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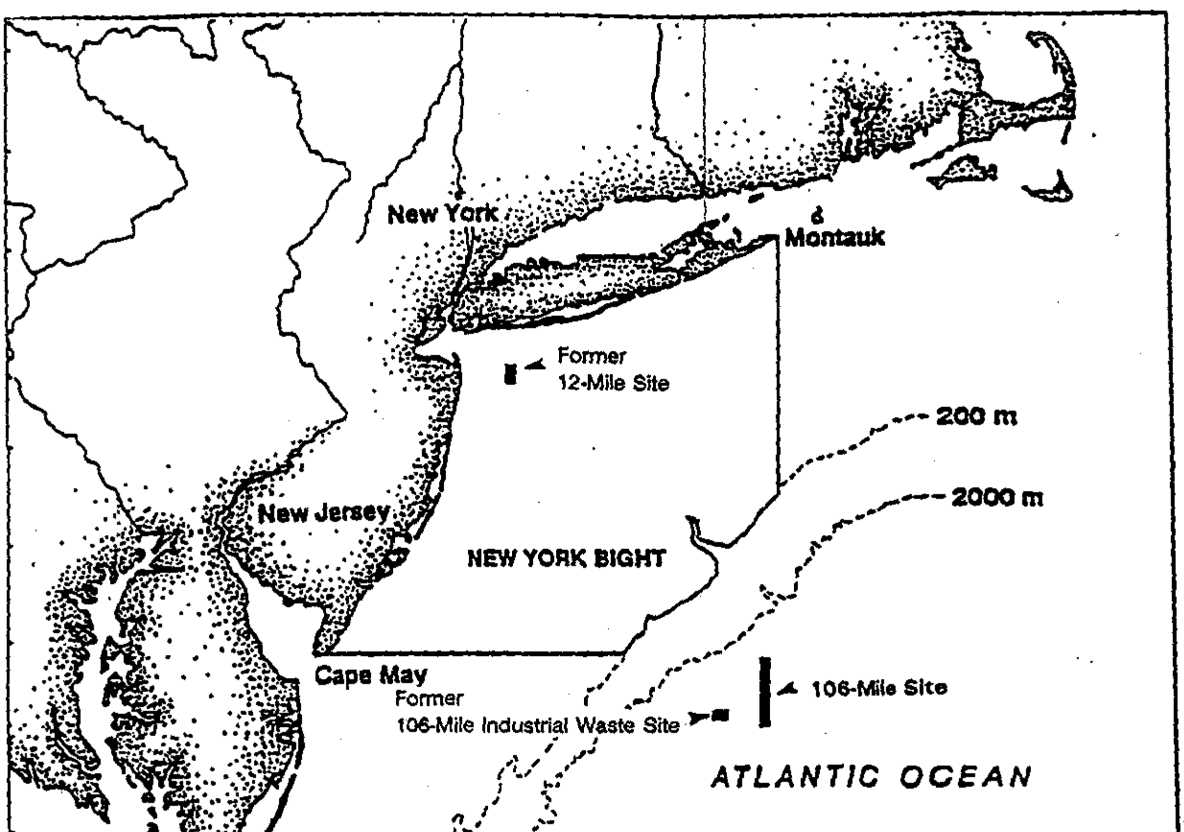
Monitoring, Research, and Surveillance of the 106-Mile Deepwater Municipal Dump Site and Environs

Report to Congress



EXECUTIVE SUMMARY

The only deep ocean disposal site designated by the U.S. Environmental Protection Agency (EPA) for barge-based disposal of municipal sewage sludge was the 106-Mile Deepwater Municipal Sludge Dump Site (106-Mile Site). Sludge disposal at the 106-Mile Site began in 1986 as a result of the phasing out of sludge disposal operations at the 12-Mile Site located in the New York Bight. Transition of sludge disposal from the 12-Mile Site to the 106-Mile Site was completed in 1987. From 1988 to 1990, 8-10 million wet tons of sludge were dumped at the 106-Mile Site each year. The amount of sewage sludge disposed at the Site decreased in 1991 and 1992 as a result of the Ocean Dumping Ban Act of 1988 (ODBA) requirement that ocean disposal of sewage sludge stop by December 1991. All sewage sludge disposal at the 106-Mile Site ended in June 1992.

In addition to requiring the cessation of ocean disposal of sewage sludge, the ODBA also mandated that EPA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Coast Guard (USCG) design a monitoring program for the 12-Mile Site, the 106-Mile Site, the industrial waste sites, and other areas that might be impacted by dumping. The monitoring program was mandated to assess the potential impact of sludge disposal on the marine environment, particularly the effects on living marine organisms. The required monitoring program was to include (1) sampling an appropriate number of fish and shellfish species and other organisms to assess the effects of environmental conditions on living marine organisms in these areas and (2) use of satellite and other advanced technologies to conduct the program. In response to this mandate, EPA, NOAA, and the USCG jointly revised the EPA monitoring plan in use at the time, and designed and implemented a comprehensive monitoring, research, and surveillance plan entitled the *Monitoring, Research, and Surveillance Plan for the 106-Mile Deepwater Municipal Sludge Dump Site and Environs* (EPA, 1990a). This joint Monitoring Plan was implemented in the spring of 1990, and monitoring and surveillance activities continued through June 1992 when ocean dumping of sewage sludge ended. Additional research studies were conducted in the summer of 1993.

The joint Monitoring Plan was organized into four areas labeled as tiers. *Tier 1: Waste Characteristics and Disposal Operations* was concerned with monitoring the waste characteristics and disposal operations. *Tier 2: Nearfield Fate and Short-Term Effects* focused on the nearfield fate and short-term effects of sludge. *Tier 3: Farfield Fate* addressed the long-term, farfield fate of sludge constituents and *Tier 4: Long-Term Effects* was concerned with resultant long-term environmental effects. A series of monitoring questions was formulated and grouped hierarchically within the four tiers of the joint Monitoring Plan. The major emphasis of the joint Monitoring Plan was placed on determining the farfield transport and fate of the sewage sludge (Tier 3), and potential long-term effects and environmental impacts (Tier 4). Among the sponsoring agencies of the joint Monitoring Plan, EPA assumed most of the responsibilities for Tier 3 activities, while NOAA was the principal agency addressing the hypotheses under Tier 4.

Several Reports to Congress related to the 106-Mile Site monitoring program were developed during the joint monitoring program and include: draft *Report to Congress on the Progress Towards Ending Ocean Dumping of Sewage Sludge*; draft *Report to Congress on the 106-Mile Site Monitoring Program: Monitoring Results from 1988 to August 1990*; and draft *Report to Congress on the 106-Mile Site Monitoring, Research, and Surveillance Results: August 1990 through October 1991*. This Final Report to Congress replaces the previous draft reports and provides a comprehensive summary of the findings of the 106-Mile Site monitoring program as related to the monitoring hypotheses, results, and management actions. This document, in concert with peer-reviewed scientific papers, fulfills commitments in the joint Monitoring Plan to disseminate findings from the monitoring program to both the scientific community and interested public sectors.

SLUDGE DISPOSAL

Sewage sludge dumping was phased in at the 106-Mile Site beginning in 1986. Dumping at both the 12-Mile Site and 106-Mile Site continued through 1987. The total annual volume of sewage sludge dumped at these two Sites increased from ≈7.7 to 8.8 million wet tons between 1986 and 1988. From 1988 through 1990, the volume of sludge dumped at the 106-Mile Site remained relatively constant at 9-10 million wet tons of sludge per year. Phase out of the disposal operations reduced the annual volume dumped from 7 million wet tons in 1991 to 2 million wet tons in 1992. No sludge was dumped after June 1992.

Nine sewerage authorities from the greater New York City area and northern New Jersey were authorized to use the 106-Mile Site for sewage disposal. Between 1986 and June of 1992, these authorities transported and dumped ≈42 million wet tons of sewage sludge at the 106-Mile Site. The largest amount of sludge (≈22 million wet tons) was dumped by New York City Department of Environmental Protection. Each of the other permittees contributed less than 6 million wet tons to the total load at the Site; three permittees dumped less than 900,000 wet tons. On a dry weight basis, a total of 1.5 million tons of sludge was dumped at the Site. Passaic Valley Sewerage Commission contributed the second largest input on a dry weight basis (450,000 dry tons), nearly the same amount dumped by the New York City Department of Environmental Protection (575,000 dry tons). More than 70% of the total dry tonnage of sludge dumped at the 106-Mile Site was contributed by these two permittees. The remaining permittees each dumped less than 130,000 dry tons.

FINDINGS

The remainder of this executive summary presents major findings from the 106-Mile Site monitoring, research, and surveillance activities. These findings address fundamental questions evaluated during the 1989

EPA/NOAA/USCG 106-Mile Site Workshop, including

1. What is the physical and chemical fate of the sewage sludge dumped at the 106-Mile Site?
2. What is the effect of the sludge dumped at the 106-Mile Site on living marine resources?

The results from the monitoring program substantiate many of the predictions made during the site designation process regarding sewage sludge behavior, transport, fate, and effects. The high quality data collected during the monitoring program (1) resulted in a more comprehensive understanding of the predictions and (2) significantly increased the database on deep-sea sediments, benthic infauna communities, fish and bacterial communities, and the physical processes operating in the environs of the 106-Mile Site and the outer continental shelf. Future programs and studies of similar scope will greatly benefit from this extensive set of new information.

COMPLIANCE

During the period that sewage sludge was dumped in the ocean, EPA required that permittees using the ocean to dispose of sewage sludge regularly provide sludge characterization data. In 1989, EPA evaluated the type of measurements, reporting frequency, and data quality for sludge characterization monitoring ongoing since 1984. Special sludge characterization studies were conducted to verify that the sludge characteristics data were adequate to meet the monitoring program goals. These special investigations determined that the data and reporting requirements were inadequate. As a result, new program-specific requirements for sludge characterization monitoring were developed. These requirements, which included modified sampling and analysis methods, and required that all analyses be conducted under approved quality assurance plans, were included as part of the permits issued in August 1989 for sewage sludge disposal at the 106-Mile Site.

The required sludge characterization measurements revealed that the sludge quality was generally similar to the sludge as characterized by measurements performed in the mid-1980s. As found previously, physical and chemical characteristics of the sludges were highly variable both within permittees and among the various treatment facilities. Between 1990 and 1991, several of the sludges were found to be more toxic to marine species than in 1989 when permits were issued; other sludges were characterized as less toxic. The timely receipt of sludge characterization data was effective for evaluating changes and making decisions regarding the rate at which sludge could be dumped in the ocean. The detection of potential sludge-associated metals and organic contaminants in sediment samples obtained from the vicinity of the 106-Mile Site, coupled with inadequate information obtained from the Tier I characterization monitoring, necessitated more detailed sludge characterization measurements. These detailed studies contributed significantly to the evaluations completed under Tiers 3 and 4.

As part of the process to develop conditions for the permits required by the ODBA, EPA evaluated whether the dumping rates in effect prior to the ODBA would result in compliance with the requirements of the ocean dumping regulations. Nearfield water quality compliance studies established that, under the conditions initially set for sludge disposal (*i.e.*, a dumping rate of 15,500 gal/min), concentrations of sludge constituents frequently did not meet regulatory requirements established by the ocean dumping regulations. As a result, the permittee dumping rates were lowered to ensure that water quality criteria were met at all times and that pathogen concentrations in the water column were reduced. Ongoing bioassay study results provided by the permittees were used in a mathematical formulation that linked dumping rates to sludge quality and enabled quarterly adjustments in the disposal rates, thereby ensuring that water quality criteria and conditions of the ocean dumping regulations were met.

In general, disposal operations were conducted in a manner that was consistent with the ocean dumping regulations and permits. However, in response to concerns of short dumping practices at the site and public concerns over sludge transfer in the Harbor, EPA determined that surveillance of all dumping activities was necessary. This was successfully completed with a cradle-to-grave manifest, seal system, and shiprider program that focused on the sludge transfer activities within the greater New York/New Jersey Harbor. This program supplemented the electronic monitoring system known as the Ocean Dumping Surveillance System developed by the USCG, and was effectively used to determine whether dumping at the 106-Mile Site was in compliance with the permits and regulations. EPA issued a number of administrative actions and fines when violations of the permit conditions were identified.

SLUDGE FATE

Nearfield Fate and Short-Term Effects. Early in the program, monitoring results indicated that sewage sludge could be transported out of the Site in the surface waters before sludge constituents were adequately diluted. Under certain oceanographic conditions, sludge constituents that were of ecological concern exceeded relevant water quality criteria outside of the Site boundaries and, on occasion, within the 106-Mile Site four hours after disposal. To ensure that water quality criteria were met under all conditions, barge dumping rates were reduced. Dumping rates were allowed to vary depending on plume dilution rates and a mathematical formulation that related sludge toxicity and the dilution rates to dumping rates. A limited set of effects measurements determined that plume dilution reduced the sludge toxicity rate below levels of concern within the four-hour post-disposal period allowed by the ocean dumping regulations.

Settling of some of the sludge from the surface waters was detected during the nearfield fate studies and by other investigations that focused on the seabed within the Site. These findings led, in part, to the extensive set of results summarized under the farfield fate and long-term effects elements of the monitoring program.

Farfield Fate. An extensive field and analytical program was developed to assess the transport and farfield fate of the sludge. The program included (1) weekly deployment of satellite-tracked surface drifters to determine movement of surface waters and potential for onshore transport, (2) satellite imagery of sea-surface temperature to determine the water masses in which dumping occurred and the relationship of these water masses to the surface water movement, (3) an array of deep-sea moorings instrumented with current meters and sediment traps to directly assess the transport and fate of the sludge, (4) sediment sampling in canyons of the outer continental shelf and the continental slope and rise areas potentially impacted by sludge to determine if and where the sludge could be found in the sediments, and (5) numerical, circulation, and probability modeling of the sludge transport and fate. The major findings from these studies include the following:

- Deployment of satellite-tracked surface drifters over an 18-month period and associated satellite sea-surface temperature measurements demonstrated that sludge particles in the surface waters were not transported beyond the continental shelf break and did not reach the shoreline of the northeastern United States.

- An array of deep-sea sediment traps deployed in the vicinity of the 106-Mile Site demonstrated significant flux of sludge-related material to the seabed. Highest fluxes were near the Site and were detectable 110 km southwest of the site. The sediment trap program also demonstrated that dispersion of the sludge to the north and south was confined to a relatively narrow band and probably did not move onto the continental shelf.

- Chemical measurements of the sediments collected within and near the Site revealed substantial increases in the concentrations of certain metals and organic compounds that are commonly found in sewage sludge. Compared to reference areas northeast of the Site, highest concentrations were confined to a relatively small area within 10-20 km southwest of the Site. The sediment concentrations rapidly decreased to background levels towards the southwest, in the direction of the long-term net water column transport. Metals and organic compounds in the surface sediments did not show the same footprint as observed for *Clostridium perfringens*.

- Measurements of other sewage sludge tracers also demonstrated that the sludge could reach the sediments in the vicinity of the 106-Mile Site. These measurements include stable isotopes of carbon, sulfur, and nitrogen, and sediment oxygen consumption rates which increased at least two-fold relative to background levels in the areas receiving the most input of sludge. Each of these increases suggests a significant input of terrestrial organic matter.

- Broad-scale sampling of the surface sediments of the outer continental shelf, continental slope, and deep-sea sediments north, south, and west of the site demonstrated a distinct *Clostridium perfringens* footprint extending to the west and south of the Site; *Clostridium perfringens* is a spore-forming bacterium common to mammals and known to be associated with sewage wastes. Outside of this footprint, concentrations of *Clostridium* were typical of pre-disposal conditions. High concentrations of

Clostridium perfringens spores were also measured in submarine canyons on the outer continental shelf, but these levels could not be linked to disposal activities at the 106-Mile Site.

- Monitoring found evidence of chemical and bacterial contamination in the heads of the submarine canyons on the outer continental shelf. However, for these sludge tracers, there was no evidence of a concentration gradient with distance from the 106-Mile Site. Thus, the anthropogenic signatures in these sediments could not be linked to the disposal activities at the 106-Mile Site. The presence of metal and organic contaminants and sewage bacterial indicators in these canyons clearly demonstrated inputs from anthropogenic sources. The consensus of the scientific investigations conducted in this geographic region was that these contaminant signatures were probably derived from offshore transport of particles or down-canyon movement of sediments contaminated by disposal activities in the New York Bight and from atmospheric inputs.

- Numerical transport and circulation models that incorporated measurements of the physical oceanographic conditions collected during the monitoring program and settling rates of sludge particles estimated that a significant fraction of the sludge would settle to the seafloor within 50 km of the Site. The depositional footprint of sludge derived from the transport models was similar to the *Clostridium* distributions measured in the sediment. Uncertainty in the actual settling rates of the sludge particles resulted in a wide range in estimates of the amount of sludge reaching the seafloor. Model predictions ranged from 20 to 70%, depending on the particle settling rates used. Circulation models suggested that sludge particles not reaching the seafloor in the vicinity of the Site were moved to the Gulf Stream and were transported out of the region. Independent mass balance estimates developed from the sediment trap data and several unique chemical tracers of the sludge suggested that at least 30% of the sludge dumped at the 106-Mile Site reached sediments in the vicinity of the Site. Probability models of the transport of sludge particles onto the continental shelf determined the transport potential to be extremely small (<0.0001).

Post-disposal monitoring studies (summer 1993) found diminished evidence of sludge. Findings of these post-disposal studies include the following:

- Sediment samples collected near the Site one year after sludge disposal stopped indicated that organic contaminants and silver remained at levels similar to those measured in 1989. The data suggested that linear alkyl benzenes (LABs), a class of chemical compounds found to be one of the best tracers of sewage sludge in this environment, had decreased disproportionately to other contaminants and thus may have undergone degradation.

- Sediment oxygen consumption rates in the areas receiving the highest input of sludge had returned to background levels one year after disposal stopped. These dramatic results indicate that the organic matter from the sludge that reached the sediments was rapidly oxidized (a half life as low as three years but no more than six years was estimated). Oxygen consumption rates remained high in sediments 95 km southwest of the Site, suggesting that erosion and transport of sediments on the continental slope may have been partially responsible.

Considered in total, the information collected under the farfield fate studies suggested that a significant fraction (at least 20% and at most 70%) of the sewage sludge reached the seafloor in and near the 106-Mile Site. The remainder of the sludge settled at slow rates and was probably transported via the Gulf Stream into the north Atlantic Ocean. No evidence was obtained that sewage sludge was transported onto the continental shelf or to areas supporting commercial fisheries. The data from the outer shelf and canyons tend to support previous hypotheses that atmospheric inputs and off-shelf transport from the inner continental shelf are the likely sources for the contaminants found in these areas.

EFFECTS

Studies to determine if sludge disposal at the 106-Mile Site resulted in significant impacts to the biology and ecology included (1) at-sea observations of endangered species, (2) surveys of midwater fish for evidence of bioaccumulation of chemical contaminants, (3) surveys of epibenthic organisms, (4) assessments of ichthyoplankton, (5) evaluations of the prevalence of chitinoclasia shell disease in lobster and red crab, (6) accumulation of metals and organic contaminants in commercially important fish species, red crabs, and lobsters, (7) evaluations of benthic and microbiological community structure, and (8) evaluations of fisheries landings. Major findings of these studies are summarized below.

Endangered Species. Observations of endangered species in and near the 106-Mile Site did not identify any adverse effects. The species identified were primarily migratory and there were no indications that the site was used as breeding or nursery grounds.

Bioaccumulation. An extensive suite of contaminant measurements in organisms ranging from deep-sea finfish and shrimp, to midwater fish, to commercially important fish, lobster and red crab were completed between 1989 and 1991. None of these studies identified significant increases in tissue concentrations of contaminants that could be related to the dumping of sewage sludge at the 106-Mile Site.

