferentially in topographic lows.

The dumping load decreased during the sampling period (see Figure 2), and examination of the TC and FC data showed a general decrease in the percentage of positive stations with time from 1978 to 1980, as well as a decrease in the areal extent of positive stations. Data from the last cruise before dumping ceased in August 1980 did show an increase in FC and TC compared to measurements from earlier cruises near the dumpsite center in fall, spring, and winter, but there were no TC- and FC-positive stations beyond 9 km. Positive FS stations were, however, found beyond 9 km on this cruise. The FS organisms survive longer than TC and FC in sediments; the summer increase in TC and FC may have been a seasonal effect.

Sampling continued for three years after the dumpsite was closed (1980-1983). Table 9 (Adams, 1983) summarizes the results of sediment sampling on a total of five cruises. It is evident that a substantial number of stations both within and outside the dumpsite continue to be positive for indicator bacteria. In all cases, however, the actual counts have been far below the established minimum risk level for shellfish growing areas. As a result, the dumpsite was reopened for shellfishing in early 1984 (Verber, personal communication).

The examination for indicator bacteria in the period 1978-1982 was carried out by generally accepted standards. However, Colwell and Grimes (1983) assert that this methodology, which uses indicator bacteria to evaluate the public health status of aquatic environments, may be inadequate. For example, total coliforms may be low when tested by standard methods, but more refined methods, which involve direct counting, may yield numbers an order of magnitude or more higher. These developments are still undergoing evaluation.

3.3 Pathogenic Amoebae in Sediments

Recent studies (e.g., Sawyer et al., 1977) have documented an association between pathogenic amoebae and wastewater associated bacteria. The importance of amoebae as agents of human disease has only recently been recognized, and intensive research on them is being conducted throughout the world. Sediment samples have been cultured for amoebae as well as wastewater bacteria at the Philadelphia site (as well as many other locations in coastal and estuarine waters) since 1978. The techniques are still being refined with the goal of providing methods by which cyst-forming acanthamoeba species may be used for routine measurements on water and sediment quality. Details of the 1978-1980 studies are given in Sawyer et al. (1982).

Table 10 summarizes the distribution of bacteria and amoebae from 325 different sampling stations around the Philadelphia site. The spatial distribution of bacteria and acanthamoeba is illustrated in Figure 4. Only 2 of 28 stations positive for amoebae were outside the area positive for fecal bacteria. One of these stations was located at the inactive sludge site near Delaware Bay. In general, both acanthamoeba and bacteria tended to spread along a northeast-southwest area for considerable distances (Figure 4).

Sampling carried out in 1981 and 1982 continued to show that about 20 percent of the samples taken near and at the site were positive for amoebae. However, samples taken from the center of the site, which had yielded amoebae during dumping, were negative in 1981 and 1982, and sampling as much as 37 km to the northeast and southwest showed a higher number of positive stations than had been reported before dumping stopped. This may indicate that sewage contaminants are being dispersed away from the site by the same storms and currents that move sediments. Moreover, fewer species of acanthamoebae collected during 1981 and 1982 were capable of growing at mammalian body temperatures; this indicates that the surviving amoebae may be the less pathogenic strains.

The public health aspects of the role of pathogenic acanthamoebae in human disease have only recently emerged as worthy of new and intensified concern. Global attention is being paid to the early diagnosis of amoebic disease, to ascertaining the source of infections, and to obtaining a correct identification of the species involved.

Results of the Philadelphia survey provide the first comprehensive account of the distribution of acanthamoeba in bottom sediments of the coastal ocean. Quantitative studies on acanthamoeba in ocean sediments have not yet been accomplished. However, there is a definite positive correlation between the presence of acanthamoeba species and the presence of FC and FS. Human health implications of this correlation are not yet clear. It is unlikely that a direct threat would occur from these contaminated sediments because they are so far from shore; however, it will continue to be important to quantify the presence of amoebae and to develop quantitative comparisons between the Philadelphia dumpsite area and other locations, some cleaner and some more contaminated.

Comparative studies of the New York Bight and the Gulf of Mexico in 1973-1978 have shown that 60-80 percent of the Bight samples yielded acanthamoeba compared with 2 percent of samples from the Gulf of Mexico (Sawyer, 1982). These studies indicate that acanthamoebae species may be present in 1-2 percent of sediment samples collected from unimpacted ocean bottoms and in up to 100 percent of the samples collected from long-term sludge disposal areas.

Although the public health significance of the amoebae with respect to wastewater disposal areas remains to be determined, acanthamoeba is a potentially important pathogen in wastewater-impacted sediments. Continued studies should establish cyst-forming amoebae as useful organisms for monitoring wastewater-impacted coastal and offshore sediments and for learning more about their role as disease agents and indicators of sewage pollution.

3.4 Viruses in Sediments and Organisms

Viruses in the marine environment contribute both potential and real hazards to human health and marine organisms. Several thousand cases of water-related disease associated with viruses are documented each year, but many cases are thought to be unreported, and the actual number of cases may be many times higher. The fraction of reported cases associated with the marine environment is not documented, but residents of coastal states seem to have a higher incidence of infectious hepatitis, for example, than residents of inland states. A summary of information on viruses in the marine environment is given by Goyal (1984).

The development of methods for the identification, classification, and enumeration of viruses responsible for disease is still in its early stages. The most readily identified viruses, the so-called enteroviruses, are not responsible for most of the incidences of disease, while the more dangerous viruses such as Hepatitus A cannot yet be routinely identified in marine sediments and organisms. Methods are, however, being developed for the detection of Norwalk and Hepatitus A viruses, which are responsible for most of the recent outbreaks of viral diseases attributed to shellfish contamination.

Conventional sewage treatment may not be adequate to deal with viruses. Viruses have been detected in treated and disinfected effluents on a number of occasions. Viruses may become embedded in sludge solids and may not be rendered inactive by sludge treatment or digestion. The concentration of viruses may be several orders of magnitude higher in sludge than in wastewater, and therefore the discharge of sludge into the ocean may involve the introduction of a concentrated source of viruses into the marine environment. There are no general standards for acceptable viral concentrations in water or sediments. However, several investigators have proposed very low acceptable levels for water: one or zero infectious units per 10 gallons of recreational water. These conservative proposals reflect the ability of even one infectious unit of virus to cause disease.

During 1980-1982, samples of water, sediments, and crabs were tested for the presence of enteroviruses (Goyal and Adams, 1984). During 1980 and 1981, twenty-eight 100- to 200-gallon samples of water and 104 300- to 500-gallon samples of sediment were examined near the Philadelphia dumpsite and along a transect to the New York Bight. One sample of water and twelve samples of sediment yielded viruses as shown in Table 11. Figure 5 indicates the locations of the four stations at the Philadelphia site. Table 12 shows the relationship of viruses to conventional indicator bacteria. Clearly, fecal indicator bacteria do not adequately reflect the virological quality of water and sediments.

In 1982, thirty-nine samples of sediment and ten samples of water were taken; crabs were also examined. These analyses are not yet published, but viruses have been isolated from both sediments and crabs. Analysis of bacterial indicators show a small and decreasing number of positive stations. Viruses can therefore survive for more than 18 months in the sediments of a temperate midshelf environment as well as in bottom organisms. Analysis of samples from the June 1983 cruise did not isolate any viruses in water or sediments. Comparative data from the New York Bight indicate that a greater percentage of stations are positive for viruses and that the number of isolates per positive station is greater.

Viruses are an important environmental contaminant, but the hazards they represent are not yet known. What is specifically needed at this point is completion of methods for isolating the hazardous Norwalk and Hepatitus A viruses and the development of comparative data from enough locations to establish hazard level and survivability as functions of location and pollutant loading. Almost certainly, as this information is developed, quantitative measures of viral contamination will be established as one of the most important indicators of a polluted marine environment.

3.5 Gill Contamination and Heavy Metal Levels in Rock Crabs

Organisms living on the ocean bottom are particularly susceptible to the effects of sewage sludge disposal. The rock crab is a common and easily collectible bottom-dwelling animal, shown in past studies to exhibit clear indications of the impact of sludge dumping (Young and Pearce, 1975): severely affected specimens tend to have a hydrogen sulfide odor and blackened discoloration of the gills. Statistics of such stressed animals are difficult to establish because weakened or diseased animals are likely to be consumed by predators and removed from sample populations. Nevertheless, a comparison between clean and contaminated areas should give a minimum indication of impact. Such studies are being carried out by T. K. Sawyer at the National Marine Fisheries Service, Oxford (Maryland) laboratory.

Numerous pollutants are found in the sludge that accumulates in the gills of rock crabs, and it might be expected that such contaminants would be measurable in gill tissues as well as in other parts of the crab. In particular, heavy metals such as copper, lead, cadmium, and silver might tend to accumulate. Moreover, although one measure of the recovery of the crab might be a cleaning out of the gills, it is important also to establish whether body burdens of other contaminants are also decreasing. Studies of this type are being carried out by R. Grieg at the National Marine Fisheries Service, Milford (Connecticut) laboratory. Results from the New York Bight are given in Grieg et al. (1982).

Gill color was recorded in over 800 specimens examined during the period of sludge disposal and in over 400 specimens taken after dumping stopped. Gill blackening during dumping ranged from about 6 percent of samples collected during the period following molting activity to 10 percent of samples collected just before the molting season. Only about 1 percent of the crabs collected in 1981 and 1982 showed slight evidence of gill blackening. By contrast, up to 30 percent of the crabs examined near the more impacted New York sludge site showed gill blackening. It appears, therefore, although complete statistics have not been developed, that gill blackening is a good qualitative indicator of degree of degradation and that the gills are cleaned relatively quickly if the direct cause stops. Gill blackening may therefore serve as a readily observable indicator of the degree of bottom impact of sewage sludge disposal. Comparisons with clean "control" sites are being made and it appears that less than 1 percent of the crabs from such sites exhibit blackening.

Studies at both the Philadelphia and New York sites have provided the first documentation of Cu, Pb, Cd, and Ag concentration in the organs of rock crabs. Table 13 compares Philadelphia levels in 1976-1979 with those from 1981 and with values from the New York Bight. One clear difference is in lead levels, which are much higher in the Bight. Studies are continuing to identify environmental factors that affect metal levels. In particular, molting activity has a major influence on copper levels in gills. Studies are also being conducted on the digestive gland, where copper levels tend to be much higher than in the gills. Lead, on the other hand does not seem to be bioaccumulated in the digestive gland.

3.6 Mortality and Growth Rings in Clams

Ocean quahogs deposit distinctive annual shell layers, which can be used to provide important information about the health of the benthic community at the Philadelphia sludge site. In cross section, these layers resemble tree rings and have many of the same properties. Shells of quahogs taken live enable growth before, during, and after dumping to be compared for locations both near and remote from the dumpsite. Years of death and partial growth rings can be examined on shells of dead organisms. Methods and results are given in Thompson and Psuty (1984).

Shells were obtained in June and August 1982 from locations in and around the dumpsite. Ocean quahogs from polluted areas under and near ocean dumpsites grew faster after dumping began than before dumping, while ocean quahogs from less polluted areas north and east of the dumpsites had the reverse pattern of growth, with slower growth after the dumping started. There is no evidence that the dumping harmed the clams in any way, and the dumping may have encouraged growth by increasing the food supply. All the ocean quahogs studied had very similar year-to-year growth patterns, which correlated better with the duration of warm core Gulf Stream rings on the shelf edge than with either ocean-dumping quantities or bottom temperatures.