- The most extensive set of contaminant measurements ever conducted in midwater fish was completed under the 106-Mile Site monitoring program. Elevated concentrations of some metals and organic compounds were sporadically found in an area immediately west of the Site. Broad-scale sampling did not identify any significant increase in contaminant concentrations away from the Site. Thus, while some short-term increases in contaminant concentrations were evident, broad-scale, longer-term bioaccumulation above background levels in these organisms was not detected. Contaminants accumulating in plankton collected from the surface waters were also sporadically detected, but could not definitively be linked to sludge dumped at the Site.

- Measurements of contaminants in deep-sea organisms are the most extensive studies of this kind. Results of these studies indicated that the concentrations of metals and organic contaminants in several hundred deep-sea finfish and shrimp, collected in the vicinity of the 106-Mile Site in 1990 and 1991, were low and approximated concentrations measured in similar species sampled in the early and mid 1970s.

- Concentrations of contaminants in lobster and red crab collected from the outer continental shelf canyons were slightly elevated and differences in contaminant levels were identified in organisms from several different canyons. Contaminant concentrations could not be related to distance from the 106-Mile Site. Rather, sources such as atmospheric inputs or transport from the inner shelf were thought to be the reason for the differences.

- Metal and organic contaminants in tilefish, a commercially important finfish harvested from canyons on the outer continental shelf, were generally low. No clear spatial patterns in concentrations were evident. The results from 1990 and 1991 were similar to results obtained in the early 1980s, prior to sludge dumping at the 106-Mile Site.

Community Structure. Changes in the structure of finfish, benthic, and microbial communities in the sediments from the continental rise in the site were evaluated, as well as communities at 700 m in the submarine canyons of the outer continental shelf. Findings include the following:

- The community structure of the deep-sea finfish collected in 1990 and 1991 was similar to the community structure described in the early 1970s. Measures of species richness, numerical abundance, depth distributions, and biomass were all similar for both sampling periods. No effects due to sludge dumping at the 106-Mile Site were evident.

- In 1989, sampling of the bacterial community in near-bottom waters revealed that the natural autochthonous bacterial community in the near-bottom waters was replaced with a community that was poorly adapted to the deep-sea conditions. The importance of this change to the ecology of the area was not clearly established. Bacterial communities in the canyons clearly included species directly associated with sewage, suggesting that the sewage wastes had reached the canyon areas. The presence of sewage-associated bacteria could not be attributed to dumping at the 106-Mile Site, but was thought to result from offshore transport of sewage-related materials from previous dumping in the New York Bight.

- Compared to results of studies conducted prior to sludge disposal, analyses of the sediment samples collected in 1989 suggested that the deep-sea benthic community had changed. Specifically, polychaete species not previously found in sediments from the continental rise were identified. Because these organisms generally respond to inputs of organic matter, the presence of polychaetes was believed to be related to the deposition of sludge near the 106-Mile Site. The results of follow-up studies conducted in 1991, 1992, and 1993 are not yet available.

- Between 1990 and 1992, extensive video surveys at 700-m depth in the submarine canyons of the outer continental shelf determined that the macrobenthic community structure and species abundances were consistent among the canyons. The behavior and habitat associations of the animal populations in the canyons were also consistent and did not appear to be affected by sludge dumping. No impact from dumping at the 106-Mile Site could be found.

RECOMMENDATIONS

Although the overall monitoring program was highly successful, ongoing data collections and data interpretation could have improved several aspects of the program, including

- Early identification of chemical and physical attributes which can be used as specific and unique tracers of the waste. These tracers must be measured using methods that provide accurate quantification.

- Better definition of the source characteristics for more accurate prediction of fate.

- Better and more complete characterization of size-specific particle-settling rates and fractions within the sludge, and characterization of the tracer concentrations within the various particle-size classes.

- More frequent acquisition of data to address the time-varying concentrations of specific tracers in the sludge.

- Consideration of cumulative impacts of the constituents of the waste material and significant ecological processes that might influence the transport and fate or effects (both positive and negative) of the material.

- Linking modeling with field measurements to improve the cost-effectiveness of monitoring designs.

- Continued use of unique waste tracers that can be used to quantitatively address fate and impact without implementation of a full priority pollutant measurement program.

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FIGURES (Continued)

1.0 INTRODUCTION

When designated in 1984 by the U.S. Environmental Protection Agency (EPA) as an authorized sewage sludge dump site, the 106-Mile Deepwater Municipal Sludge Dump Site (106-Mile Site; **Figure 1-1**) was the only location in U.S. waters that was used for barge-based disposal of sewage sludge. All disposal activities were regulated by the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA). The MPRSA was amended in 1988 by the Ocean Dumping Ban Act of 1988 (ODBA) to prohibit the ocean disposal of municipal sewage sludge and industrial wastes after December 31, 1991.

In 1987, prior to the passage of the ODBA, EPA had developed a monitoring plan to study and document potential adverse effects of sludge disposal at the 106-Mile Site on marine life and human health (EPA, 1992a,b). This plan was responsive to the ocean dumping regulations and was designed to generate data for use by site managers in making decisions about site re- or de-designation; development of conditions to include in disposal permits; and continuation, termination, or modification of dumping permits. Under this plan, EPA conducted baseline studies and several field surveys to evaluate the nearfield fate and short-term effects of sludge

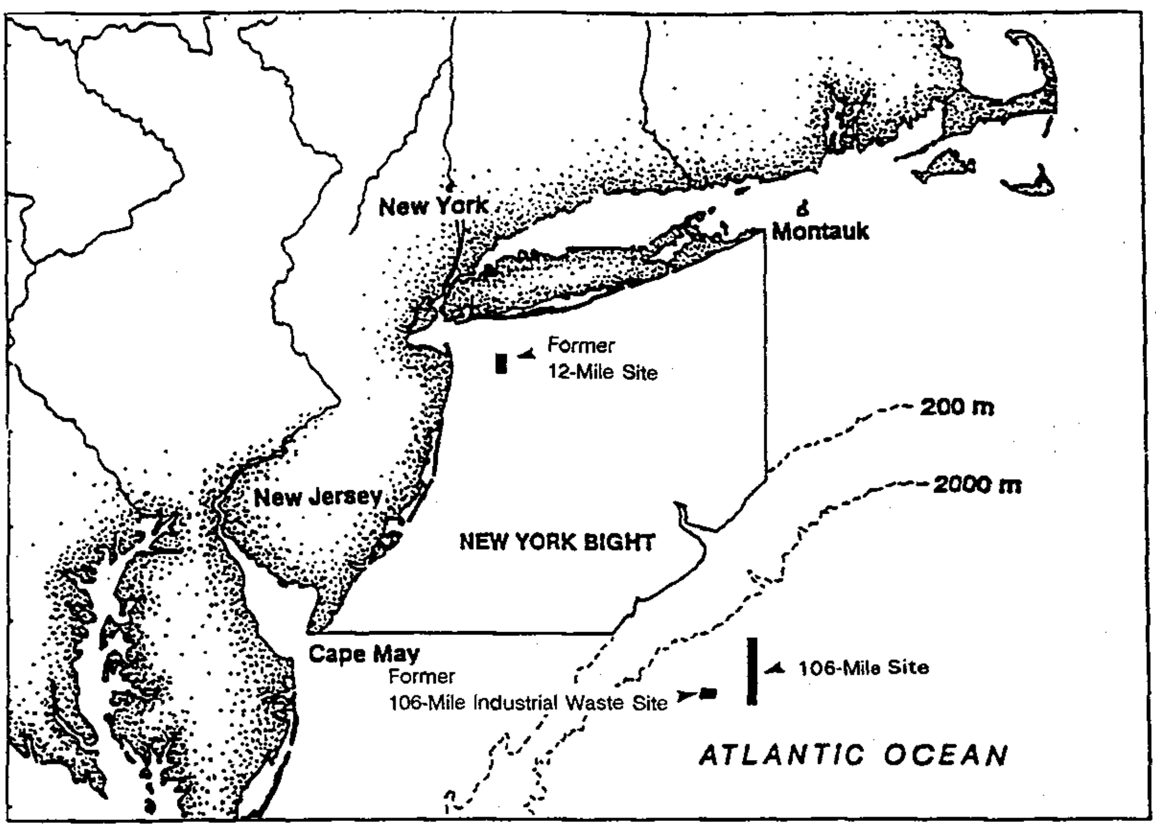


Figure 1-1. **Several ocean disposal sites, including the *106-Mile Site*, were located in the New York Bight and environs.**

disposal at the Site (Redford *et al.*, 1992). Information obtained during this monitoring phase was also used to address site management and permitting issues.

With the passage of the ODBA, EPA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Coast Guard (USCG) were required to design a monitoring program to assess the potential impact of sludge disposal on the marine environment, with particular emphasis on living marine organisms. To meet this requirement, EPA, NOAA, and the USCG designed and implemented a comprehensive monitoring, research, and surveillance plan (joint Monitoring Plan) for the Site and surrounding environs (EPA, 1990a). Implementation of the joint Monitoring Plan brought together research teams representing EPA and NOAA in a broad-based program to study the physical and chemical fate of the sludge dumped at the 106-Mile Site and the biological effects of sludge. Overall, the monitoring program was one of the most comprehensive studies of its kind implemented in U.S. territorial waters.

This report summarizes the findings of the 106-Mile Site monitoring program as related to the monitoring hypotheses and management actions, and partially fulfills commitments made in the joint Monitoring Plan to disseminate findings to the regulatory, legislative, and scientific communities, and interested public sectors. Detailed presentations of results are provided in project reports (see EPA, 1995 for a comprehensive listing of references and data archival locations) and peer-reviewed papers presented at a closeout symposium for the 106-Mile Site held in October 1993. Many of the peer-reviewed papers have been published in 1995 and 1996 volumes of the *Journal of Marine Environmental Engineering*. Other papers can be found throughout the oceanographic and general environmental literature.

1.1 History of Sewage Sludge Disposal in the New York Bight and at the 106-Mile Site

Prior to the initiation of sewage sludge disposal at the 106-Mile Site in 1986, sludge was disposed at the 12-Mile Site, located in shallow continental shelf waters in the apex of the New York Bight, 12 nmi from Sandy Hook, New Jersey (**Figure 1-1**). Designation of the 106-Mile Site in 1984 resulted from the EPA decision to end municipal sludge disposal at the 12-Mile Site.

Prior to the designation of the 106-Mile Site for sewage sludge disposal, a larger area ($\approx$500 nmi^2), also known as the 106-Mile Site, was located in continental slope waters $\approx$100 nmi southeast of New York City. This site, which had been used since 1961 for the intermittent disposal of industrial waste (byproducts of industrial processes, such as paint and chemical production and petroleum processing), sewage sludge (from the City of Camden, New Jersey, for 12 months during 1977-1978), sewage-sludge-digester clean-out wastes, and, on one occasion, fly ash (a barge load dumped for research purposes), came under EPA regulation in 1978. After 1981 and until 1986, the site was used only for the disposal of industrial waste.

The total quantity of waste dumped at the Site peaked in 1978 at $\approx$800,000 wet tons per year.

After 1978, the amount of industrial waste dumped in the site decreased steadily. Between 1981 and 1987, the annual amount of industrial waste disposed in the 106-Mile Site (**Table 1-1**) ranged between 28,000 and 245,000 wet tons per year. All industrial waste disposal at the 106-Mile Site stopped in 1987 when the last permit application for disposal of industrial waste was withdrawn. The 106-Mile Industrial Waste Site was officially de-designated in 1992.

Table 1-1. Annual amounts of industrial waste dumped at the 106-Mile Site from 1961 through 1988. [From: EPA, 1992c]

Year	Tons (wet)
1961 to 1977	≈3,500,000
1978	800,000
1981	245,000
1982	193,000
1983	(Not available)
1984	155,000
1985	100,000
1986	213,000
1987	28,000
1988 on	None
TOTAL	≈5,234,000

In 1982, EPA published its intention of formal designation of the site for sewage sludge disposal. However, concern that mixed dumping of municipal sludges and industrial wastes would complicate monitoring efforts led to the decision to designate two smaller sites (one for sewage sludge and one for industrial waste) within the larger site. The resulting site for sewage sludge disposal, known as the 106-Mile Deepwater Municipal Sludge Dump Site (hereafter referred to as the 106-Mile Site), was located on the east side of the original site. The area of this Site was ≈28 nmi^2 with boundaries at 38°40′00″ to 39°00′00″ north latitude and 72°00′00″ to 72°05′00″ west longitude. The Site was located ≈120 nmi southeast of Ambrose Light and 115 nmi from Atlantic City, New Jersey. The location was seaward of the continental slope/shelf break, where the water depths range from 2400 to 2700 m. The Deepwater Industrial Waste Site, also located within the larger original site, was circular, with a radius of 3 nmi, centered at 38°40′00″ north latitude and 72°20′00″ west longitude.

Transfer of sludge disposal from the 12-Mile Site to the 106-Mile Site began in 1986. During 1986-1987, nine sewerage authorities (permittees) from New York and New Jersey completed the transfer of their sludge disposal operations from the previously designated 12-Mile Site to the 106-Mile Site.

MUNICIPALITIES AUTHORIZED TO USE THE 106-MILE SITE FROM 1986 TO 1992

Bergen County Utilities Authority (BCUA), New Jersey
Joint Meeting of Essex and Union Counties (JMEUC), New Jersey
Linden-Roselle Sewerage Authority (LRSA), New Jersey
Middlesex County Utilities Authority (MCUA), New Jersey
Nassau County Department of Public Works (NCDPW), New York
New York City Department of Environmental Protection (NYCDEP), New York
Passaic Valley Sewerage Commission (PVSC), New Jersey
Rahway Valley Sewerage Authority (RVSA), New Jersey
Westchester County Department of Environmental Facilities (WCDEF), New York

From 1988 through 1990, the volume of sludge dumped at the 106-Mile Site was relatively constant (**Figure 1-2**), ranging between 8 to 10 million wet tons of sludge per year. From 1986 until August 1989 disposal operations and dumping rates were stipulated by the conditions of the 1981 court order (City of New York v. EPA, 543 Supp. 1084) which regulated disposal at the 12-Mile Site and the 106-Mile Site prior to issuing permits. In August 1989, the nine authorities using the 106-Mile Site were issued EPA permits. During 1991, in response to the ODBA requirements, the permittees began phasing out their ocean dumping of sewage sludge to meet the deadlines mutually agreed to by EPA, the States of New York and New Jersey, the sewerage authorities, and the U.S. Department of Justice in enforcement agreements and consent decrees signed in August 1989. Only one permittee, the NYCDEP, exceeded the December 31, 1991 deadline and continued dumping operations at the 106-Mile Site during 1992. The site designation expired in December 1991. As of June 30, 1992, all sewage sludge disposal at the 106-Mile Site ceased and the Site was closed to ocean dumping.

Between 1986 and June 1992, ≈42 million wet tons (**Figure 1-3**), or 1.5 million dry tons, of sewage sludge were disposed at the Site. The total wet tons of sludge dumped by each permittee between 1986 and 1992 varied.

The largest total amount of sludge (≈22 million wet tons) was dumped by NYCDEP. Each of the other permittees contributed less than

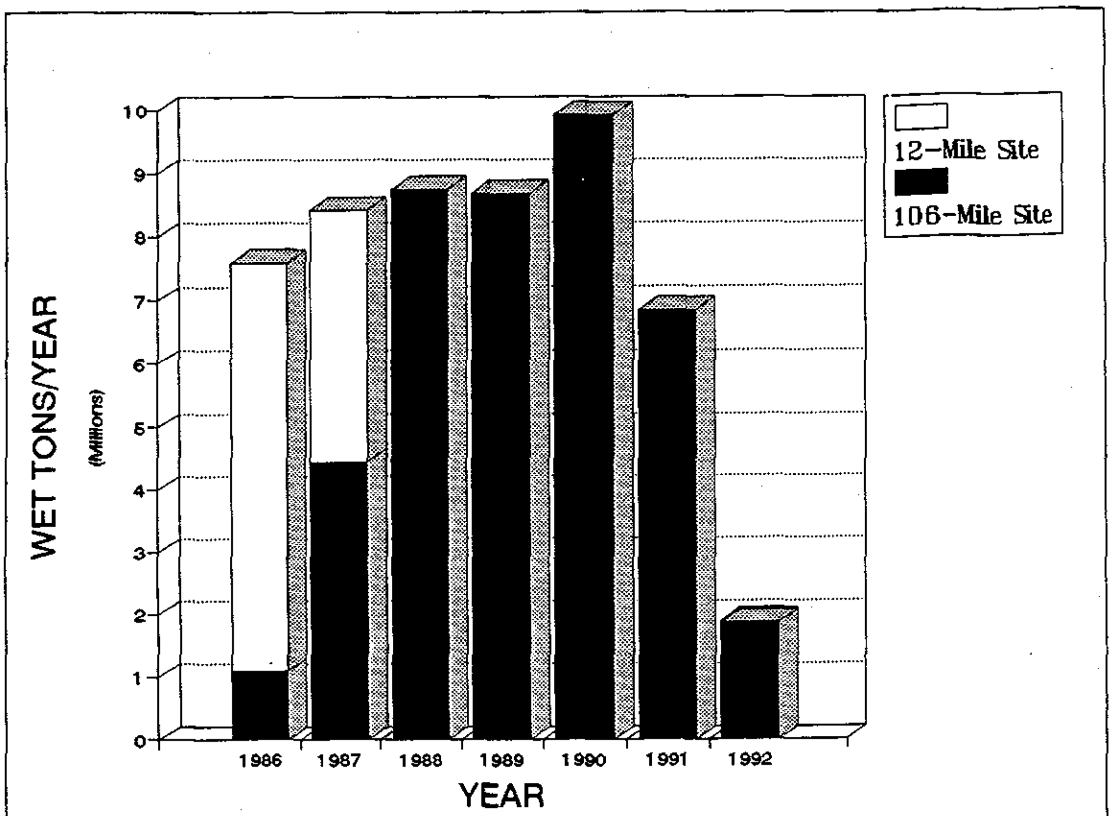


Figure 1-2. **Annual disposal of sewage sludge (wet tons) at the 12-Mile Site and the 106-Mile Site from 1986 through June 1992 when sludge disposal ceased.**

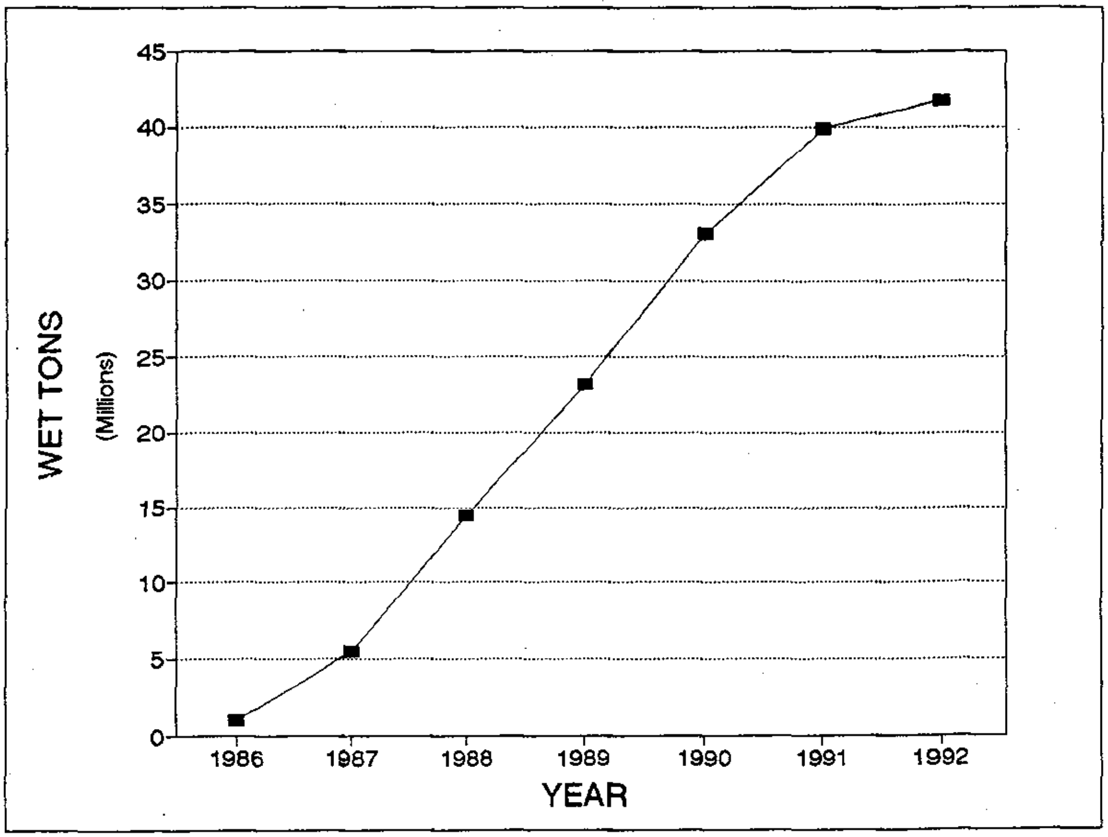


Figure 1-3. **Cumulative discharge of sewage sludge (wet tons) to the 106-Mile Site from 1986 through June 1992.**

6 million wet tons of the total load to the Site; three permittees each dumped less than 900,000 wet tons. NYCDEP contributed ≈50% of the wet tons dumped, and NCDPW and PVSC contributed 10% and 14%, respectively (**Figure 1-4**). The remaining permittees contributed less than 10% each to the total wet tons dumped. The smallest percentage of sludge was disposed by RVSA and LRSA.