4. SUMMARY AND CONCLUSIONS

The studies sponsored by NOAA show a measurable and decreasing impact of dumping at the Philadelphia site. The presence and concentrations of enteric bacteria, pathogenic amoebae, and viruses are specific indicators of the presence of sewage sludge. The presence of black gills in crabs also appears to be a good indicator of the direct impact of dumping and one that ceases very quickly when dumping stops. Metal studies of sediments continue to be inconclusive, as was indicated by Oostdam (1983) for similar earlier efforts.

None of the studies that have been carried out at the Philadelphia site indicates any direct threat to human health or any widespread degradation of the ocean ecosystem. The ocean bottom has been impacted, but the degree of impact cannot be quantified. This is true to some extent of all studies of degraded oceanic ecosystems. Unlike regions around the New York dumpsite and Los Angeles outfalls, however, a very degraded bottom area cannot be identified at the Philadelphia site.

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Table 1. Comparison of metal compositions of Philadelphia and Camden sludge.[1]

Constituent	Philadelphia (mg kg^{-1}) 1973	1975	1977	1979	Camden (mg kg^{-1}) 1973-1976
Arsenic	22	1	--	--	1
Beryllium	22	2	--	--	1
Cadmium	41	70	43	54	72
Chromium	1,880	930	1,140	840	58
Copper	1,080	980	1,790	1,020	63
Iron	19,300	11,300	16,500	16,400	--
Lead	2,940	1,950	2,370	1,720	90
Manganese	1,800	895	2,080	1,400	--
Mercury	85	4.4	2.4	2	3
Nickel	300	230	250	380	12
Selenium	371	12	--	--	0
Vanadium	27	40	--	--	5
Zinc	5,840	4,040	5,380	4,510	270

[1] From Muir, 1983.

Table 2. Trace metal concentration (mg/kg) in sediments at grid stations.[1]

Survey	Chromium	Copper	Nickel	Lead	Zinc
Dec. 1975					
Mean	2.39	0.54	1.52	3.67	4.55
Low	0.98	0.05	0.15	0.74	0.92
High	4.77	1.96	3.38	10.28	9.73
Aug. 1976					
Mean	3.40	--	1.02	2.17	6.12
Low	1.60	--	0.25	0.45	2.43
High	6.07	--	2.43	4.13	12.83
Feb. 1977					
Mean	2.78	0.95	1.76	3.01	6.98
Low	1.33	0.20	0.40	0.40	1.73
High	5.33	3.278	3.53	6.73	15.20

[1] From Guarino et al., 1979.

Table 3. Trace metal concentrations (mg/kg per dry weight) in sediments.[1]

Survey	Lead	Chromium	Nickel	Zinc	Zirconium	Copper	Cadmium	Manganese
May 1973	1	2.1	1	7	na	1	1	29
Nov. 1973	3.6	2.5	1	5	na	1	1	33
March 1974	4.1	2.3	1.2	5.6	na	1	1	37
Aug. 1974	3.3	1.7	1.3	5.1	na	0.63	0.09	32
Dec. 1975	3.39 ± 1.69	3.50 ± 1.27	1.38 ± 1.03	4.15 ± 1.80	na	0.40 ± 0.39	0.09 ± 0.11	na
Aug. 1976	1.0 ± 0.8	3.3 ± 1.1	0.5 ± 0.5	4.7 ± 2.4	5	na	na	na
Feb. 1977	2.2 ± 1.3	2.2 ± 1.1	1.5 ± 0.8	6.4 ± 2.7	na	0.7 ± 0.4	na	na

[1] From Guarino et al., 1979.

Table 4. Comparison of physical and chemical parameters in dumpsite and reference grids.[1]

Parameters	Mean	Standard deviation	Range	Mean	Standard deviation	Range	t-Statistic	Degrees of freedom
Depth (m)	61.5	11.0	44.2 -85.4	65.6	10.0	48.8 -83.9	1.57	41
Median grain size (phi)	1.25	1.07	-1.60- 2.51	1.53	0.35	0.85- 2.12	1.06	31
Percentage fines	2.66	3.31	0.16-12.1	0.71	0.87	0.13- 3.71	2.45[a]	31
Lead (mg kb^{-1})	3.28	1.59	0.74- 6.70	1.82	0.92	0.40- 4.80	3.66[a]	41
Copper (mg kg^{-1})	1.52	0.56	0.93- 2.90	1.07	0.21	0.87- 1.67	3.45[a]	41
Chromium (mg kg^{-1})	3.57	1.01	2.20- 5.87	3.47	0.82	2.23- 5.17	0.34	41
Zinc (mg kg^{-1})	6.69	2.84	2.87-13.4	6.43	1.86	3.93-11.3	0.35	41
Nickel (mg kg^{-1})	1.21	0.86	0.23- 3.47	1.24	0.61	0.31- 2.50	0.13	41
Silver (mg kg^{-1})	0.1			0.1				
Organic carbon (mg kg^{-1})	1330	1000	270-4480	830	440	380-2160	2.10[a]	41
PCB (ng g^{-1})	18.9	9.2	7.5 -34.0	11.8	4.9	7.1 -18.4	1.68	10

[1] From Lear and O'Malley, 1983a.