In contrast to the wet tons dumped, the contribution to the total dry tons dumped was significantly larger for PVSC (**Figure 1-5**). From 1986 through June 1992, PVSC dumped 450,000 dry tons compared to the 575,000 dry tons dumped by NYCDEP (**Figure 1-5a**). The remaining authorities each dumped less than 130,000 dry tons; JMEUC, RVSA, and LRSA each dumped less than 30,000 dry tons. On a percentage basis (**Figure 1-5b**), NYCDEP contributed ≈40% of the dry tons disposed while PVSC contributed ≈30%. Thus, more than 70% of the total dry tonnage of sludge dumped at the 106-Mile Site was contributed by just two permittees.

The sludge dumped at the 106-Mile Site was primarily biological sludge which also contained small amounts of sand and grit, paper, and other fibers. The sewage sludges disposed at the Site were somewhat buoyant, generally comprising 2-4% solid material for the majority of the sewerage authorities and more than 7% for the

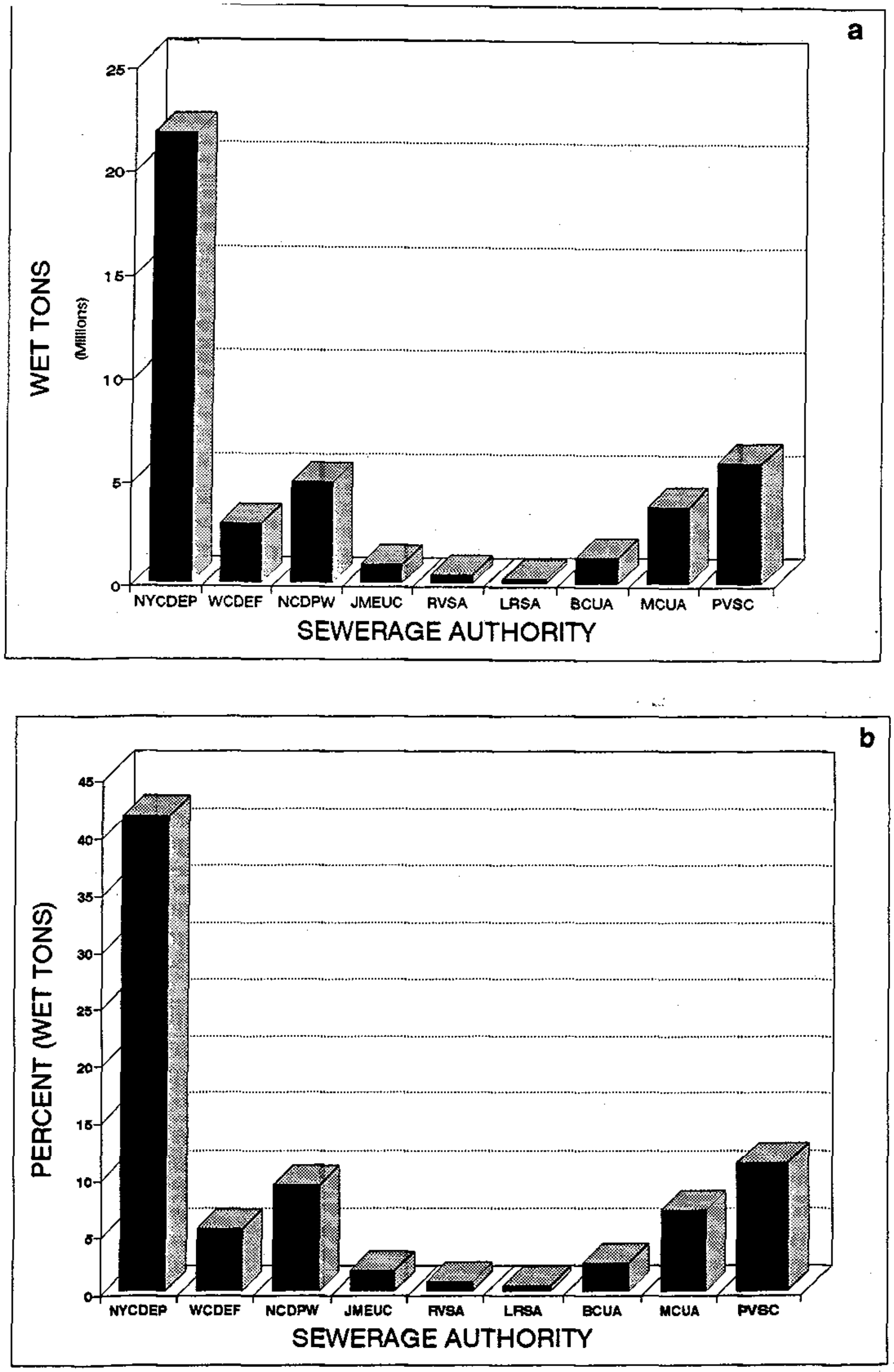


Figure 1-4. **Sewage sludge disposed between 1986 and 1992 at the 106-Mile Site varied by municipality.**
(a) Wet Tons
(b) Percentage

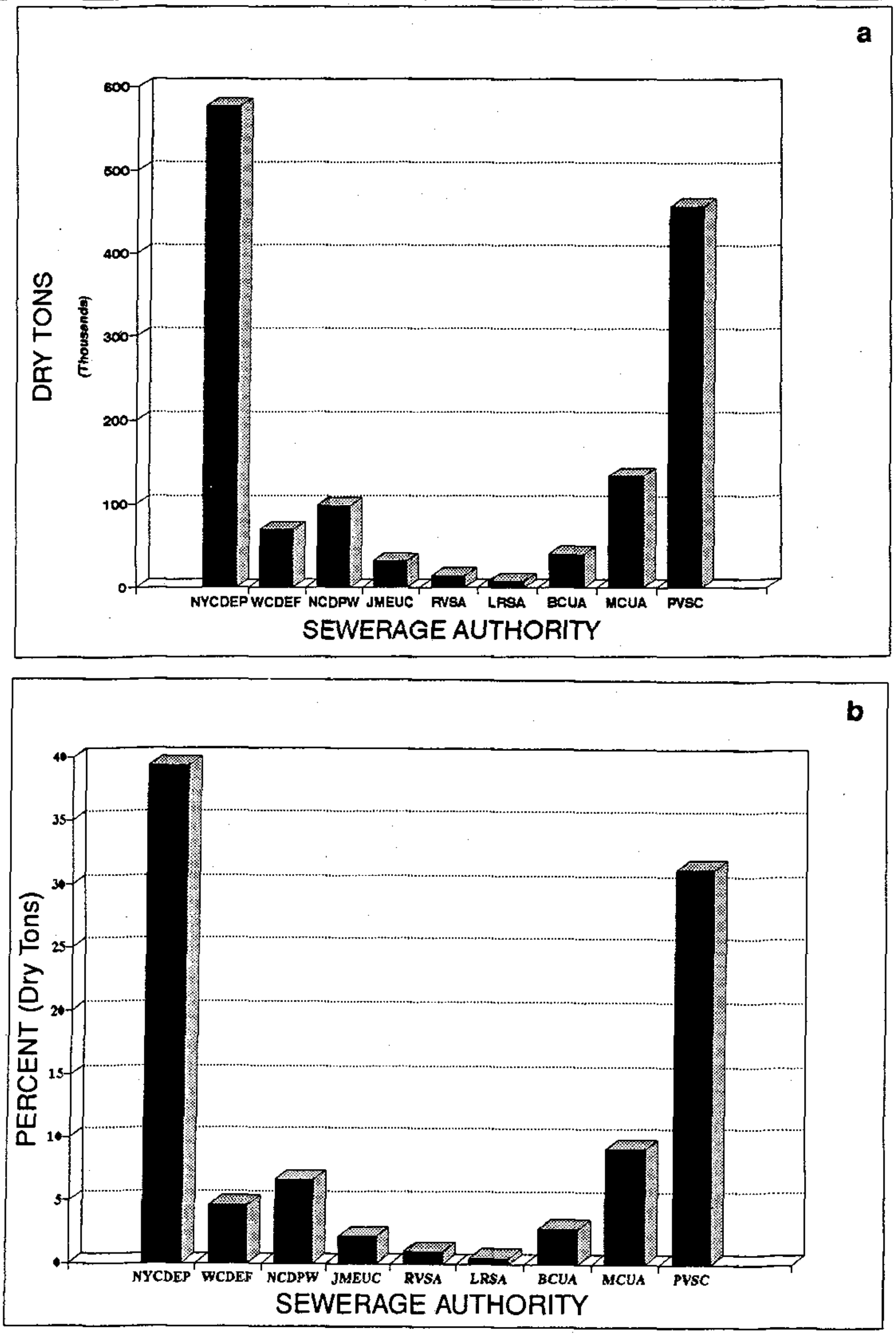


Figure 1-5. **Sewage sludge disposed between 1986 and June 1992 at the 106-Mile Site varied by municipality.**

(a) Dry Tons

(b) Percentage

PVSC (**Figure 1-6**), reflecting different treatment levels and technologies.

The different physical and chemical characteristics of the sludges reflected the different mixes of domestic and industrial activities that contributed to the influent of the treatment plants and the varied treatment processes by which the sludge was generated. The total solids content and concentrations of chemicals in the sewage sludge reported by the permittees during 1982-1985 varied both within individual treatment plants and among the various authorities (Santoro and Fikslin, 1987; EPA, 1992d,e). Within-plant variability was generally much lower than among the sewage treatment plants. The sludge contained trace levels of organic contaminants, such as aldrin, dieldrin, chlordane, heptachlor epoxide, DDT and its degradation products, and polychlorinated biphenyls (PCBs). Metals including cadmium (Cd), copper (Cu), chromium (Cr), and mercury (Hg), were also present at trace levels.

1.2 Predictions Made During Site Designation

The 106-Mile Site was selected for waste disposal in part because the receiving waters are dispersive (EPA, 1980; O'Connor *et al.*, 1983, 1985; Walker *et al.*, 1987, 1989). Major factors affecting the fate of wastes disposed at the 106-Mile Site were discussed by O'Connor in the NOAA report, *106-Mile Site Characterization Update*, (Pearce *et al.*, 1983) and in O'Connor *et al.* (1983). O'Connor suggested that the initial dilution of sewage sludge in the wake of

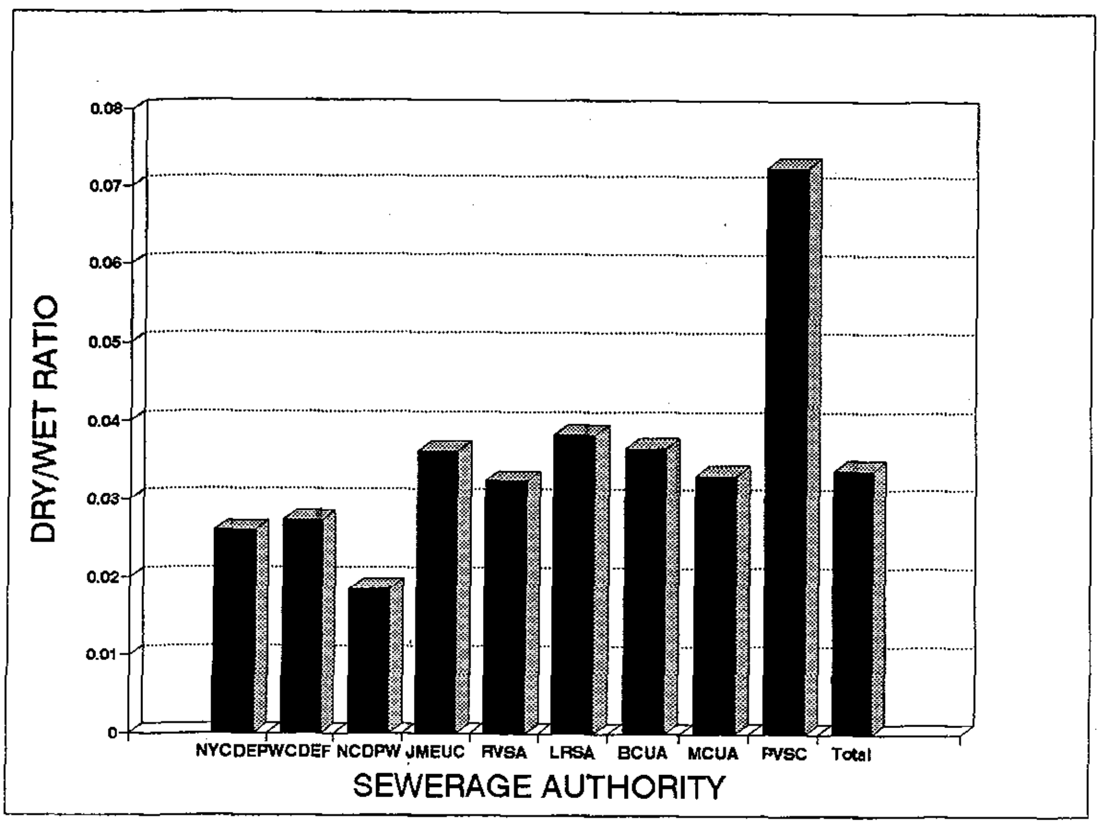


Figure 1-6. **Dry/wet ratio of sewage sludge disposed from August 1989 through June 1992 by municipality.**

the barges dumping the sludge would be rapid. Other factors that were thought to control dilution of the sludge included the rate of disposal and the depth of the pycnocline.

Evidence from the disposal of acid iron waste at the larger 106-Mile Site in the early 1980s indicated that, after the rapid mixing and dilution of the waste caused by the momentum of the barges, additional dilution by oceanic processes would be slow. Initial dilutions in the wake of the barges were predicted to be on the order of 5000:1 (Pearce *et al.*, 1983; O'Connor *et al.*, 1983). These authors also speculated that episodic high-energy events, such as storms, would increase the rate of dilution.

Ocean currents were predicted to cause movement of individual plumes away from the Site in all directions (Pearce *et al.*, 1983; O'Connor *et al.*, 1983, 1985). However, the long-term transport of the material was predicted to be toward the southwest, the direction of the net current drift in the area and deposition in the sediments near the Site was expected to be minimal. Sludge dilutions in the farfield (days to weeks after disposal) were predicted to be on the order of 500,000:1 or more. Because of these great dilutions, detection of sludge particles or constituents away from the Site was considered to be difficult. Among the critical factors for detecting the sludge was the identification of parameters that could be linked to sludge.

Many of the predictions made during the site designation process were evaluated during the monitoring program. Where new data were required, the program developed study plans and obtained the required information. Information gathered during the monitoring program and reported on here improved our understanding of many of the concepts offered during the site designation process.

PREDICTIONS MADE DURING THE SITE DESIGNATION

- Rapid initial dilution with slow oceanographic dilution (5000 to 1)
- Initial movement out of the Site in all directions
- Long-term drift to the southwest
- Farfield dilution of 500,000 to 1 or more
- Chemical signals may be evident in the seasonal mixed layer
- No violations of water quality criteria (WQC) in or downstream of the Site
- Episodic events increase dilution
- Little or no transport onto the shelf
- Small flux to the benthic environment
- Surface sediment PAHs and PCBs may increase 0.2 to 0.3 ppm after 100 years
- Limited bioaccumulation in organisms
- No violations of U.S. Food and Drug Administration tolerance levels for edible fish/shellfish

1.3 Organization of this Report

The remainder of this report is organized as follows:

Section 2.0 presents essential components of the legislative mandates that affected the disposal of sludge at the 106-Mile Site; the management questions and hypotheses that were addressed during the 106-Mile Site monitoring program; a discussion of the roles and responsibilities of EPA, NOAA, and the USCG; and an overview of the studies conducted during the monitoring of the Site. This summary is organized according to the monitoring tiers included in the joint Monitoring Plan.

Section 3.0 summarizes the monitoring results. This summary is organized according to the monitoring tiers in the joint Monitoring Plan.

Section 4.0 presents a summary of significant Federal management actions that were completed during the period that the 106-Mile Site was used for sludge disposal. Management actions include various statutory, regulatory, and permit conditions. Also included in the section are recommendations for future researchers and managers relative to large multidisciplinary monitoring programs.

Section 5.0 presents references used in preparing this report.

2.0 OVERVIEW OF THE 106-MILE SITE MONITORING PROGRAM

Prior to the passage of the ODBA, EPA had developed and implemented a plan to monitor sewage sludge disposal at the 106-Mile Deepwater Municipal Sludge Dump Site (EPA, 1992a,b). This plan was implemented in response to legislative and regulatory mandates included in the MPRSA and the ocean dumping regulations.

MARINE PROTECTION, RESEARCH AND SANCTUARIES ACT OF 1972 (MPRSA, P.L. 92-532) AS AMENDED January 11, 1977 (40 CFR 220-228, 42 FR 2462).

- The MPRSA is the primary legislative authority directly related to ocean dumping at the 106-Mile Site. It is commonly referenced as the Ocean Dumping Act, and is the domestic legislation implementing the London Convention (formerly the London Dumping Convention).

- EPA and the USACE administer the permit programs under the MPRSA. EPA issues permits for disposal of all materials except dredged material; the USACE issues permits for disposal of dredged material. Surveillance and enforcement of permit conditions are joint responsibilities of EPA and the USCG. EPA is authorized to designate disposal sites and is responsible for site monitoring. The USCG is assigned responsibility for surveillance to ensure that operational aspects of the permit conditions are met. NOAA is responsible for initiating research programs on long-range effects of pollution and people-induced changes to the marine environment. Two major sections of the MPRSA are summarized below.

  - **40 CFR Part 227 Criteria for Evaluation of Permit Applications for Ocean Dumping of Materials:** This part of the ocean dumping regulations develops criteria for determining acceptability of materials, evaluating environmental impacts, determining materials that are prohibited as other than trace contaminants, and developing limits for disposal rates and quantities and other criteria for evaluating applications for ocean dumping of wastes.

  - **40 CFR Part 228 Criteria for Management of Disposal Sites for Ocean Dumping:** This section of the ocean dumping regulations deals with evaluation of the proposed dumping of material in ocean waters in relation to continuing requirements for effective management of ocean disposal sites. Three site management functions are addressed: (1) site designation, (2) permitting, and (3) site monitoring. These functions consist of conducting disposal site evaluation and designation studies, and recommending modifications to site use and/or designation (site designation); regulating times, rates, and methods of disposal, and quantities and types of materials that can be disposed (permitting); and developing and maintaining effective monitoring programs for dumpsites (site monitoring). The three management functions are interdependent and are intended to prevent unreasonable degradation of the marine environment by wastes dumped in the ocean.

During the development of the plan, EPA considered regulatory requirements, characteristics of the Site, and characteristics of the sludge to develop a set of questions related to compliance, transport and fate, and potential impacts of sludge disposal at the Site. The impact categories itemized in the ocean dumping regulations that were used to develop predictions of possible impacts included:

- Impingement of sludge onto shorelines
- Movement of sludge into marine sanctuaries or shellfishery or fishery areas
- Effects of sludge on commercial fisheries
- Accumulation of sludge constituents in biota
- Progressive changes in water quality related to sludge disposal
- Progressive changes in sediment composition related to sludge disposal
- Impacts of sludge disposal on pollution-sensitive species or life cycle stages
- Impacts of sludge disposal on endangered species
- Progressive changes in pelagic, demersal, or benthic biological communities as a result of sludge disposal

To guide the monitoring, a series of predictions was developed for each of these impact categories. These predictions served as the conceptual foundation for formulating a series of hypotheses for the monitoring program. The hypotheses addressed assessment of permit compliance as well as transport, fate, and potential impacts of the sludge. Between 1986 and 1988, EPA conducted baseline studies and completed several field surveys to evaluate the nearfield fate and short-term effects of sludge disposal at the Site (Redford *et al.*, 1992). Information obtained from these studies was used in 1989 to develop permit conditions and to modify site management plans.

OCEAN DUMPING BAN ACT (ODBA) OF *1988 (P.L. 100-688) (AMENDS MPRSA)*

This act prohibits the dumping of sewage sludge or industrial waste in the oceans after December 31, 1991. The ODBA prohibits new entrants to ocean disposal, prohibits the dumping of sewage sludge or industrial waste without a permit and compliance or enforcement agreement, provides for dumping fees imposed starting 270 days from the enactment of the Act and continuing until December 31, 1991, and provides for financial penalties for those dumping in the ocean after December 31, 1991. The monitoring plan included a series of studies to determine whether (1) conditions of permits to dump sludge were met and (2) sludge dumping at the site adversely affected the environment or human health. Although permit conditions were set to protect the environment, EPA's monitoring efforts assessed not only whether those actions were being met, but whether the conditions were sufficiently protective.

SPECIAL MONITORING AND SURVEILLANCE REQUIREMENTS IN ODBA

- The Ocean Disposal Surveillance System (ODSS) was to be installed on all barges/vessels using the Site.
- EPA and NOAA were required to carry out a monitoring program for the 12-Mile Site, 106-Mile Site, and potential area of influence of disposed sewage sludge and industrial waste.
- The agencies were also required to employ advanced technologies and satellites for monitoring.

With the passage of the ODBA, EPA, NOAA, and the USCG were required to design a monitoring program to assess the potential impact of sludge disposal at the 106-Mile Site and in areas of potential impact. To meet this requirement, the agencies used the EPA Monitoring Plan as a framework and developed a joint Monitoring Plan. To ensure that public, scientific, and legislative concerns were addressed, EPA, NOAA, and the USCG held a workshop in March 1989 to solicit recommendations for monitoring, research, and surveillance of the 106-Mile Site (EPA, 1989a,b). Discussions at the workshop focused on four questions:

1. What is the physical and chemical fate of the sewage sludge dumped at the 106-Mile Site?
2. What is the effect of sludge dumping at the 106-Mile Site on living marine resources?
3. What is the effect of sludge dumping at the 106-Mile Site on human health?
4. Are there changes in site designation, permits, or surveillance that can provide better protection of the environment, living marine resources, or human health?

EPA, NOAA, and the USCG used the recommendations and findings from the workshop to develop a joint strategy for monitoring, research, and surveillance (EPA, NOAA, and USCG, 1989) in response to ODBA. The agencies considered monitoring and scientific priorities, and available resources in developing the strategy and joint Monitoring Plan.

The joint Monitoring Plan was published and implemented in 1990 as the *Monitoring, Research, and Surveillance Plan for the 106-Mile Deepwater Municipal Dump Site and Environs* (EPA, 1990a). Activities conducted under the joint Monitoring Plan were funded partly under the ODBA through fees imposed on the permittees prior to the 1991 deadline for stopping sludge disposal and by penalties for dumpers who continued dumping after the deadline. In addition, EPA and NOAA's National Underseas Research Program (NURP) supported a number of the studies with programmatic and research funds, respectively.

The joint Monitoring Plan was constructed very much like its predecessor. Both were organized around a series of monitoring questions, formulated as predictions and stated as hypotheses that could be examined through field and laboratory assessments. The original 23 hypotheses in the EPA Monitoring Plan (EPA, 1992a) were refined and expanded to 29 hypotheses (**Table 2-1**) to ensure that all concerns raised in ODBA and at the workshop were addressed. In the EPA Monitoring Plan, the original hypotheses were grouped into the following four tiers, which were structured so that data collected in one tier could be used to guide the monitoring activities in the next:

Tier 1: **Waste Characteristics and Disposal Operations** was concerned with monitoring of waste characteristics and disposal operations.

Tier 2: **Nearfield Fate and Short-Term Effects** focused on the nearfield fate and short-term effects of sludge.

Tier 3: **Farfield Fate** addressed the long-term, farfield fate of sludge constituents.

Tier 4: **Long-Term Effects** was concerned with resultant long-term environmental effects of the sludge.

This tiered structure was retained in the joint Monitoring Plan. In practice, monitoring activities planned for higher tiers were not

Table 2-1. The 1989 106-Mile Site Monitoring and Research Plan contained a series of hypotheses.

Tier	No.	Description
1		WASTE CHARACTERISTICS
	$H_0$1:	The physical and chemical characteristics of sludge are consistent with waste characterization information available at the time permits for the 106-Mile Site were issued.
		DISPOSAL OPERATIONS
	$H_0$2:	Disposal rates and operations are consistent with the requirements of the ocean dumping permits.
2		NEARFIELD COMPLIANCE
	$H_0$3:	Concentrations of sludge and sludge constituents are below the permitted LPC and WQC outside the site at all times.
	$H_0$4:	Concentrations of sludge and sludge constituents are below the permitted LPC and WQC within the site 4 h after disposal.
	$H_0$5:	Pathogens or biological tracers of sewage sludge do not exceed ambient levels 4 h after disposal.
		NEARFIELD FATE
	$H_0$6:	Sludge particles do not settle in significant quantities beneath the seasonal pycnocline (50 m) or to the 50-m depth at any time, within the site boundaries or in an area adjacent to the site.
	$H_0$7:	The concentration of sludge constituents within the site does not exceed the LPC or WQC 4 h after disposal and is not detectable in the site 1 day after disposal.
	$H_0$8:	The concentration of sludge constituents at the site boundary or in the area adjacent to the site does not exceed the LPC or WQC at any time and is not detectable 1 day after disposal.
	$H_0$9:	The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water nor a significant change in the pH of the seawater in the area.
		SHORT-TERM IMPACTS
	$H_0$10:	No significant biological effects in the water column are measurable within the site within 1 day after disposal.
	$H_0$11:	No increase in primary productivity or any changes in planktonic biomass or species composition occurs.

Table 2-1. The 1989 106-Mile Site Monitoring and Research Plan contained a series of hypotheses *(Continued).*

Tier	Hypothesis No.	Description
	$H_0$12:	Sludge constituents do not accumulate in the surface microlayer in the vicinity of the site.
	$H_0$13:	No evidence of short-term bioaccumulation of sludge constituents by commercially important species or important prey species found at or adjacent to the site will be found within 1 day after disposal.
3	FARFIELD FATE	
	$H_0$14:	Significant amounts of sludge do not settle below the surface mixed layer outside the disposal site.
	$H_0$15a:	Ocean currents do not transport sludge to any adjacent shoreline, beach, marine sanctuary, fishery, or shellfishery.
	$H_0$15b:	Ocean currents do not transport sludge onto the continental shelf.
	$H_0$16a:	Recirculation of slope water through the 106-Mile Site is not significant.
	$H_0$16b:	Concentrations of sludge constituents dumped at the 106-Mile Site that are associated with any recirculating slope water do not exceed EPA chronic Marine Water Quality Standards.
	$H_0$17a:	Significant amounts of sludge particles do not settle to the sea floor in the vicinity of the site or in the region predicted as a plausible settling region.
	$H_0$17b:	Organic, inorganic, and bacterial contaminants that are present in sewage sludge discharged at the 106-Mile Site do not measurably increase concentrations of contaminants in the sediment within the expected dispersion area or reference areas.
4	LONG-TERM IMPACTS	
	$H_0$18:	Sludge constituents have no significant long-term effect on the distribution of endangered species in the vicinity of the site.
	$H_0$19:	Sludge constituents do not accumulate in the tissues of commercially important species resident in the shelf and slope areas adjacent to the site.
	$H_0$20:	Benthic metabolism, populations, and/or communities do not change significantly because of sludge disposal.
	$H_0$21:	Sludge disposal has no effect on eggs and larval stages of indigenous animals.
	$H_0$22:	This hypotheses from the EPA Monitoring Plan is not included because lack of baseline data makes a definitive test difficult.
	$H_0$23:	Pathogens or biological tracers of sewage sludge do not increase in the water column or biota as a result of sludge disposal.

Table 2-1. The 1989 106-Mile Site Monitoring and Research Plan contained a series of hypotheses *(Continued).*

Tier No.	Hypothesis Description
$H_0$24:	There are no detectable differences in the body burdens of sludge contaminants in midwater fishes in the immediate vicinity of the 106-Mile Site compared to a broad area surrounding the dumpsite.
$H_0$25:	The prevalence of shell disease exhibited by commercially important crustaceans is not significantly different in collections of commercially valuable American lobsters and red crabs, off New Jersey, adjacent to and downstream from the 106-Mile Site, from those in collections off Georges Bank and southern New England.
$H_0$26:	Body burdens of trace metals, polynuclear aromatic hydrocarbons (PAH), and polychlorinated hydrocarbons (PCBs) and pesticides are not significantly different in collections of commercially valuable American lobsters and red crabs, off New Jersey, adjacent to and downstream from the 106-Mile Site, from those in collections off Georges Bank and southern New England.
$H_0$27:	*There is no difference in the chemical body burdens in American lobsters and red crabs* showing evidence of shell disease and lobsters and crabs without substantial shell disease manifestations.
$H_0$28:	Body burdens of sludge-related contaminants in epibenthic megafauna are not detectably different in animals found in the vicinity of the 106-Mile Site and from those animals found in reference areas.
$H_0$29:	The distribution or abundance of the dominant commercially exploited fisheries are not influenced by sludge disposal at the 106-Mile Site.

delayed until all results were available from lower tiers (*i.e.*, activities in each of the tiers were conducted simultaneously due to pressing concerns voiced by the public). A major emphasis of the joint Monitoring Plan was placed on determining the farfield transport and fate (Tier 3) and potential long-term effects and environmental impacts (Tier 4) of the sewage sludge. Monitoring of sludge characteristics and disposal operations under Tier 1 received a similar level of attention under both plans.

To implement the joint Monitoring Plan, EPA, NOAA, and the USCG signed a Memorandum-of-Understanding (MOU) that defined the role of each agency. An interagency agreement administered the MOU. With respect to the conduct of the joint Monitoring Plan, the agency responsibilities were as follows:

- **EPA** — Monitoring disposal operations and short-term effects of sludges within and in the vicinity of the 106-Mile Site, and monitoring the farfield fate and long-term effects of dumped waste.
- **NOAA** — Monitoring the farfield fate and long-term effects of dumped wastes on living marine resources and the marine environment.

- USCG — Conducting surveillance of transportation of wastes under the MPRSA Permit Program and reporting violations to EPA.

2.1 Summary of Monitoring Program Design

This section presents an overview and schedule of the major studies conducted under the four tiers of the monitoring program. Details of the studies are contained in quality assurance project plans, survey plans and reports, technical reports, and peer-reviewed papers (see EPA, 1995 for a comprehensive listing of references and data archival locations). **Figure 2-1** summarizes the major study elements and time periods when field studies were conducted.

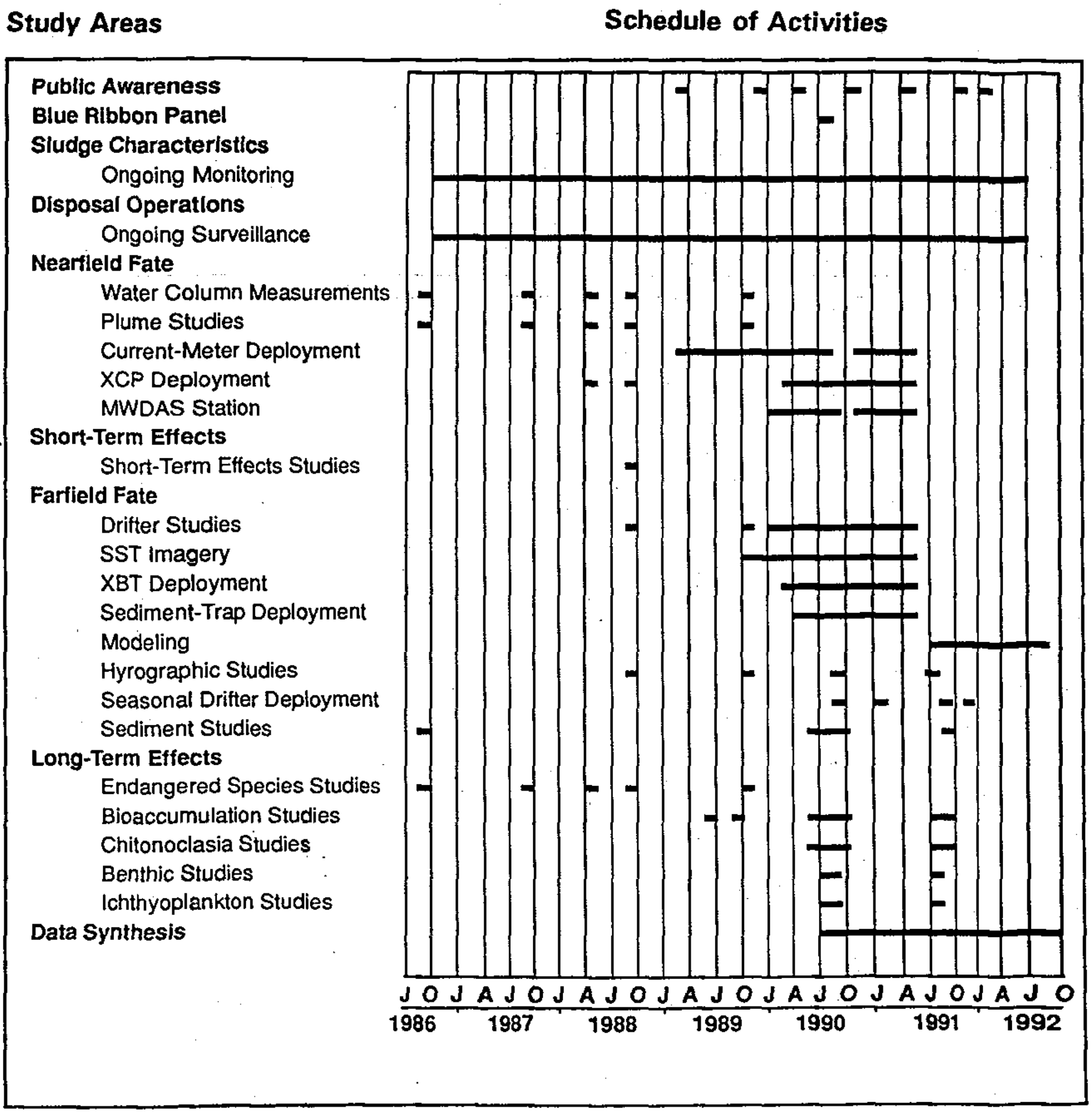
Monitoring sludge characteristics was an ongoing activity required of all permittees using the 12-Mile Site and the 106-Mile Site. Sludge characterization data from 1982 to 1985 were summarized in Santoro and Fikslin (1987). Other data, submitted in 1988 as part of permit applications for continued dumping of sludge at the 106-Mile Site, were summarized by EPA (1992f). Monitoring at the 106-Mile Site began in 1984 with surveys designed to collect baseline information in support of the site designation process. Additional baseline data were collected during 1985 and 1986. Dumping at the Site had already begun when the 1986 data were collected; however, stations were selected to avoid contamination from sludge plumes. Monitoring nearfield fate and short-term effects at the Site was initiated after the commencement of dumping in 1986 and continued through 1989. Beginning in 1989 and continuing through 1993, extensive farfield fate and long-term impact studies were conducted.

2.2 Tier 1: Sludge Characteristics and Disposal Operations

Tier 1 monitoring activities were designed to assess sludge characteristics and disposal operations to determine if the assumptions used in setting permit conditions were correct or if sludge quality was changing. Tier 1 also provided for surveillance of disposal operations to ensure that dumping occurred within the Site boundaries and at permitted rates. These requirements were addressed through the specific monitoring and surveillance activities contained in the ocean dumping permits.

Studies of Sludge Characteristics

Prior to 1989 when permits for the 106-Mile Site were issued, municipalities using the 12-Mile Site and 106-Mile Site for sludge disposal were required to report data on sludge quality and characteristics to EPA Region II on a quarterly basis (Santoro and Fikslin, 1987). These data included measurements of priority pollutants, toxicity to representative marine organisms, and standard measures of sludge characteristics. In addition, EPA Region II required permit applicants to submit additional sludge characterization data in support of the applications. A detailed review of the sludge characteristics data (EPA, 1992f) found the data to be questionable due to the lack of adequate quality control information, exceedance of holding times prior to analysis, inconsistent identification of measurement units, or poor identification of analytical methods used to obtain the data. As a result, EPA conducted an independent characterization study in 1988 to obtain more reliable information regarding sludge characteristics (EPA, 1992d).



XCP = **expendable current profiler**
MWDAS = **Marine Weather Data Aquisition System**
SST = **sea surface temperature**
XBT = **expendable bathythermograph**

Figure 2-1. **Major study elements of the 106-Mile Site joint monitoring program.**

EPA sampled and analyzed sludge from the nine sewerage authorities for a variety of parameters including toxicity to representative marine species (the fish *Menidia beryllina* and the mysid shrimp *Mysidopsis bahia*), organic priority pollutants, metals, and other characteristics (settleable matter, total suspended solids, total solids, wet-to-dry-weight ratio, density of solid matter, and specific gravity). Samples were collected as one-time grab samples or composites during barge-loading operations in August 1988. These data, in combination with quality control data from the sewerage authorities, were used to develop more stringent analytical requirements than previously required for monitoring sludge characteristics (EPA, 1989c). These new requirements were implemented in the permits issued by EPA in 1989.

A second sludge characterization study was conducted by EPA in 1991 to coincide with farfield monitoring activities (EPA, 1992e). Sludge samples were collected from seven permittees in March 1991 and analyzed for selected metals, organic compounds, pesticides, polychlorinated biphenyls (PCBs), linear alkylbenzenes (LABs), coprostanol, and other sterols to produce a set of the chemical data for the sludge that matched the sludge signature tracers used in fate and transport studies at the Site.

Disposal Operations

Disposal operations were monitored through surveillance of all ocean disposal activities. Several surveillance mechanisms were used, including a sludge manifest system designed to track sludge transfers from treatment plant to holding areas to barges, placing a shiprider on barges transporting sludge in the Harbor and barges transporting sludge to the 106-Mile Site, and by electronically monitoring disposal with the computerized ODSS developed by the USCG (EPA/NOAA, 1991).