Table 5. Comparative sediment trace metal (mg/kg per dry weight) data.[1]

Location		Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Wastewater sludge from 17 plants	Gross, 1970	--	1 450	1 150	540	260	1,760
Wastewater sludge dumpsite	Carmody et al., 1973	--	209	240	262	37	415
Sandy New York Bight sediment	Carmody et al., 1973	--	6	3	12	3	18
Hempstead survey	Udell et al., 1974						
East dumpsite		2.5	29	42	59	8	84
Control		0.1	5	2	10	3	12
Acid waste disposal area	Vaccaro et al., 1972						
Station three		1.3	34	15	37	8.2	41
Control		0.2	5.5	1.8	7.5	1.2	7
Hudson Canyon		2.3	130	83	110	11	170
Alternate disposal site	Raytheon 1976						
Stations 1-5[a]		1	4.4[b]	7[b]	9[b]	12[b]	8.4
Deepwater ("106") disposal area							
Stations A1-6		--	25.2	28.6	26.5	25.6	55.6
Test stations (on shelf)		--	6.7	3.0	7.0	3.7	14.0

1 From Guarino et al., 1979.
a Mean of all stations.
b Detectable and less than values averaged for conservative mean.

Table 6. Analysis of variance of lead concentrations in sediments as a function of topography.[1]

Cruise	Ridge	Flank	Swale	F
February 1975	2.79 (7)	2.28 (14)	4.02 (8)	4.95*
December 1975	2.75 (25)	3.32 (45)	4.88 (42)	26.33**
February 1977	1.69 (16)	2.57 (23)	3.66 (16)	12.72**
August 1977	2.41 (10)	2.10 (30)	-3.53 (14)	6.47**
April 1978	1.59 (17)	1.77 (22)	4.17 (20)	23.18**
ALL DATA	2.25 (75)	2.41 (134)	4.05 (100)	58.03***

1 From Lear et al., 1983b.
* Significant at p less than 0.05.
** Significant at p less than 0.01.
*** Significant at p less than 0.001.
___ Underline indicates no significant difference (p less than 0.05) by the Student-Neuman-Keuls test.
( ) Numbers in parentheses are number of stations.

Table 7. Trace concentrations (mg/kg per dry weight) in clams.[1]

Survey	Cadmium	Copper	Nickel	Vanadium
IDES (Mar. 1974)	2.22[a] (1.48-4.01)[b]	8.52 (6.64-11.30)	8.74 (4.21-13.36)	10.63 (4.26-20.63)
Deep six (Aug. 1974)	2.15 (1.61-4.31)	9.20 (13.23- 4.47)	8.42 (4.04-18.37)	2.56 (1.57- 4.31)
Midwatch (Feb. 1975)	2.82 (1.06-4.09)	5.71 (4.44- 7.51)	10.66 (5.42-29.29)	2.47 (1.63- 3.11)
Dragnet (June 1975	2.29 (1.41-3.60)	7.32 (4.52- 9.25)	8.01 (3.05-22.65)	2.09 (1.26- 2.88)

[1] From Guarino et al., 1979.
NOTE: Dry weight is approximately 10 to 15% of wet weight.
[a] Mean of all stations (excluding values at the limit of detection).
[b] Range.

Table 8. TC, FC, FS, and Amoebae (Am) data by cruise as a function of distance from the dumpsite.[1]

Distance in km	0-9	9-14	14-19	19-23	23-28	28-41
Date 4/78						
TC positive/total	12/13	2/12	3/10	0/12	0/5	4/9
FC positive/total	9/13	0/12	1/10	0/12	0/5	1/9
AM positive/total	5/13	2/12	0/10	0/12	0/5	0/9
Percent TC positive	92	17	30	0	0	44
Percent FC positive	69	0	10	0	0	11
Percent Am positive	38	17	0	0	0	0
Percent AM positive	38	17	0	0	0	0
Date 9/78						
TC positive/total	6/20	2/10	0/3	0/2	0/1	1/4
FC positive/total	5/20	0/10	0/3	0/2	0/1	1/4
AM positive/total	4/9	0/5	0/2	0/2	--	0/2
Percent TC positive	33	20	0	0	0	25
Percent FC positive	25	0	0	0	0	25
Percent Am positive	44	0	0	0	--	0
Date 10/78						
TC positive/total	4/13	11/43	8/56	6/48	1/6	1/6
FC positive/total	4/13	8/43	3/56	3/48	0/6	0/6
AM positive/total	1/5	0/1	0/1	0/5	--	--
Percent TC positive	31	25	14	13	17	17
Percent FC positive	31	19	5	6	0	0
Percent Am positive	20	0	0	0	--	--
Date 4/79						
TC positive/total	2/9	1/3	0/7	0/8	2/10	1/10
FC positive/total	0/9	0/3	0/7	0/8	0/10	1/10
AM positive/total	5/11	2/3	0/7	0/6	1/6	0/6
FS positive/total	2/7	1/2	--	--	0/2	0/1
Percent TC positive	22	33	0	0	20	10
Percent FC positive	0	0	0	0	0	10
Percent Am positive	45	67	0	0	17	0
Percent FS positive	28	50	--	--	0	0
Date 11/79						
TC positive/total	2/14	0/5	0/5	0/4	0/4	0/6
FC positive/total	0/14	0/5	0/5	0/4	0/4	0/6
AM positive/total	2/4	1/4	--	--	--	1/3
FS positive/total	1/7	1/2	0/1	0/1	0/4	0/5
Percent TC positive	14	0	0	0	0	0
Percent FC positive	0	0	0	0	0	0
Percent Am positive	50	25	--	--	--	33
Percent FS positive	14	50	--	--	0	0

1 From O'Malley et al., 1982.

Table 8 (continued).

Distance in km	0-9	9-14	14-19	19-23	23-28	28-41
Date 8/80						
TC positive/total	5/11	0/1	0/5	0/5	0/4	0/9
FC positive/total	2/11	0/1	0/5	0/5	0/4	0/9
AM positive/total	5/10	0/1	1/5	0/5	0/4	0/8
FS positive/total	3/10	0/1	0/5	0/5	1/4	1/9
Percent TC positive	45	0	0	0	0	0
Percent FC positive	18	0	0	0	0	0
Percent Am positive	50	0	20	40	0	0
Percent FS positive	30	0	0	0	25	11

Table 9. Comparative bacterial sludge indicators isolated from Philadelphia Dumpsite stations.[1]

Survey	DUMPSITE STATIONS			TOTAL CRUISE STATIONS		
	Site stations	Indicator position stations	% Positive stations	Sampling station	Indicator position sites	% Positive stations
August 1980	7	5	71	34	8	23
May 1981	8	2	25	47	5	11
August 1981	4	2	50	7	3	43
June 1982	8	7	87	34	19	56
June 1983	9	5	55	46	11	24

1 From Adams (1983)

Table 10. Summary of cruises and sediment collections in Philadelphia-Camden wastewater sludge disposal site, including control stations.[1]

Cruise no.	Date	No. of samples*	No. with coliforms	No. with fecal coliforms	No. with fecal streptococci	No. with amoebae
1	Apr. 1978	80	20	11	Not done	8/78
2	Aug. 1978	9	Not done	--	Not done	2/9
3	Oct. 1978	172	30	18	Not done	1/12
4	Sept. 1978	56	9	6	Not done	4/32
5	Apr. 1979	48	5	1	3/48	8/44
6	Sept. 1979	10	Not done	--	Not done	5/10
7	Nov. 1979	48	3	0	4/48	4/21
8	Feb. 1980	3	Not done	--	Not done	0/3
9	Aug. 1980	34	5	2	5/34	8/20
TOTAL		460	72/438 (16%)	38/438 (8.7%)	12/130 (9%)	40/229 (17.5%)

1 From Sawyer et al. (1982).

* Total number samples taken from 325 different stations.

Table 11. Isolation of viruses from Philadelphia Dumpsite and the transect of the New York Bight.[1]

Year	Station No.	Depth (M)	Virus type	Number of viral isolates per KG of sediment
1980	8	46	Echo 1	20
	G-19	65	Unidentified	46
	80-6	25	Coxsackie B3	50
	SH 45	18	Coxsackie B5	15
	KN 49	58	Coxsackie B5	12
	KN 49	58	Coxsackie B3	2
1981	E-12	49	Polio 2	12
	205	57	Echo 9	8
	80-6	27	Echo 1; Polio 2	22
	81-11	21	Polio 2	30
	81-14	21	Coxsackie B5	8
	KN 46	42	Echo 1	56
	KN 50	24	Echo 1	4

1 From Goyal, 1984.

Table 12. Relationship of virus isolation with indicator bacteria.[1]

Virus positive stations	Indicator Bacteria/100 ml[a]				
	Water		Sediment		
	TC	FC	TC	FC	FS
8	ND[b]	ND	60	60	BL[e]
G-19	ND	ND	BL[e]	ND	BL[e]
80-6	BL[d]	BL[d]	60	BL[e]	270
SH 45	8	BL[d]	620	230	2400
KN 49	3	ND	BL[e]	ND	BL[e]
KN 49	3	ND	BL[e]	ND	BL[e]
E-12	ND	ND	BL[e]	BL[e]	60
205	ND	ND	BL[e]	BL[e]	BL[e]
80-6	BL[d]	BL[d]	BL[e]	BL[e]	BL[e]
81-11	10	7	60	BL[e]	BL[e]
81-14	BL[d]	BL[d]	130	BL[e]	60
KN 46	ND	ND	BL[e]	BL[e]	BL[e]
KN 50	TNTC[c]	ND	2400	60	ND

[1] From Goyal, 1984.
[a] Most probable numbers; TC = total coliform;
FC = fecal coliform;
FS = fecal streptococci
[b] Not done.
[c] Too numerous to count.
[d] Below detection limit of 1
[e] Below detection limit of 46

Table 13. Means and standard deviations of metal concentrations at the Philadelphia and New York dumpsites.[1]

		Metal Concentrations (PPM)			
		Co	Cd	Ag	Pb
Philadelphia 1976-1979 (N = 50)	X	33.5	0.82	0.72	*
	SD	19.8	0.64	0.56	
Philadelphia May 1981 (N = 45)	X	20.1	1.10	0.76	**
	SD	12.2	0.50	0.52	
New York Bight 1978-1980 (N = 97)	X	22.5	0.7	0.9	3.8
	SD	14.4	0.4	0.7	6.9

1 From Griet et al. (1982) and Grieg and Sawyer (1982)
* 9 crabs had concentrations greater than 1; maximum was 6.8.
** 8 crabs had concentrations greater than 1; maximum was 3.5.