2.3 Tier 2: Nearfield Fate and Short-Term Effects

Nearfield assessments of permit compliance and short-term environmental impacts were addressed under this tier. In the context of the joint Monitoring Program, *nearfield* refers to locations within the Site. The ocean dumping regulations require adherence to marine water quality criteria (WQC) and, where WQC do not exist, require that waste concentrations not exceed a factor of 0.01 of the concentration known to be acutely toxic to marine organisms after initial mixing (*i.e.*, the limiting permissible concentration or LPC). Concentrations of sludge and/or sludge constituents may not exceed these limits 4 h after dumping in the Site, and may not exceed these values outside the Site at any time.

To address whether these requirements were met, Tier 2 monitoring focused on understanding the short-term behavior of sludge plumes (dilution and settling characteristics); transport in and near the Site; and short-term effects of the sludge during initial dilution. Tier 2 monitoring was initiated with preliminary observations of sludge plumes in the summer of 1986 (EPA, 1988). More sophisticated plume tracking that included collection of water samples for laboratory analysis, was conducted in the summer of 1987 (EPA, 1992g). In addition, winter and summer measurements of plume behavior were made in 1988, and summer measurements were repeated in 1989 (Hunt *et al.*, 1992). Short-term biological assessments were made during the summer 1988 survey.

During 1987 and 1988, samples of sewage sludge were collected from barges before they departed for the Site. The barge samples were analyzed for selected physical parameters, trace metals, and other tracers of sludge. Spores of the microbe, *Clostridium perfringens* (a microbial tracer used to indicate the presence of sewage sludge), were also enumerated. Samples from 10 sludge plumes were obtained during 1987 and 1988 (EPA, 1992g,h,i; Redford *et al.*, 1992). For these pre-characterized sludges, sludge plumes were tracked and sampled at the Site for up to 12 h following disposal. The plume samples were analyzed for the same parameters used to characterize the barge samples. The immediate fate of the disposed sludge was estimated by a variety of plume-tracking observations, including monitoring the movement of surface drogues deployed directly into sludge plumes to determine the direction of transport; marking the surface expression of the plume with dyes to examine dilution characteristics; collecting *in-situ* data including salinity, temperature, and beam transmissometry to evaluate sludge dilution behavior, and direct sampling for laboratory measurements of chemical and biological tracers of sludge; and visually monitoring the plume movement from survey vessels and from an airplane.

Samples were also collected in the seasonal pycnocline to determine if sludge could be located in this biologically important oceanic feature. All surveys included sampling reference stations upstream of the 106-Mile Site. Data from these stations were used to evaluate changes in receiving water quality in the disposal site.

Short-term effects monitoring was conducted in September 1988 (EPA 1992h,i; Redford *et al.*, 1992). These activities included rapid chronic-toxicity tests using sea urchin sperm and eggs, and acute-toxicity tests using the mysid shrimp *M. bahia* and indigenous zooplankton (copepods). In addition, fish eggs were examined for genetic mutations and other potential developmental abnormalities. Ambient conditions indicative of biological function, specifically phytoplankton biomass, dissolved oxygen, and pH, were also monitored. Chlorophyll *a* was measured in surface seawater both within plumes and at locations within 20 km of the Site.

As part of both Tier 2 and Tier 3 studies, a long-term mooring to measure near-surface currents (30 m) and meteorological conditions was deployed in 1989 (EPA, 1992j) adjacent to the 106-Mile Site (**Figure 2-2**). The data from this mooring were transmitted to shore via satellite in near-real time. The current data from the mooring were used during plume-tracking measurements made during the summer of 1989 to aid in plume tracking and to allow estimates of sludge dispersion and transport (Hunt *et al.*, 1992). In addition, the continuous record of currents from the mooring was used in conjunction with the seasonal plume tracking data to estimate the inter-seasonal behavior and nearfield fate of sludge plumes (EPA, 1992j). EPA Region II used the meteorological and wave data in near-real time to monitor permit

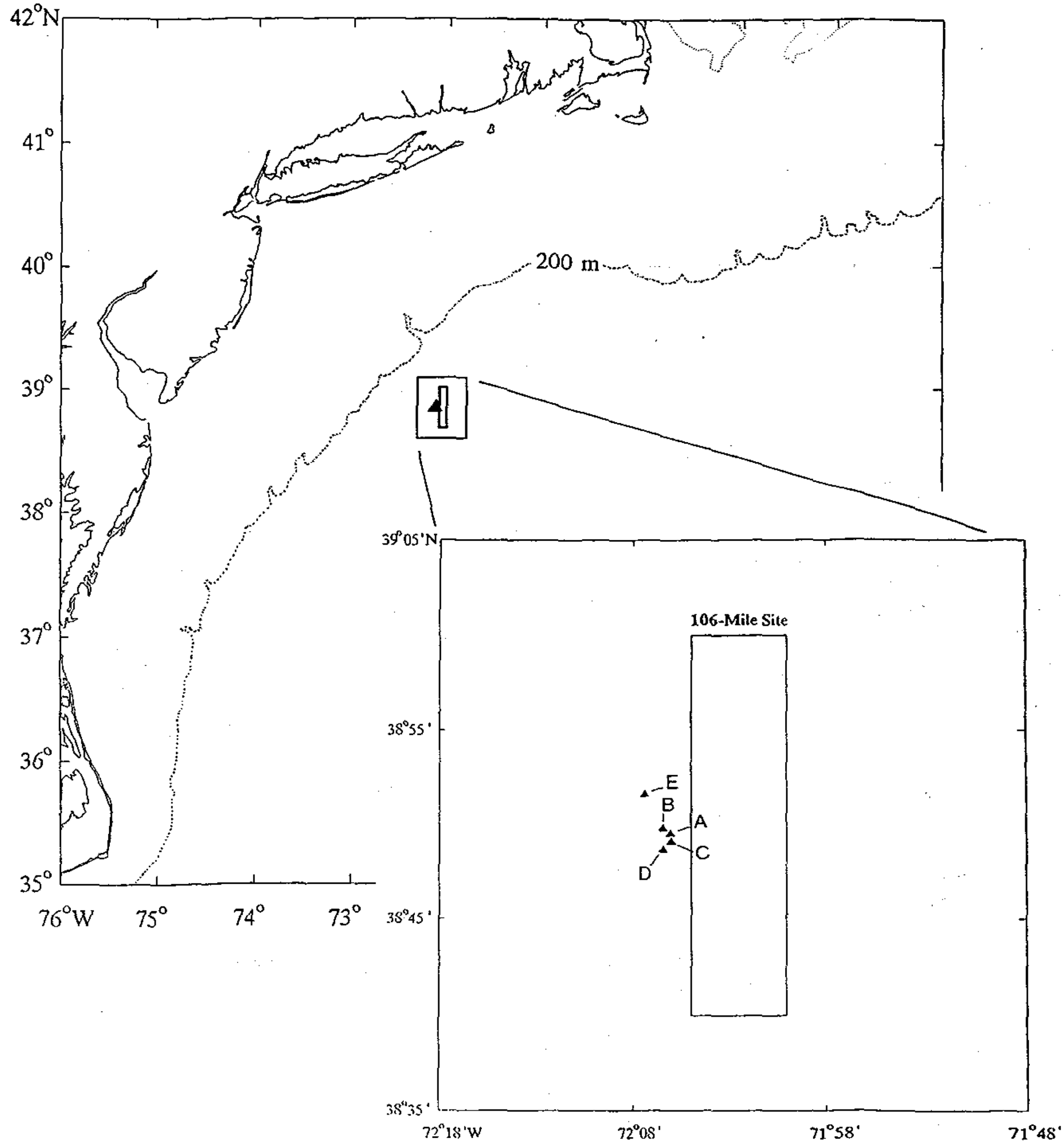


Figure 2-2. **The locations of long-term, real-time mooring deployments at the 106-Mile Site during the 106-Mile Site monitoring studies. Information from the moorings was used by EPA to determine wind and wave conditions, and to validate dumping reports.**

compliance under emergency dumping conditions. From August 1990 through Site closure in 1992, no specific studies were conducted to address nearfield fate or short-term effects hypotheses under Tier 2.

2.4 Tier 3: Farfield Fate

The studies conducted under Tier 3 were designed to provide information on the transport and fate of sewage sludge once it left the disposal site. This information was needed to evaluate whether the sludge was transported to sensitive areas noted in the ocean dumping regulations, and to understand locations where the sludge could accumulate. The Tier 3 information was also critical in interpreting the results from the Tier 4 long-term effects studies. Farfield fate information provided linkage between the potential sources of impact (*i.e.*, sludge disposal at the Site, transport off the continental shelf) and defensible conclusions regarding farfield, long-term effects.

Tier 3 monitoring activities were initiated in 1986 with the deployment of the real-time current meter mooring deployed adjacent to the Site (EPA, 1992j). Transport of sludge away from the 106-Mile Site in the surface waters (0 to 75 m) was evaluated in October 1989 through an extensive water column sampling program (Hunt *et al.*, 1992). This study was coupled with the deployment of four satellite-tracked drifting buoys in the Site (EPA, 1991a) to evaluate their utility for tracking the long-term movement of sludge from the 106-Mile Site, and to reveal information about the regional circulation and probable transport of sludge in near-surface waters. The drifter study was continued from December 1989 through June 1991 with weekly deployment of the drifters by EPA or the permittees (Dragos, 1993). This study was complemented by seasonal, simultaneous deployment of multiple drifters on the continental shelf and in the Slope Sea (Dragos *et al.*, 1995). Each of these studies was conducted in conjunction with sea-surface temperature (SST) studies designed to evaluate sludge interactions with major water masses in the region (EPA, 1992k,l,m).

In addition to these studies, a major deep-water current-meter mooring and sediment trap program was implemented between May 1990 and June 1991 (EPA, 1992n; Hunt *et al.*, 1993). This study was complemented by a number of surveys designed to evaluate sludge transport to and accumulation within sediments of the continental slope and outer continental shelf. The specifics of these and other studies that were conducted to determine the farfield fate of the sludge are described below.

Satellite-Tracked Drifter Studies

The four satellite-tracked surface drifters deployed in October 1989 revealed valuable information about the regional circulation and probable transport of sludge in near-surface waters. EPA determined that continued deployment of these drifters would provide valuable information about sludge transport onto the continental shelf and recirculation of surface waters through the Site. Thus, EPA resumed weekly drifter deployments in December 1989 and, in March 1990, permittees took over the drifter program as mandated in their disposal permits. The drifters were each tracked for four months. Between October 1989 and June 1991,

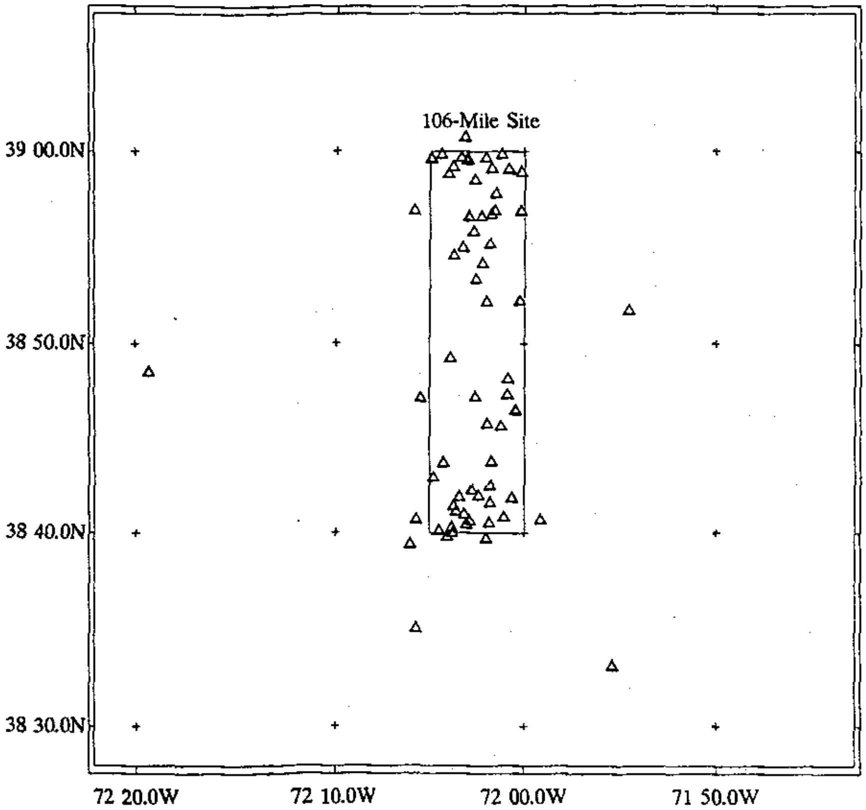


Figure 2-3. **Drifter deployment positions based upon first satellite-derived position for all drifters deployed at the 106-Mile Site between October 1989 and June 1991.**

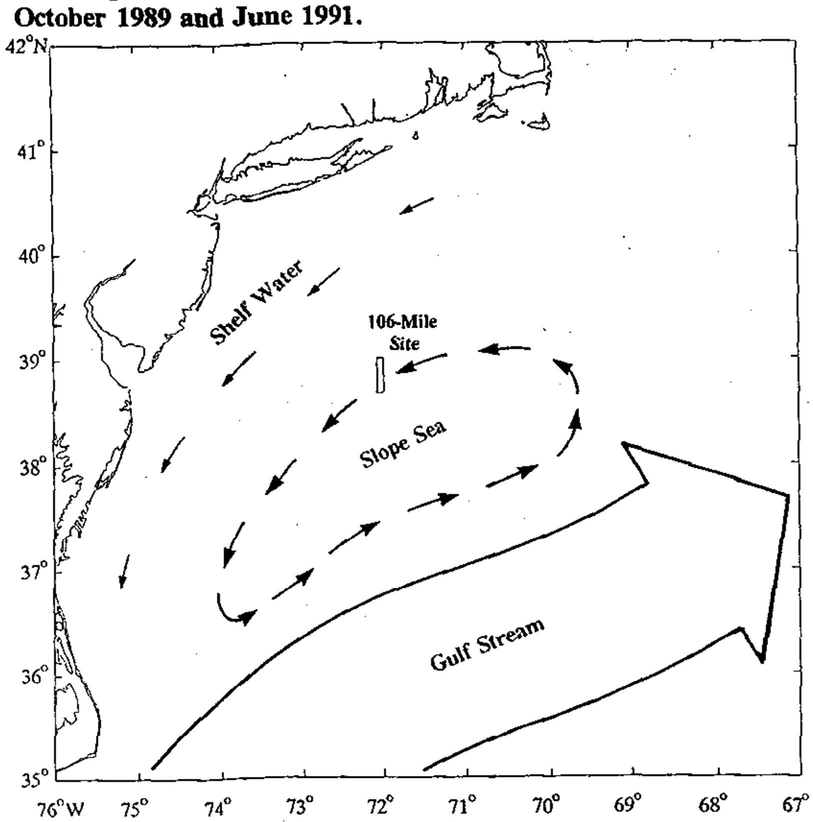


Figure 2-4. **Regional circulation in the Mid-Atlantic Bight.**

EPA and the permittees released a total of 66 drifters at the Site (Figure 2-3; Dragos, 1993). Seasonal deployments of surface drifters were completed by the NOAA National Ocean Service (NOS) in August 1990 (eight drifters), followed by seasonal cross-shelf break deployments of four drifters each in February, May, and August 1991 (Aikman and Empie, 1991). NOAA NOS deployed the final set of four drifters in October 1991 (Aikman and Empie, 1992). The simultaneous seasonal deployments were designed to examine the large-scale southwest drift and recirculation of the Slope-Sea gyre; the existence and role of convergence at the shelf break; movement of surface waters onto the continental shelf; and modes of entrainment by the Gulf Stream versus possible transport to the South Atlantic Bight (Figure 2-4). The drifter studies were also designed to aid in estimating the effects of features such as wind, warm-core rings, Gulf Stream meanders, and meso-scale shelf-break eddies on the dispersion of the sludge. The drifters, deployed in the upper layer (10 m) of the ocean, tracked the likely movement of dissolved constituents and suspended sludge particles that move with the upper ocean.

Sea-Surface Temperature Studies
Composite weekly SST maps were prepared by NOAA from Advanced Very-High Resolution Radiometer (AVHRR) SST imagery from satellite-based sensors (EPA, 1992k,l,m). These measurements were made in conjunction with the drifter studies. Satellite imagery data on surface temperature were used to identify the water masses in the study area over time and to determine other features such as the shelf/slope and Gulf Stream fronts, and the presence of meanders, eddies, and rings associated with the Gulf Stream. Weekly composite images of the study area (including the 106-Mile Site) were produced and overlain with drifter tracks to aid in interpreting drifter interactions with the major water masses in the study region.

In addition, the NOAA National Marine Fisheries Service (NMFS) used daily sludge disposal information and water mass type (shelf water, slope water, warm core rings) derived from SST data to determine the frequency of dumping into each water mass type. Results from the start of dumping in 1986 through June 1992 were complied (Ruhsam, 1995).

Expendable Current Profiler Deployments
The permits issued for sludge disposal at the 106-Mile Site required the permittees to deploy an expendable-current-profiler (XCP) at the Site approximately once per week. The XCPs continuously recorded water temperature and current speed and direction, in relation to depth. From March 1990 to March 1991, the XCPs were deployed from the permittee barges. In April 1991, after the New Jersey authorities responsible for the deployments stopped ocean dumping, deployment responsibility was transferred to New York City. EPA Region II approved deployments from aircraft flying over the Site as a substitute for barge deployments. The aircraft deployments continued until June 1, 1991, when the XCP program was formally terminated (EPA, 1992o,p,q).

Expendable Bathythermograph Deployments
In 1990 and 1991, NOAA NMFS's Atlantic Regional Group increased the frequency of ship-of-opportunity temperature profile acquisition along a transect from New York to Bermuda. Surface temperatures (taken with a thermometer) and temperature profiles to about 500 m (obtained using expendable bathythermographs or XBTs) were obtained from the apex of the New York Bight (shoreward of the shelf break) to the north (cold) wall of the Gulf Stream. These data were supplied to project scientists to aid in interpreting water-mass, drifter, and moored current-meter studies. Data from 48 transects, collected between March 1990 and June 1991, are available from EPA (EPA, 1990b; 1991b,c). NOAA NOS continued to acquire XBT data through December 1991.

CTD Transmissometer Surveys
During the October 1989 farfield survey (Hunt *et al.*, 1992), two methods were used to search for evidence of sludge in surface waters outside the Site. In one method, the distribution of particles was measured by using a real-time conductivity, temperature, density and transmissometer (CTD/TR) system towed at a depth of 10-15 m along three transects of

stations downcurrent of the Site (**Figure 2-5**; Hunt *et al.*, 1992). In the second method, hydrographic profiles were made to a depth of 75 m at a series of stations located to the southwest of the 106-Mile Site (**Figure 2-6**). Water samples were obtained from three depths at these same stations and examined for the presence of various sludge tracers (xylem tracheids or plant cells that conduct water in plant stems; spores from the bacterium *C. perfringens*; and trace metals such as cadmium, copper, chromium, and mercury). This survey focused on (1) detecting the presence of large particles that may settle rapidly, (2) determining if sludge could be detected in surface waters away from the Site, and (3) determining if WQC were exceeded outside the Site.