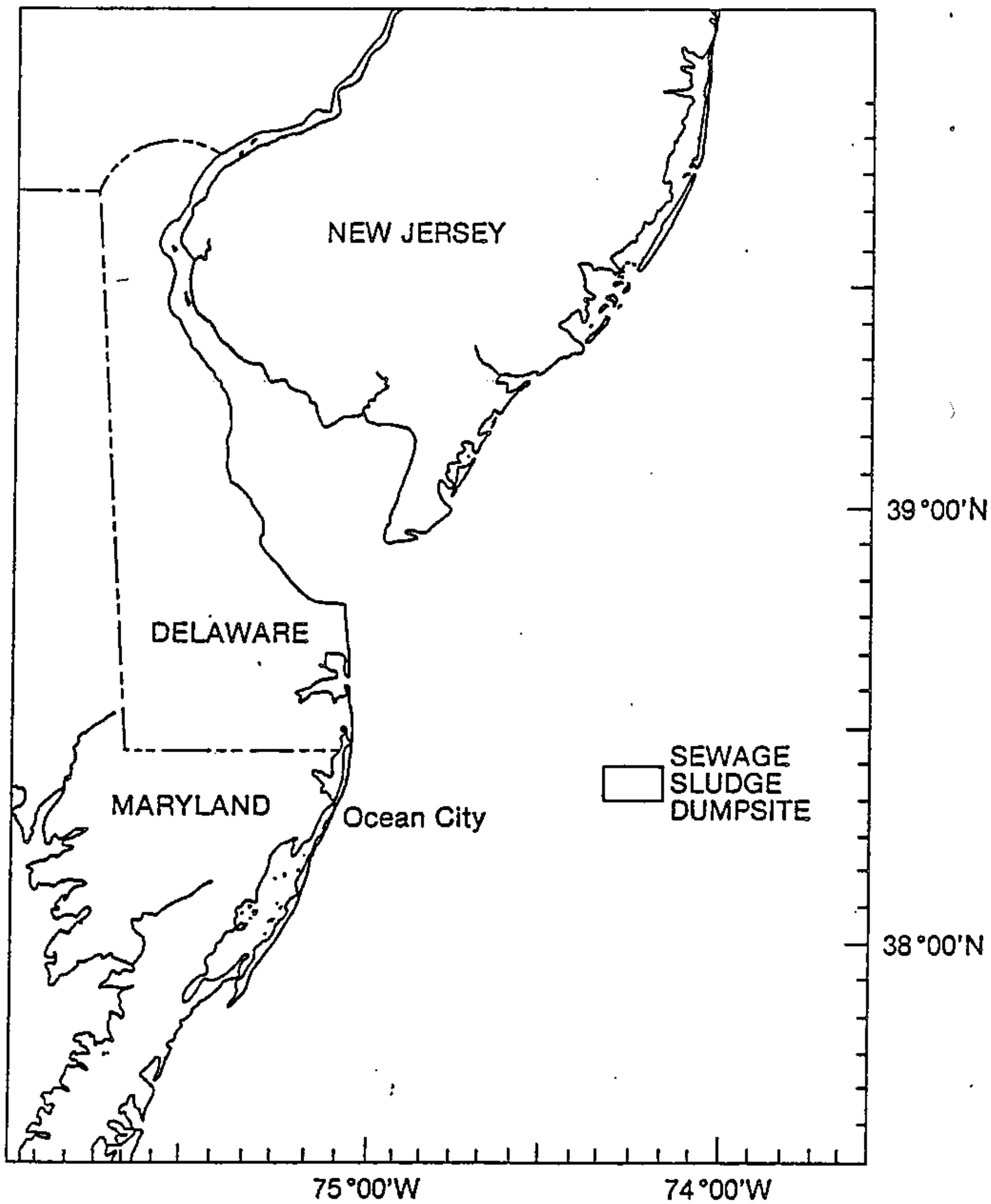

Figure 1. Philadelphia Sewage Sludge Dumpsite

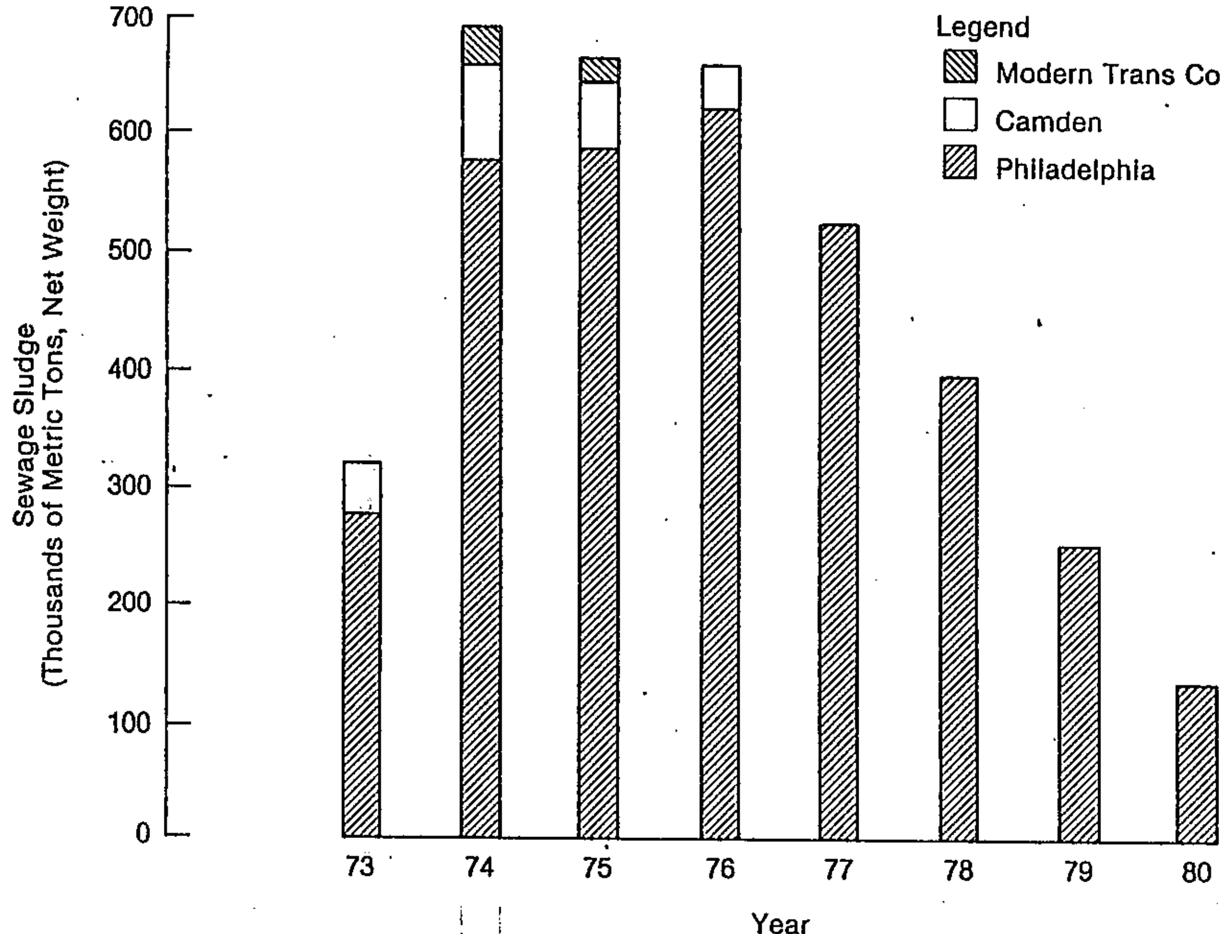

Figure 2. (from Muir, 1983) Dumping at the Philadelphia sewage sludge dumpsite.

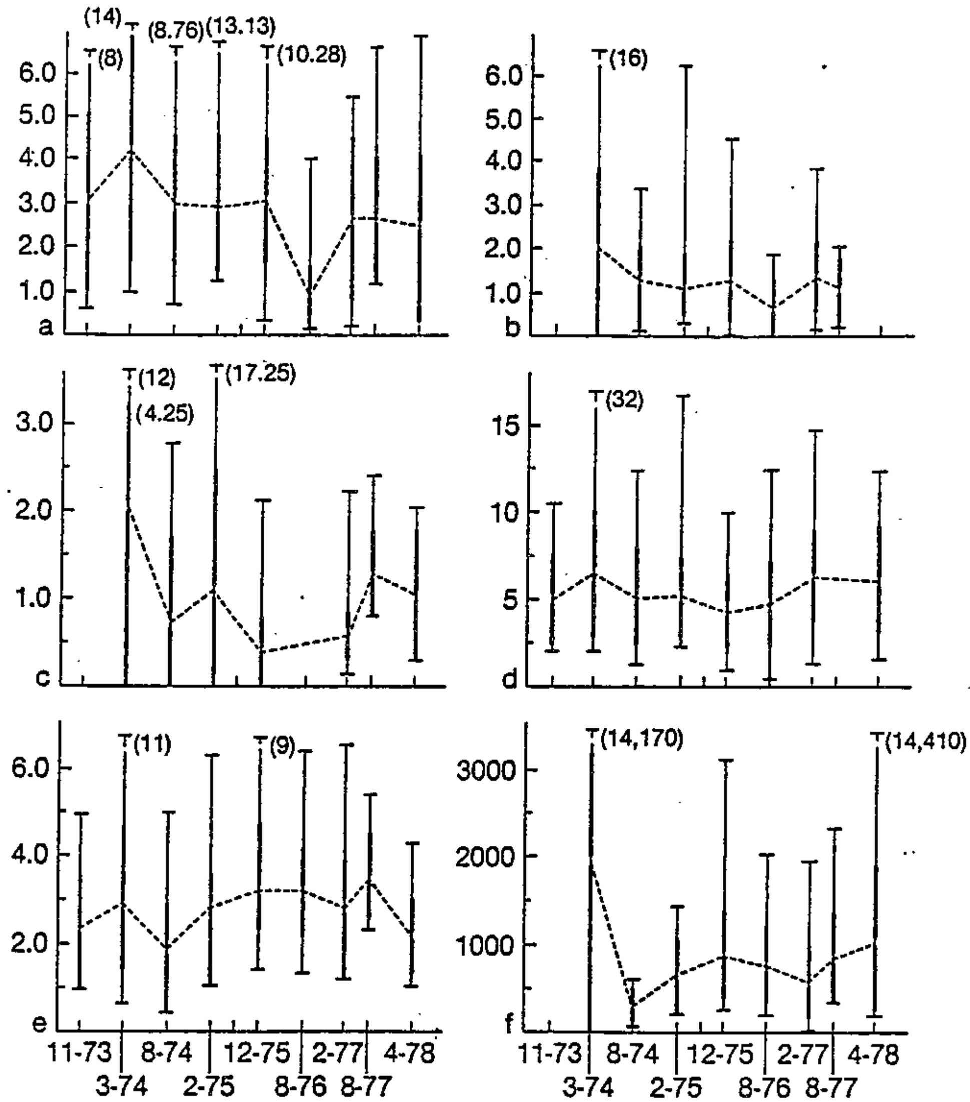

Figure 3. (from Lear et.al., 1981) Ambient midshelf concentrations of metals and TOC in sediments. Means between sampling dates are connected; standard deviation is shown by vertical heavy bars, and vertical thin lines show range. Concentrations are mg/kg dry wt. –a, Pb; b, Ni; c, Cu; d, Zn; e, Cr; and f, TOC.