Traditional hydrographic surveys in the vicinity of the 106-Mile Site were conducted by NOAA NOS in 1990 (*Delaware II* Cruise 90-08; Aikman and Empie, 1991) and 1991 (*Delaware II* Cruise 91-09; Aikman and Empie, 1992). The CTD/TR and XBT profiles were collected to a depth of 500 m. The CTD/TR data and XBT data from the first survey (**Figure 2-7**) provided a description of the water-mass structure which helped in the identification of the water-mass type for a NMFS midwater fish study (see Tier 4), and provided a

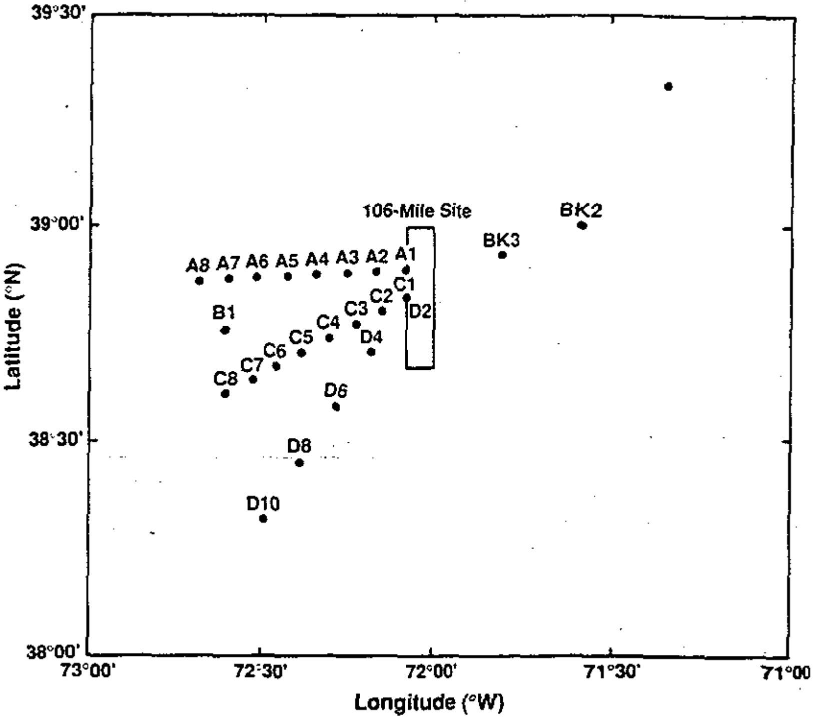


Figure 2-5. **Location of the discrete stations along three transects sampled during the October 1989 survey to the 106-Mile Site. Samples collected from these stations were used to evaluate transport of sludge in surface waters from the 106-Mile Site.**

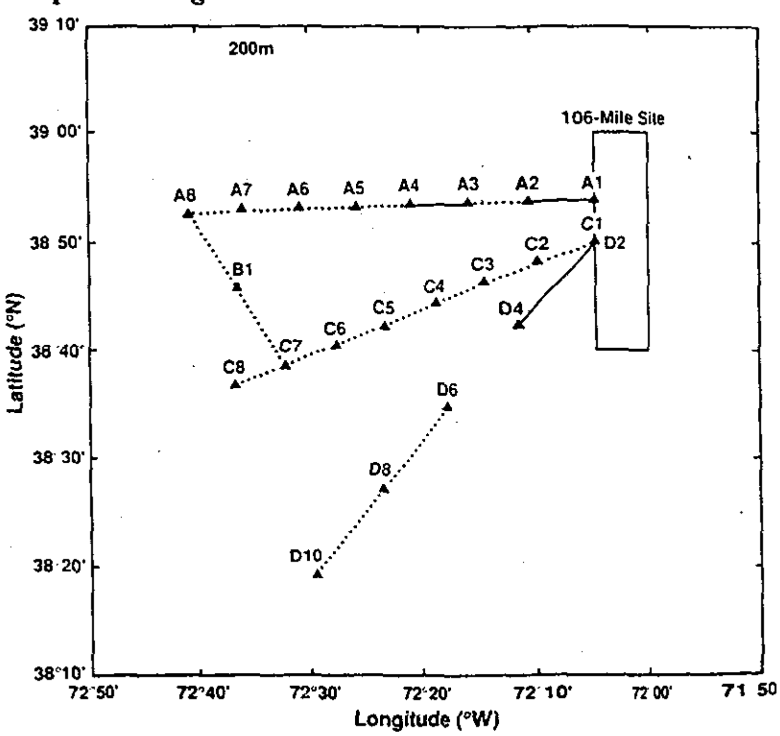


Figure 2-6. **October 1989 survey study area west of the 106-Mile Site indicating locations where horizontal transects of near-surface turbidity were acquired (dashed lines). Sewage sludge plumes were observed only along transects that are indicated by bold lines.**

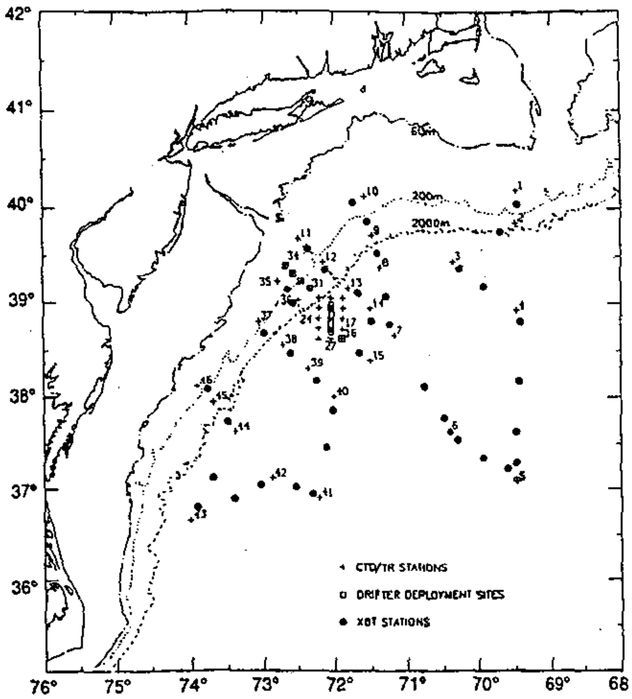


***Figure 2-7.* Location of CTD/TR, XBT, and drifter deployment sites in the Mid-Atlantic Bight from the *Delaware II* Cruise 90-08 of 6-18 August 1990. The 106-Mile Site is represented by the rectangle outlined in the center of the figure with its upper right corner at 39°N, 72°W.**

synoptic description of the three-dimensional structure in the vicinity of the 106-Mile Site.

The second hydrographic survey of the Mid-Atlantic Bight and the 106-Mile Site was work was conducted during a NOAA NMFS midwater fish survey. The hydrography consisted of 66 CTD/TR profiles and 45 XBT drops **(Figure 2-8)**. Survey activities were concentrated to the southwest of the Site in an effort to collect multiple samples of midwater fish in the region most likely to be impacted by sludge contaminants.

Real-Time Current Meter Studies

The EPA real-time current-meter mooring, deployed 1 nmi west of the Site, was used to obtain statistical information on the near-surface currents (30 m), temperature, and meteorological conditions at the Site. Current data from the mooring were transmitted to EPA in real time via ARGOS satellite and were used, in association with other Tier 3 studies, to evaluate farfield movement of the sludge. The initial deployment was made in January 1989, and four re-deployments were made through October 1990 (EPA, 1992j) with recovery of the system in July 1991.

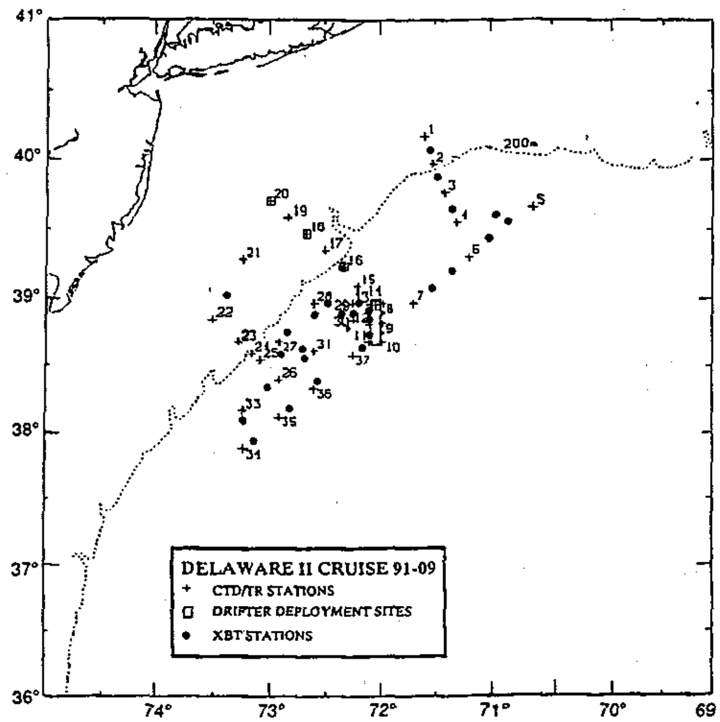


***Figure 2-8.* Station map of the *Delaware II* Cruise 91-09 of 5-16 August 1991. Only the original 37 CTD/TR stations are numbered on the map and repeat locations are as indicated. The 106-Mile Site is represented by the rectangle in the center of the figure.**

A major current meter measurement program was conducted from May 1990 through June 1991 as part of the sediment trap program. The sediment trap program is described below.

Sediment Trap Studies

EPA Studies. In the spring of 1990, EPA designed and implemented a deep-water mooring program to obtain data on oceanographic currents and to collect information on the flux of sludge particles falling through the water column. Between May 1990 and June 1991, 10 deep-water moorings (**Figure 2-9**), instrumented with internal-recording current meters and sediment traps, were deployed in the vicinity of the 106-Mile Site (Hunt *et al.*, 1993; EPA, 1990c,d,e; 1991d). Six moorings were positioned on an along-slope transect. One of these was a reference mooring located upstream of the 106-Mile Site away from any influence of sludge disposal. Three moorings were positioned across the continental rise to the west and southwest of the Site; these moorings intersected one of the along-slope moorings to form a transect of four moorings positioned across the continental slope. An additional mooring was located in the mouth of the Hudson River Canyon.

The objectives of the sediment-trap program were to determine whether sludge was (1) deposited in significant quantities on the seafloor at or near the 106-Mile Site; (2) transported toward the continental shelf and deposited in regions of significant marine resources; or (3) suspended in the water column for months, such that it was carried into the central North Atlantic by the Gulf Stream or recirculated with the Slope Sea gyre. The sediment trap program was designed to obtain direct evidence of sludge-transport pathways, and to acquire sufficient information on particle flux and current velocities to allow better predictions of post-disposal transport and fate of the sludge. Towards this end, the moorings were designed (**Figure 2-10**) with sediment traps located at ≈100 m (surface) and 1000 m (mid-depth) below the ocean surface, and ≈250 m above the sediment (bottom). Mooring locations and the deployment depths of the sediment traps were chosen to resolve expected horizontal gradients in sludge deposition near the seafloor

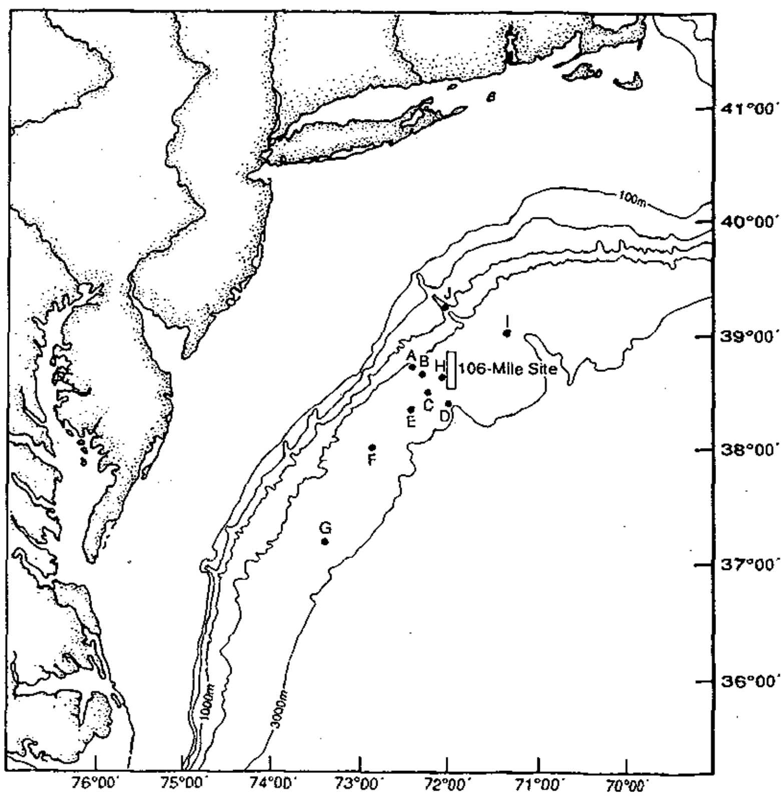


Figure 2-9. **Locations of the sediment trap moorings deployed in the vicinity of the 106-Mile Site between May 1990 and June 1991.**

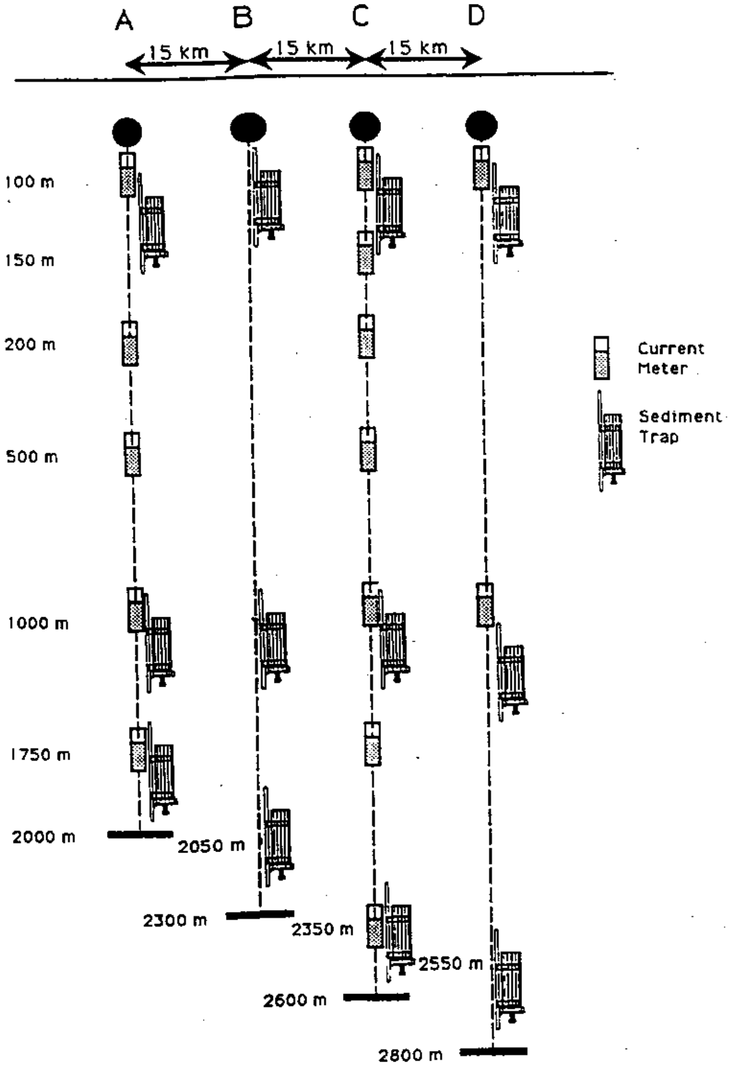


Figure 2-10. **Configuration of the deep sea mooring array deployed at the 106-Mile Site showing sediment trap and current meter depths.**

and vertical gradients in the water column. Because there was abundant historical information on currents near the disposal site, current meters were not located on all moorings; rather, current meters were clustered on several of the moorings to maximize data return on information necessary to refine predictions of sludge transport and fate. Specifically, the current meter program was focused on developing information on vertical shear downcurrent of the disposal site and cross-isobath variability in current velocities.

The sediment-trap moorings were first deployed in May 1990, recovered and redeployed in September and November 1990, and recovered again in June 1991. Details of deployment, recovery, and servicing are given in a series of EPA reports (EPA, 1990c,d,e; 1991d; Hunt *et al.*, 1993; 1995a).

The material collected in the sediment traps was analyzed for chemical, microbiological, and physical characteristics, including

- Mass (wet, dry, carbonate-free, organic matter, and ash weights)
- Physical characteristics of the particles (visual observations and xylem tracheid enumeration)
- Trace metals (*e.g.*, copper, cadmium, chromium, mercury)
- *C. perfringens* spores
- Stable isotopes of carbon, nitrogen, and sulfur
- Organic contaminants (PAHs, LABs, cyclic alkanes, and sterols).

Results from these analyses were used to calculate the flux of the various sludge tracers through the water column at each trap location.

NOAA National Underwater Research Program (NURP) Studies. The transport of sludge from the Site was also studied by a consortium of Federal and university researchers with funding from the NOAA NURP program.

This research was conducted relatively close to the 106-Mile Site, and included collection of sediment samples and deployment of sediment traps (within 10 to 100 m of the seafloor) and current meters for one year (July 1989 through June 1990) at two locations near the western boundary of the Site (Takada *et al.*, 1994). Samples from these sediment traps and the sediments (both surface sediments and cores) were analyzed for chemical tracers of the sludge.

Sediment Studies

The potential accumulation of contaminants in sediments due to sludge disposal was further evaluated by NOAA through the analysis of sediment samples collected during a survey on the R/V *Oceanus* in October 1991 (White *et al.*, 1993). Samples were obtained within and near the 106-Mile Site (**Figure 2-11**), from locations removed from the Site but in areas where sludge could be transported based on transport models, and from reference areas located beyond any significant influence from the Site. Sediment box cores were obtained from 34 stations. From these samples, sub-cores were taken for analysis of trace metals, organic contaminants, total organic carbon, and sediment grain size. In addition, the top layer of each core was sampled for spores of *C. perfringens*.

Modeling Studies

Several modeling studies were completed to address the distribution of sludge concentrations in the water column, to estimate the areal extent of sludge deposition in the sediments and the fraction of the sludge reaching the sediments, and to assess the transport of sludge from the slope towards and onto the continental shelf. Fry and Butman (1991) developed the first post-disposal model of the sludge fate. In addition, a number of modeling exercises were completed as part of the site designation study (O'Connor *et al.*, 1983, 1985; Walker *et al.*, 1987, 1989). These studies, however, were constrained by the lack of current meter data and information on the settling characteristics of the sludge. The Fry and Butman model improved on the earlier models by using more recent current meter results from the vicinity of the 106-Mile Site and updated sludge settling rates published by Lavelle *et al.* (1988).

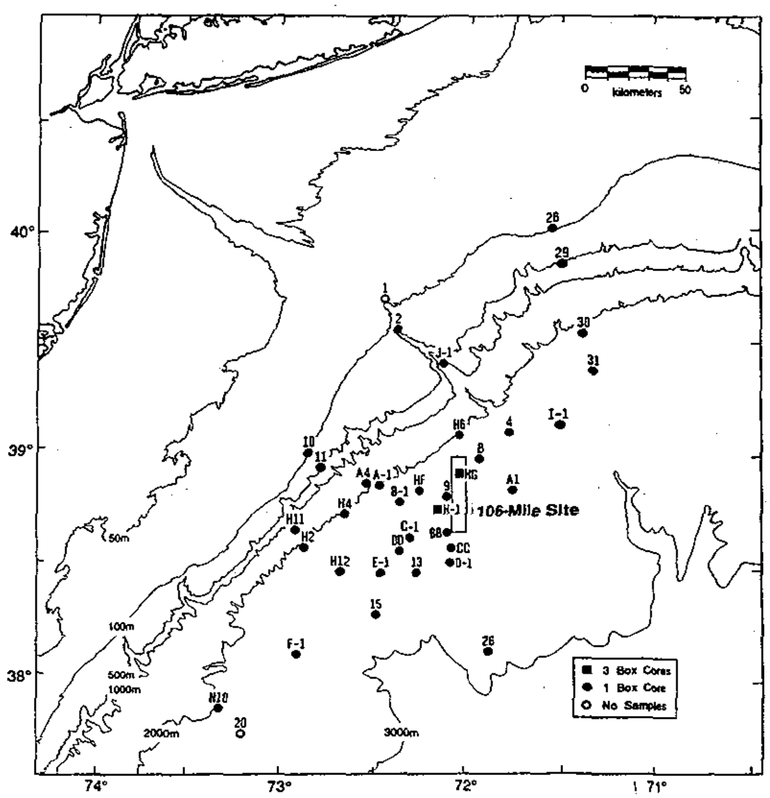


Figure 2-11. **Sediment samples collected during the October 1991 NOAA survey on the R/V *Oceanus* covered the area of potential impact from sludge dumping.**

In 1990, NOAA NOS evaluated the suitability of several modeling approaches, such as hydrodynamic, particle transport, dispersion, and deposition models, to determine their utility in predicting the fate of sewage sludge originating at the 106-Mile Site (Aikman *et al.*, 1991).