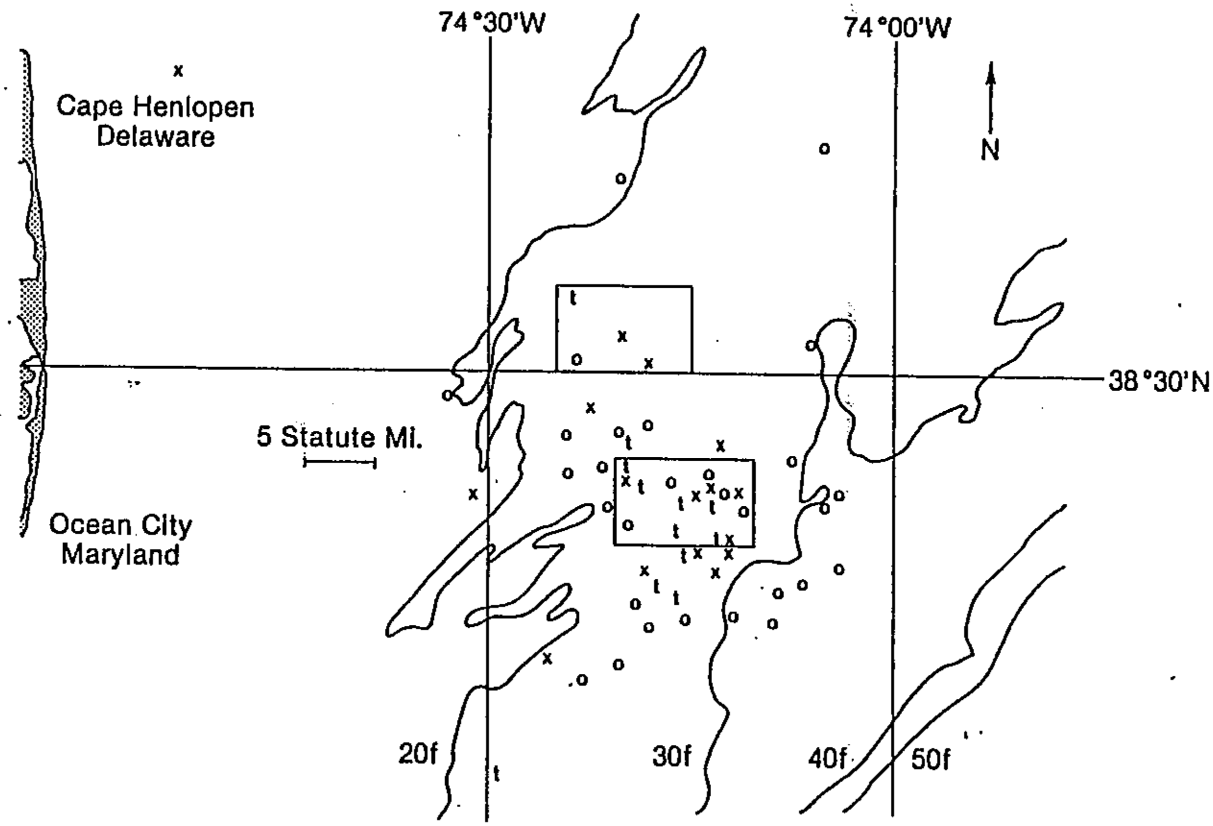

Figure 4. (from Sawyer et.al., 1982) Distribution of wastewater-associated bacteria and *Acanthamoeba* in Philadelphia-Camden wastewater sludge disposal site in Northeast Atlantic Ocean. Upper box outlines an inactive acid dumpsite. Legend: x = *Acanthamoeba* only, o = fecal coliform bacteria only, t = *Acanthamoeba* and fecal coliforms.

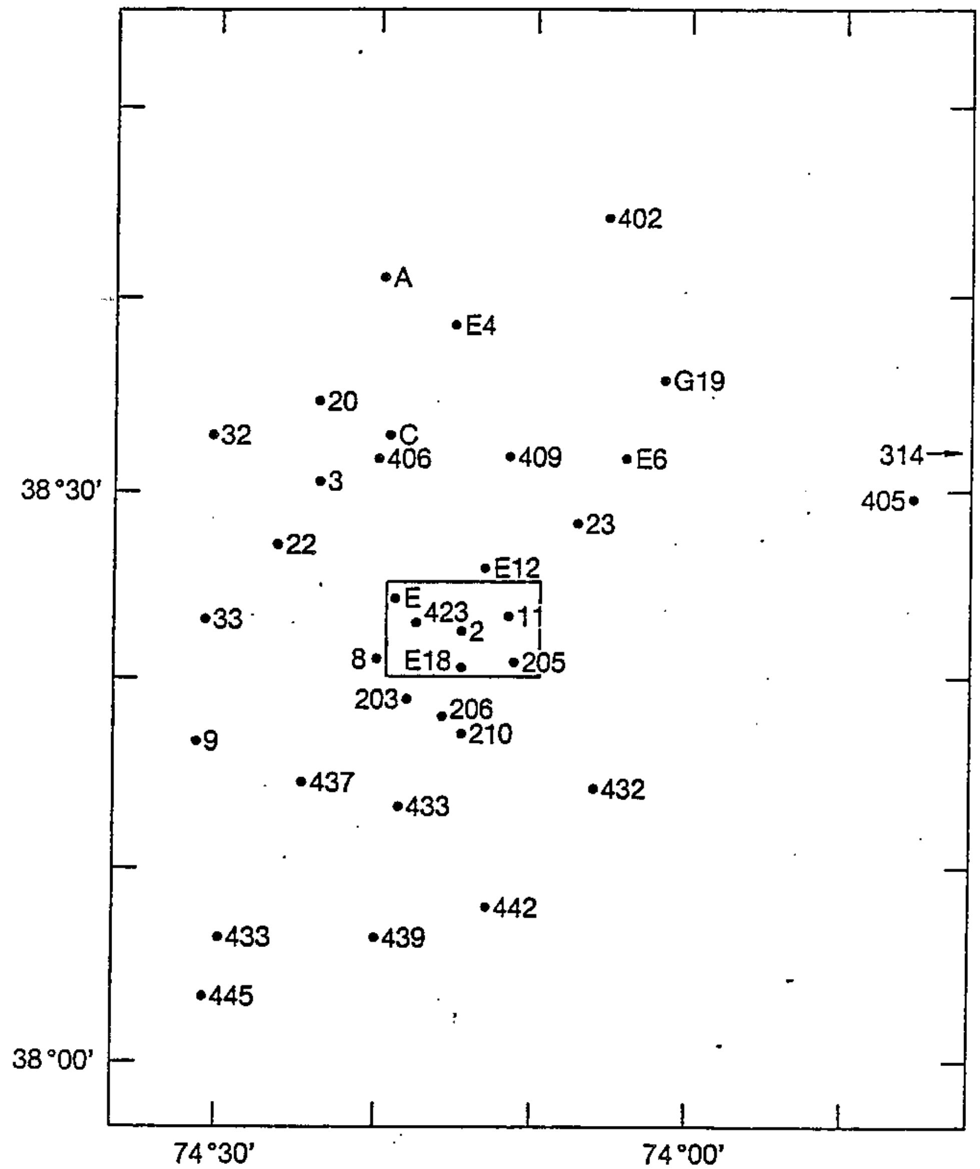

Figure 5. (from Goyal, 1983) Location of stations at and near the Philadelphia Dumpsite. The box encloses the boundaries.