Nearfield and farfield conditions were considered, as was the suitability of both historical and contemporary data that could be employed by the models. The models were analyzed according to their potential for addressing the question of suspended sludge concentrations, estimating sludge depositional areas, and assessing the transport of sludge from the slope to the shelf.

For the 106-Mile Site program, an approach was chosen that combined several different models, including (1) a numerical sludge dispersion model that examines the transport and farfield fate of sludge (Isaji *et al.*, 1995); (2) a statistical model that addresses suspended sludge constituents and the probability of transport in the upper ocean (Churchill, 1990; Churchill and Aikman, 1995); and (3) a hydrodynamic model that simulates the three-dimensional velocity, sludge concentration, and deposition fields for the entire farfield region (Patchen and Herring, 1995).

Results from the numerical dispersion model and the sediment trap program were used to complete estimates of transport from mass balance considerations (Burch *et al.*, 1993, Hunt *et al.*, 1993, 1995b). Two approaches were used. The first examined the transport of the sludge by accounting for the mass of sludge distributed into a number of possible compartments in the water column and sediments (Burch *et al.*, 1993). The second approach evaluated the deposition of sludge to the sediments based on specific chemical tracers in the sludge and the input of these tracers at the Site (Hunt *et al.*, 1993, 1995b).

Special Studies

NOAA NURP Outer Shelf/Canyon Study. The University of Connecticut, with funding from NOAA NURP, conducted a series of studies that focused on the potential transport of sludge from the 106-Mile Site to undersea canyons located on the outer continental shelf. The study, which was conducted between 1990 and 1992 in the heads of eight canyons in the outer New York Bight, evaluated whether contaminant gradients in the sediments from heads of these canyons (200-700 m depth) could be detected and related to dumping at the 106-Mile Site. Submersible craft were used to conduct video surveys of the bottom community and sediment substrates, and to collect representative sediments for analysis of contaminants and other sewage tracers.

Sludge Degradation Studies. Degradation rates of organic matter in the sediments of the continental margin near the 106-Mile Site were investigated to ascertain the impact of sludge disposal in the surface waters upon benthic processes (Sayles and Martin, 1991; Sayles *et al.*, 1995). Nutrient profiles for pore waters of sediments within the disposal area, as well as from regions not influenced by disposal activities, were assessed to determine the impact of sludge on metabolic rates. Estimates of the oxygen flux were also made from a free-vehicle benthic lander deployed in the area of the Site.

The lander data were used to assess the existence of non-diffusive transport, as well as the fluxes of nitrate and carbon resulting from benthic metabolism. Physical processes of mixing were studied through analysis of ^{234}Th in the top 5 cm of sediment.

Stable Isotope Transfer into Organisms. As part of the NOAA NURP studies, the stable isotopes of carbon, nitrogen, and sulfur were measured in the sea urchin *Echinus affinis*, an opportunistic deposit-feeder that is attracted to local aggregates of plankton-derived organic material (Van Dover *et al.*, 1992). Measurements of these isotopes were made to determine if the sewage-derived organic material reaches the seafloor and enters the benthic food web, specifically through the surface-deposit feeding activities of *E. affinis*.

2.5 Tier 4: Long-Term Effects

Numerous studies were conducted to evaluate the effects of sludge disposal on the receiving environment. These studies included observations of endangered species, contaminant uptake studies using midwater and benthic organisms, and benthic community assessments in canyons and on the continental shelf. In addition, a series of studies was conducted on the continental shelf to evaluate potential impacts on important commercial fisheries.

Endangered Species Studies

The occurrence of endangered species in the vicinity of the 106-Mile Site was assessed throughout the EPA monitoring program conducted between 1986 and 1989. During this period, trained observers of marine mammals, turtles, and seabirds were included on all EPA surveys to the 106-Mile Site. The observers recorded the presence, number, and behavior of all endangered species sighted along the survey tracks.

Midwater Fish Studies

In 1989, the Northeast Fisheries Center of NOAA's NMFS conducted a pilot study to evaluate the feasibility of collecting midwater fish in the vicinity of the Site and their utility for detecting uptake of contaminants associated with the sewage sludge. The midwater fish were selected because they live in the upper water column and are a major component of the food web in the upper water column in the region of the Site. Certain midwater fish, mainly lantern fish (Myctophidae) and hatchet fish (Sternoptychidae), are also relatively abundant throughout the upper layers of the offshore waters of the northwestern Atlantic. The daily pattern for these fish is to migrate vertically from a depth of 200-700 m, where they spend daylight hours, and back to the upper layers where they spend the night. This behavior increases the likelihood that some of the fish would encounter water or food sources that had been in contact with sewage sludge dumped at the surface, and thus they could be used as sentinel organisms for the presence of sludge contaminants.

Based on the success of the pilot feasibility study, NOAA NMFS conducted a second survey in August 1990 (NOAA, 1992). During this study, samples of midwater fish, plankton, and micronekton were collected from 32 stations near the 106-Mile Site and along transects over a broad area around the Site (**Figure 2-12**).

Stations were selected to provide samples of water from the outer shelf, the slope, and Gulf Stream rings (if present). Stations in the Sargasso Sea were chosen for comparison, and to provide samples indicative of background levels of contamination. A total of 1311 midwater fish specimens from 42 species and 32 plankton samples was collected. Samples of these organisms were analyzed for metals and organic contaminants.

A third midwater fish survey was conducted in August 1991 (Zdanowicz *et al.*, 1995). This effort focused on collecting samples of midwater fish and their prey from the area southwest of the 106-Mile Site in the region most likely to be affected by the sludge disposal (**Figure 2-13**). Seventeen stations were each sampled two or three times to increase the probability of detecting a sludge signature. A total of 3761 midwater fish from 25 representative species and plankton samples from 17 stations was obtained for contaminant analysis.

Epibenthic Organisms – Bottom Fish Studies

In September 1989, bottom fish from the vicinity of the 106-Mile Site (EPA, 1992r) were collected as part of the NOAA NURP studies. Fish collected in two trawls from

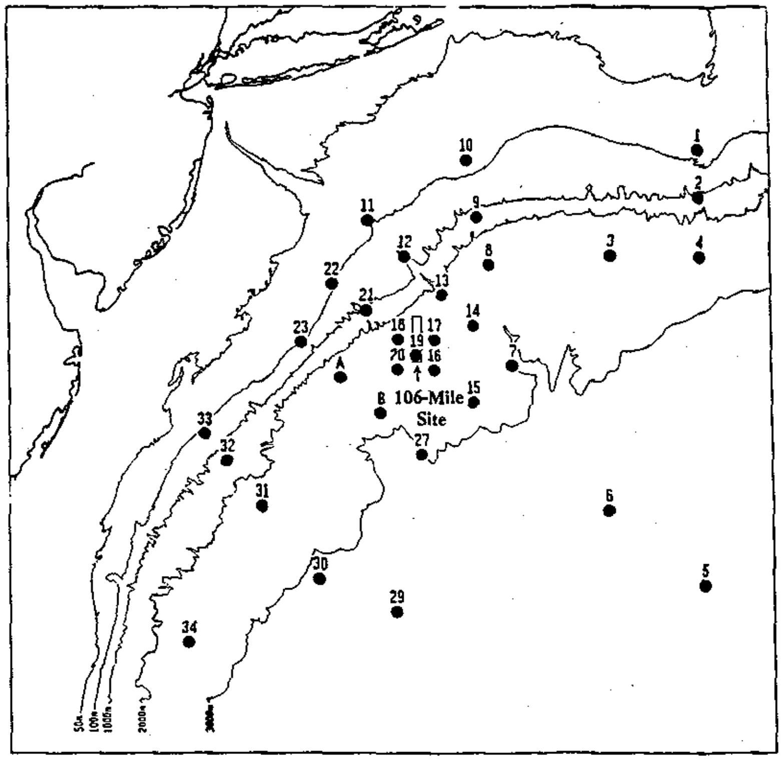


Figure 2-12. **Station locations for the August 1990 NOAA/NMFS midwater fish survey covered a broad area around the 106-Mile Site.**

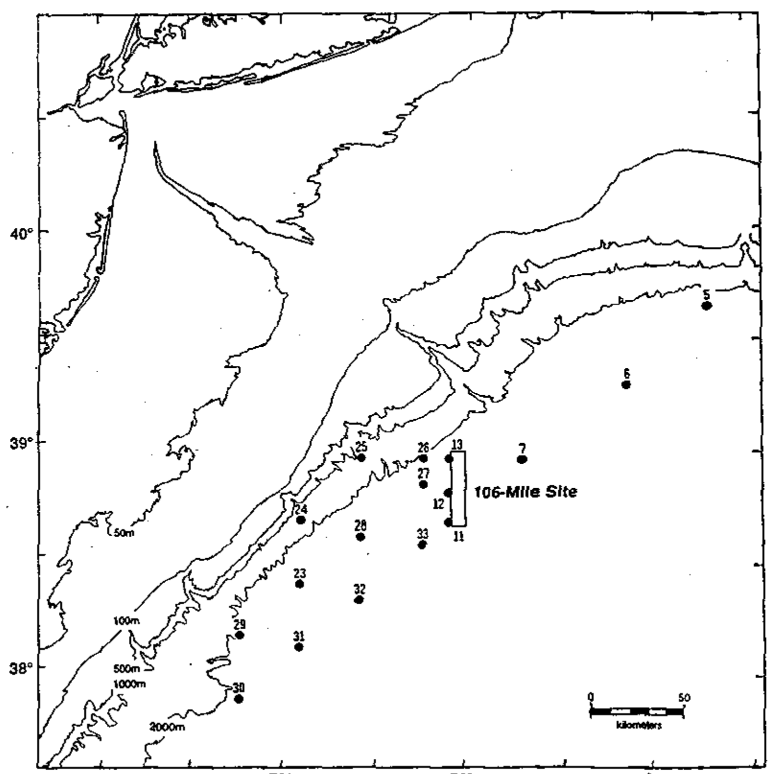


Figure 2-13. **Station locations for the August 1991 NOAA/NMFS midwater fish survey primarily covered the area southwest of the 106-Mile Site.**

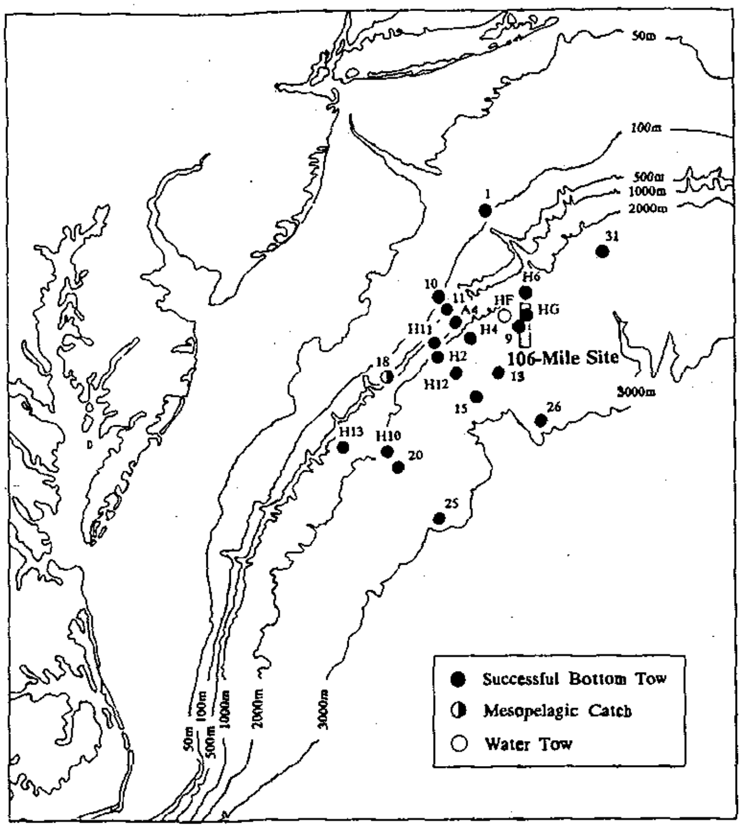


Figure 2-14. **During the 1990 and 1991 NOAA surveys, trawl collections of epibenthic megafauna for analysis of chemical contaminants were made at 21 stations in and around the 106-Mile Site in the area of expected sludge dispersion.**

the northern end of the 106-Mile Site were split for histopathological/ biochemical analysis and trace metal and organic analysis. These analyses were made to (1) provide an initial assessment of the impact of sewage sludge disposal on bottom fish in the vicinity of the 106-Mile Site and (2) evaluate the feasibility of monitoring the bioaccumulation of sludge-related contaminants in these fish. Fish liver and muscle samples from three blue hake *(Antimora rostrata)*, two rattail *(Coryphaenoides armatus)*, and one cutthroat eel *(Synaphobranchus kaupi)* were analyzed for PCBs, halogenated pesticides (including DDT and its metabolites), polynuclear aromatic hydrocarbons (PAHs), and trace metals. Histopathological condition and P450 cytochrome inducement were also evaluated (Steinhauer *et al.*, 1995).

In August 1990 and 1991, NOAA used deep-sea trawling to collect epibenthic megafauna for analysis of chemical contaminants (NOAA, 1992). These collections included many of the same bottom fish sampled in 1989. Samples were taken at stations in the area of expected sludge dispersion and in surrounding areas (**Figure 2-14**). In 1990, a total of 817 finfish and invertebrates was collected for potential chemical analysis. Nine species of finfish were collected in sufficient quantities for analysis. Of these, three species (*C. armatus*, *S. kaupi*, and *A. rostrata*) were obtained from at least five stations and were the dominant megafauna. In August 1991, NOAA collected more than 500 mega-invertebrates from 28 stations (**Figure 2-15**) for analysis of heavy metals and organic contaminants. Thirteen species of finfish and two shrimp species were collected. Between the two collection periods, more than 900 organisms were subjected to chemical analysis (Sennefelder *et al.*, 1995).

NOAA NMFS also commissioned commercial long-line fishers to collect tilefish *(Lopholatilus chamaeleonticeps)* from submarine canyons located between Lydonia and Wilmington Canyons (Steimle *et al.*, 1995). Between the fall/winter 1990 and winter 1992, 90 fish were

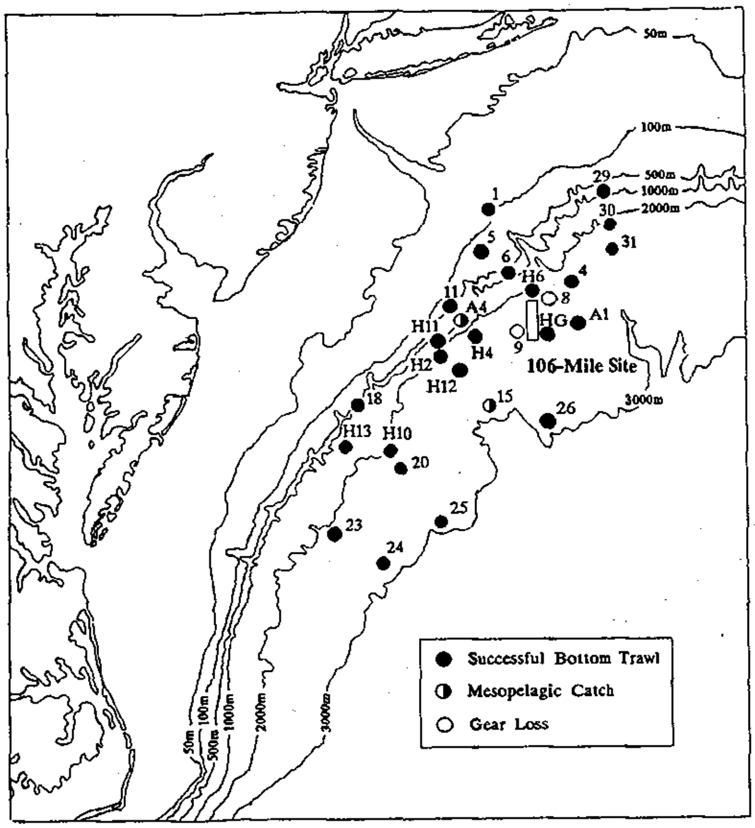


Figure 2-15. **More than 500 mega-invertebrate samples, for heavy metal and organic contaminant analysis, were collected by NOAA from 27 stations during an August 1991 survey.**

obtained from 6 canyons. Two canyons (Atlantis and Hudson) were sampled on three occasions over this time period. Animals between 50 and 70 cm in length were analyzed for metals and organic contaminants.

Lobsters collected as part of the chitinoclasia shell disease study (see below) were also analyzed for metals and organic contaminants. Where possible, equal numbers of lobsters with and without shell disease were analyzed. Both the tail muscle and hepatopancreas (liver) were analyzed.

Contaminant levels in commercially important fish (tilefish, flounder) and shellfish (red crabs and lobsters) were also measured. Between 1990 and 1992, more than 1000 red crabs were collected from the heads of 11 submarine canyons on the outer continental shelf. In addition to assessing the general condition of these organisms, the concentrations of metals and PCBs were measured.

Fisheries Bottom Trawl Surveys

From 1963 through the present, the NOAA NMFS Northeast Fisheries Center has conducted bottom trawl surveys on the Northwest Atlantic Shelf and upper slope between Cape Hatteras and the Scotian Shoals (Chang, 1993). These studies continued during the period when sludge was being dumped at the 106-Mile Site. Data from the spring of 1982 through the spring of 1986 (pre-dumping period) were evaluated and compared with data from the autumn of 1986 through the spring of 1990 to determine if dumping had any effect on 11 economically important fish species from this area.

Benthic Community Studies

The NOAA NURP program initiated long-term benthic community effects studies in 1989. These studies continued through the summer of 1992. In addition to these studies, the NOAA NMFS sampled 18 stations for benthic infaunal community structure in October 1991.

Bacterial Studies

The autochthonous bacterial community in water overlying core samples collected from the 106-Mile Site was tested for its ability to grow under *in-situ* conditions of temperature and pressure. Responses of the bacterial community at this Site were compared to those of a community collected in the same manner and depth at a control site (Straube *et al.*, 1991). In addition, the NOAA NURP Outer Shelf/Canyon study (Sawyer *et al.*, 1995) examined the sediment–water interface along transects in the canyon heads for bacterial communities and the presence of sewage indicators such as *Clostridium perfringens*, cyst-forming amoebae, and bacterivorous ciliates and flagellates.

Chitinoclastic Shell Disease in Lobster

Prior to the passage of ODBA, fishermen catching lobsters in offshore waters of the mid-Atlantic Bight reported high prevalence of chitinoclastic shell disease and declining catches, which they associated with sludge dumping at the 106-Mile Site. In 1989, a joint NOAA/EPA Working Group examined available information and reported "no conclusive evidence to associate shell disease in offshore (crustacean) populations with sludge dumping activities at the 106-Mile Site" (NOAA and EPA, 1989). However, the Working Group also pointed out the scarcity of data from offshore populations, and recommended monitoring and research that would address such information gaps.

- **Commercial Catch Inspections.** This NOAA NMFS study (NOAA, 1992) was designed to determine the prevalence and severity of shell disease in commercially collected lobster from canyons along the Atlantic continental shelf from Georges Bank to Virginia (**Figure 2-16**). Beginning in July 1990 and continuing through the summer of 1992, 15,004 legal-size American lobsters *(Homarus americanus)* from 185 commercial catches from 9 canyons were examined for signs of chitinoclasia (Ziskowski *et al.*, 1995). Samples were

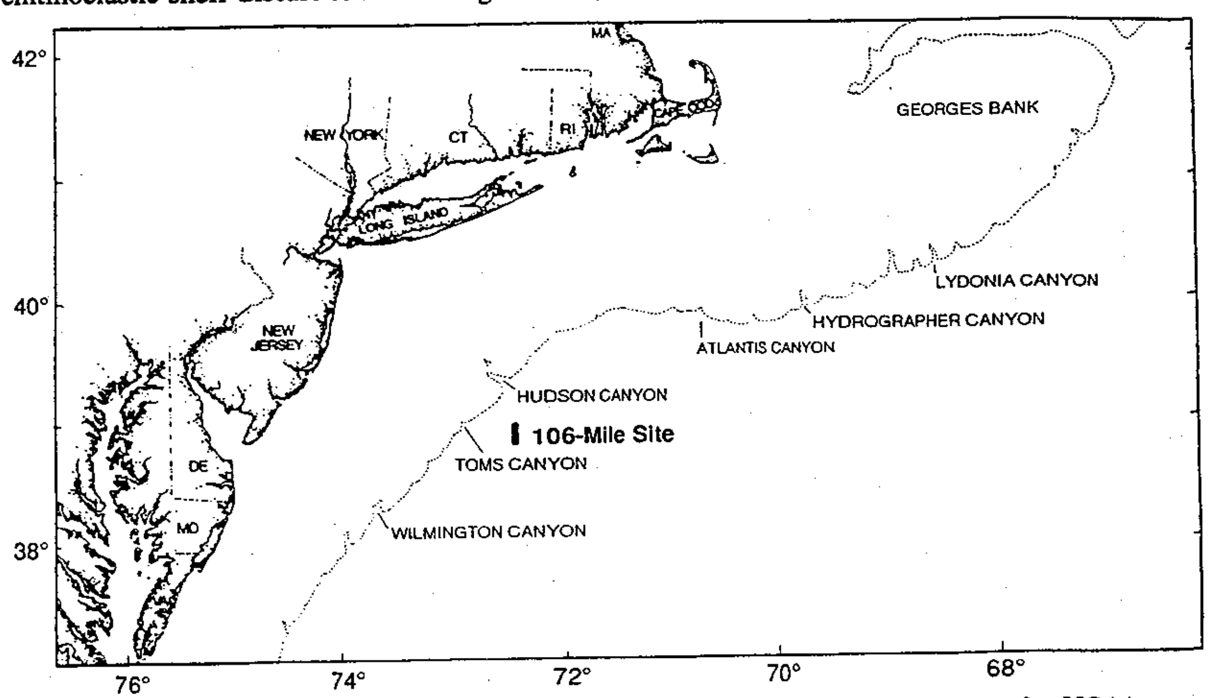


Figure 2-16. **Canyons sampled by commercial lobster and/or tilefish vessels during the NOAA canyon studies along the Atlantic continental shelf.**

obtained through the cooperation of a group of lobster-boat operators who allowed regular inspection of a portion of their catches. Although weather and equipment problems made it impossible to conform to an ideal sampling schedule, one or two samples from each canyon were obtained during each season from July 1990 through August 1992, providing estimates of seasonal changes in prevalence and variance of chitinoclasia.

- **NOAA NMFS Groundfish Survey.** Results from commercial catch inspection were further supplemented with data collected during five groundfish surveys conducted by NOAA NMFS in 1990 (fall) and 1991 (spring and fall) (NOAA, 1992; Ziskowski *et al.*, 1995). The randomly stratified trawls provided an independent database for comparison with the data obtained from commercial vessels. In addition, because the trawls permit examination of animals below the legal catch limit, determination of the prevalence of shell disease in juvenile lobster was possible. Trawls were made at shelf stations from Cape Hatteras to Nantucket Shoals and on Georges Bank. More than 460 specimens were examined during the two years of this study.

- **Commercial Catch Observer Program.** In support of the 106-Mile Site monitoring program, the ongoing NOAA NMFS Northeast Fisheries Center commercial catch observer program extended observations on chitinoclastic shell disease in lobster over the entire continental shelf from Cape Hatteras to the Gulf of Maine (NOAA, 1992). From January 1989 to December 1991, observers made 461 trawl trips (**Figure 2-17**) and 24 pot trips (**Figure 2-18**), providing information from 1449 trawls and 485 pot hauls (Wilk *et al.*, 1995). A total of 3420 lobsters, obtained from 60 trawls and 186 pot hauls, was examined for chitinoclasia prevalence and severity.

- **NOAA NURP Outer Shelf/Canyon Studies.** Chitinoclastic shell disease observations on both red crabs and lobsters were also made during the NOAA NURP studies in the heads of submarine canyons (Feeley, 1993).

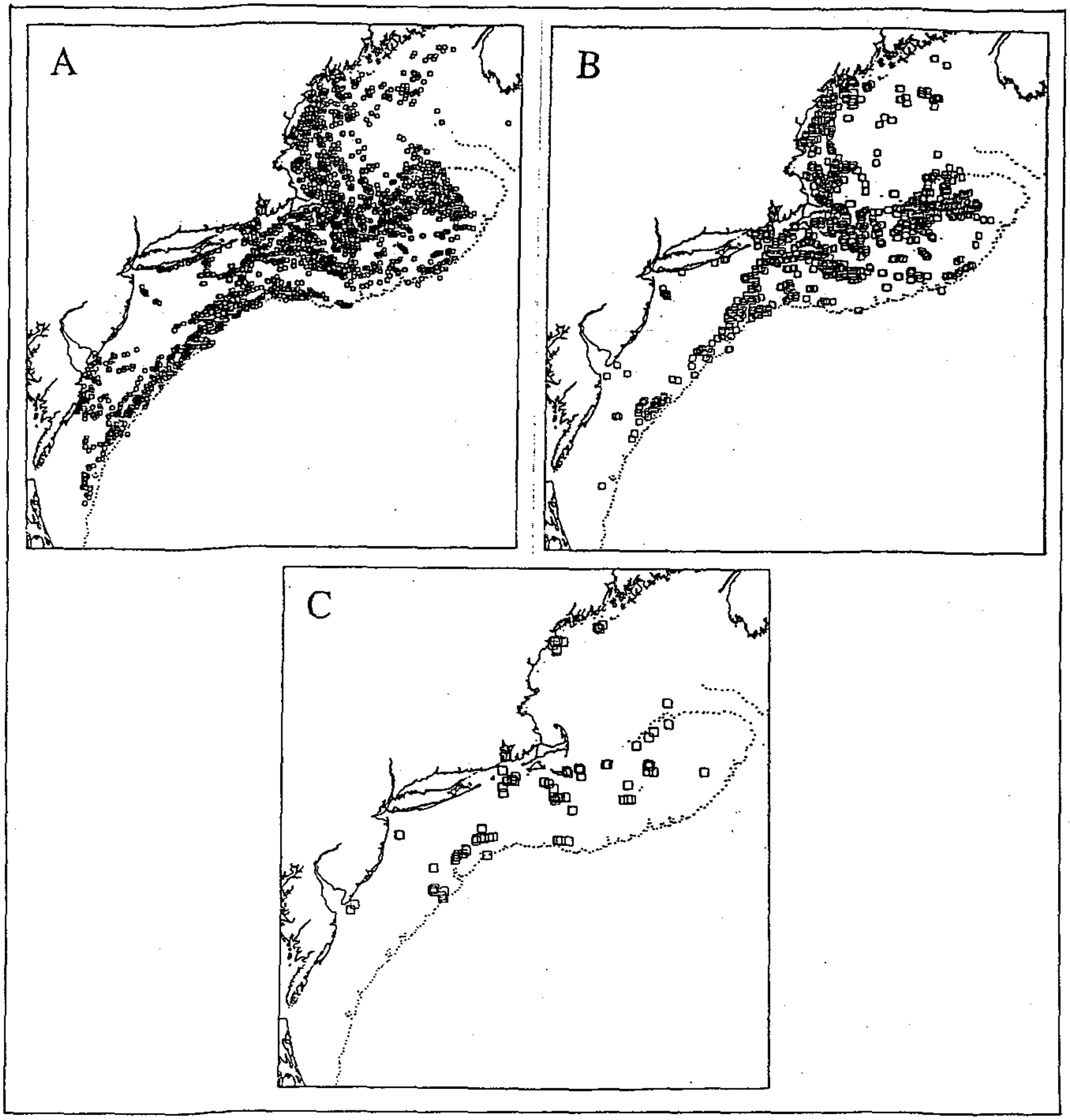


Figure 2-17. Observations relevant to the 106-Mile Site American lobster (*Homarus americanus*) chitinoclasia studies made between January 1989 and March 1991 by sea samplers while on board trawlers.

(a) Location of all tows monitored.
(b) Location of tows where American lobster occurred.
(c) Location of tows where observations for the incidence and severity of chitinoclasia were made.

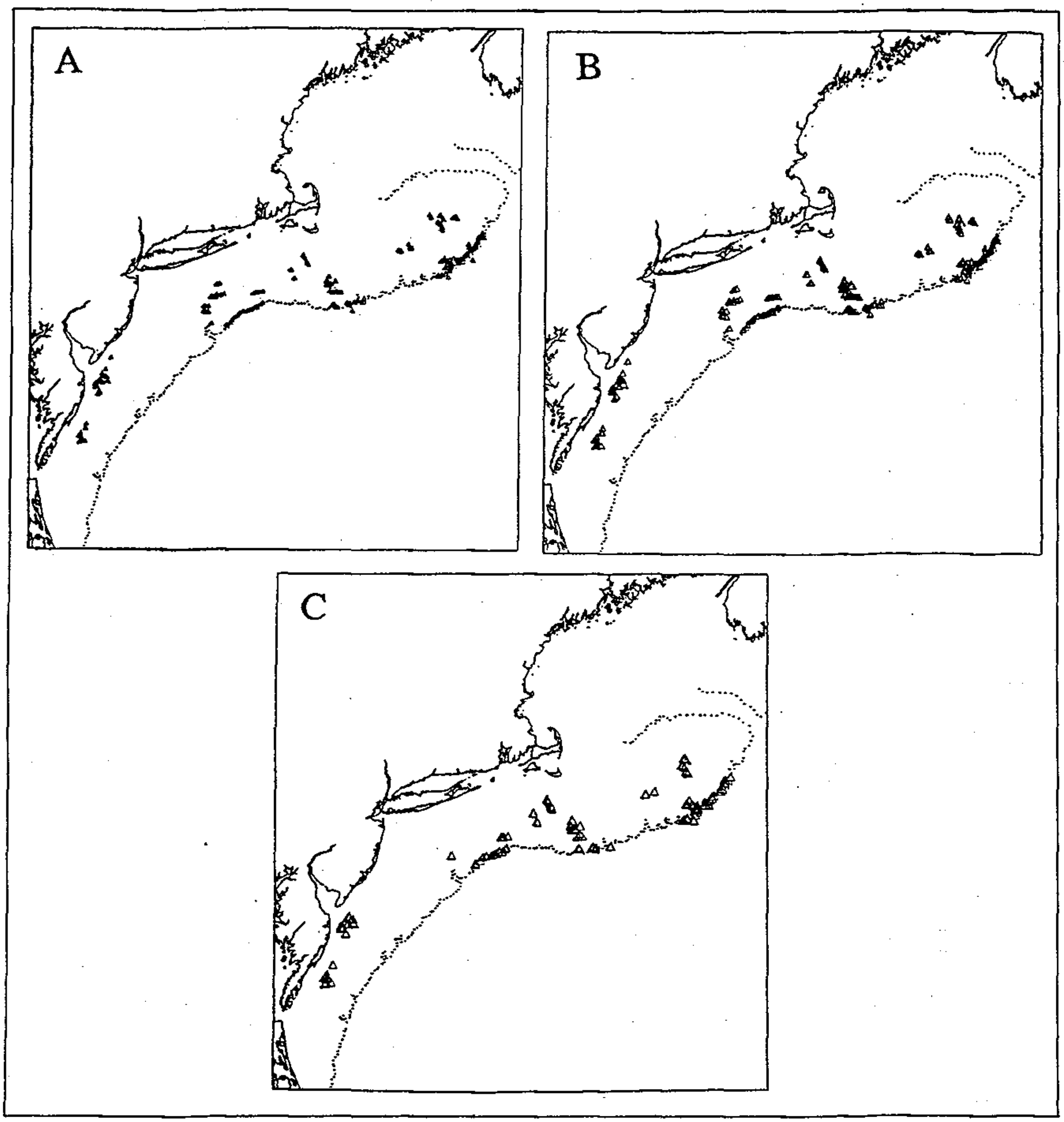


Figure 2-18. **Observations relevant to the 106-Mile Site American lobster (*Homarus americanus*) chitinoclasia studies made between January 1989 and March 1991 by sea samplers while on board lobster pot fishing vessels.**

(a) Location of all hauls monitored.

(b) Location of hauls where American lobster occurred.

(c) *Location of hauls where observations for the incidence and severity of chitinoclasia were made.*

3.0 MONITORING RESULTS AND CONCLUSIONS

The 106-Mile Site monitoring program produced an extensive data set on sewage sludge characteristics plus transport, fate, and effects in the receiving waters. This section summarizes the major results and conclusions of the program. Readers are referred to the numerous papers published in the peer-reviewed literature and in EPA and NOAA reports generated during the program (EPA, 1995) for more detailed information. The presentation is organized by monitoring tier. Each hypothesis is stated, followed by a brief summary of the major conclusions, and supported by relevant study results. In some instances, several hypotheses are grouped together because information from the various studies are related to these hypotheses. A complete summary of reports and papers published through 1995 and data archival locations can be found in EPA (1995).

3.1 Tier 1: Sludge Characteristics and Disposal Operations

The objectives of Tier 1 monitoring were to (1) assess sludge characteristics to determine if the sludge quality was changing, and to verify if the assumptions made in setting permit conditions were correct and valid throughout the period when the Site was in use, and (2) to provide surveillance of disposal operations to ensure that dumping occurred within the 106-Mile Site boundaries and at permitted rates. These objectives were addressed by activities directed at hypotheses H_01 and H_02. In addition, the data were used in several of the other evaluations examining the fate and transport of the sludge. Several of the key results are summarized below.

H_01: The physical and chemical characteristics of sludge are consistent with waste characterization information available at the time the permits for the 106-Mile Site were issued.

Sludge characteristics were generally similar to results from the waste characterizations performed in the mid-1980s. Physical and chemical characteristics were highly variable both within permittees and among the various treatment facilities.

Sludge Characterization

- The physical characteristics of sludges examined by EPA in 1988 (EPA, 1992g) were generally similar to those reported by the sewerage authorities between 1985 and 1987. Metal concentrations were slightly lower than reported by the sewerage authorities. Organic contaminant concentrations were substantially lower than the minimum detection limits of standard EPA methods. The toxicity to representative test species was variable among the sewerage authorities and was generally similar to previous results.

- An EPA review of sludge characterization data in 1988 found that bioassay and chemical results, although variable, were generally consistent with waste characterization information supplied with the permit applications (**Table 3-1**). However, applicants were neither using the most appropriate methods nor conducting analyses under rigid quality assurance plans.

- Sludge bioassay results submitted by the permittees during 1990-1991 were variable both within and among sewerage authorities. Sludges were frequently more toxic to representative marine species (*M. beryllina* and *M. bahia*) than when the permits were established in August 1989. Thus, sludge quality during the 1990-1991 period was generally lower than in August 1988.

Table 3-1. Comparison of sludge toxicity in August 1988 to information provided in permit applications [From EPA, 1992g]. The LC_{50} (concentration at which 50% of the test organisms do not survive) results are reported as the percentage of the whole sludge.

Authority	*Menidia beryllina* August 1988 Application	*Menidia beryllina* Permit Application	*Mysidopsis bahia* August 1988	*Mysidopsis bahia* Permit
PVSC	0.49	0.63	0.17	0.09
MCUA	5.95	1.95	2.11	2.80
BCUA	1.55	1.95	2.10	0.66
LRSA	0.53	0.96	0.06	0.20
RVSA	1.49	1.60	0.88	0.11
JMEUC	1.92	1.35	1.68	1.50
NYCDEP	1.59	1.30	2.25	1.41
NCDPW	2.33	2.87	0.92	1.40
WCDEF	0.91	1.47	1.17	1.16

PVSC: Passaic Valley Sewerage Commission, NJ
MCUA: Middlesex County Utilities Authority, NJ
BCUA: Bergen County Utilities Authority, NJ
LRSA: Linden-Roselle Sewerage Authority, NJ
RVSA: Rahway Valley Sewerage Authority, NJ
JMEUC: Joint Meeting of Essex and Union Counties, NJ
NYCDEP: New York City Department of Environmental Protection, NY
NCDPW: Nassau County Department of Public Works, NY
WCDEF: Westchester County Department of Environmental Facilities, NY

Improved sludge quality was noted for two authorities after April 1991.

- Very low concentrations of several priority pollutant chemicals and other compounds that are good tracers of sewage in the marine environment were found in the March 1991 sludge characterization (EPA, 1992e). This study showed that

  (1) Total PAH concentrations ranged from 1.95 $\mu g/g$ to 14.3 $\mu g/g$ dry weight. Among the PAH compounds measured, fluorene, phenanthrene, fluoranthene, and pyrene were present in the highest concentrations in most sludge samples.

  (2) Total linear alkyl benzenes (LABs), compounds that are not priority pollutants but that have been found to be extremely useful tracers of sewage-related material in the oceans, were detected in all sludge samples analyzed. Concentrations of LABs ranged from 39.8 $\mu g/g$ to 145 $\mu g/g$ dry weight.

  (3) PCBs and several chlorinated pesticides were found in low concentrations in every sludge sample. The lower-chlorinated PCB congeners (Cl_3-Cl_4) dominated the PCB distribution. Aroclor 1242 provided the closest match to the PCB patterns detected. Total PCB concentrations differed by less than a factor of 2.5 among the sludges analyzed and ranged from 0.190 $\mu g/g$ to 0.450 $\mu g/g$ dry weight. Of the chlorinated pesticides, DDT and its metabolites DDD and DDE, dieldrin, and *cis*-chlordane were most often detected.

  (4) Coprostanol, a sterol common to mammals and useful as a tracer of sewage in

receiving environments, was present in higher concentrations than all other sterols. The concentration varied widely, ranging from 62.8 μg/g to 3980 μg/g dry weight.

(5) The metal silver (Ag), another useful tracer of sewage sludge, was found in all samples. Concentrations ranged from 23.0 μg/g to 156 μg/g dry weight. Aluminum (Al) concentrations ranged from 9600 μg/g to 50,300 μg/g dry weight. Copper (Cu) concentrations ranged from 520 μg/g to 2030 μg/g dry weight. Other metals were found in varying concentrations.

(6) Stable isotope values in the sludge were typical of terrestrial plants and varied among the treatment plants.

Sludge Input to the Site

- Beginning in August 1989, permittees were required to provide EPA Region II with monthly information on the total dry and wet tons of sludge dumped at the Site. Each permittee reported annual data from January 1986 through August 1989.

(1) From 1988 through 1990, the volume of sludge dumped at the 106-Mile Site was relatively constant, ranging between 8 and 10 million wet tons of sludge per year (see Section 1.0). Between 1986 and June 1992, a total of ≈42 million wet tons (1.5 million dry tons) of sewage sludge was disposed at the Site. Approximately 50% of the total wet tons dumped (≈22 million wet tons) was dumped by NYCDEP. Each of the other permittees contributed less than 6 million wet tons to the total load to the Site; three permittees each dumped less than 900,000 wet tons. On a dry weight basis, NYCDEP and PVSC contributed ≈40% and ≈30%, respectively, of the dry tons disposed at the Site.

(2) Representative estimates of the input of sludge were derived for the period that sediment traps were deployment near the Site (May 1990 through June 1991). During this period, ≈322,000 dry tons of sludge were

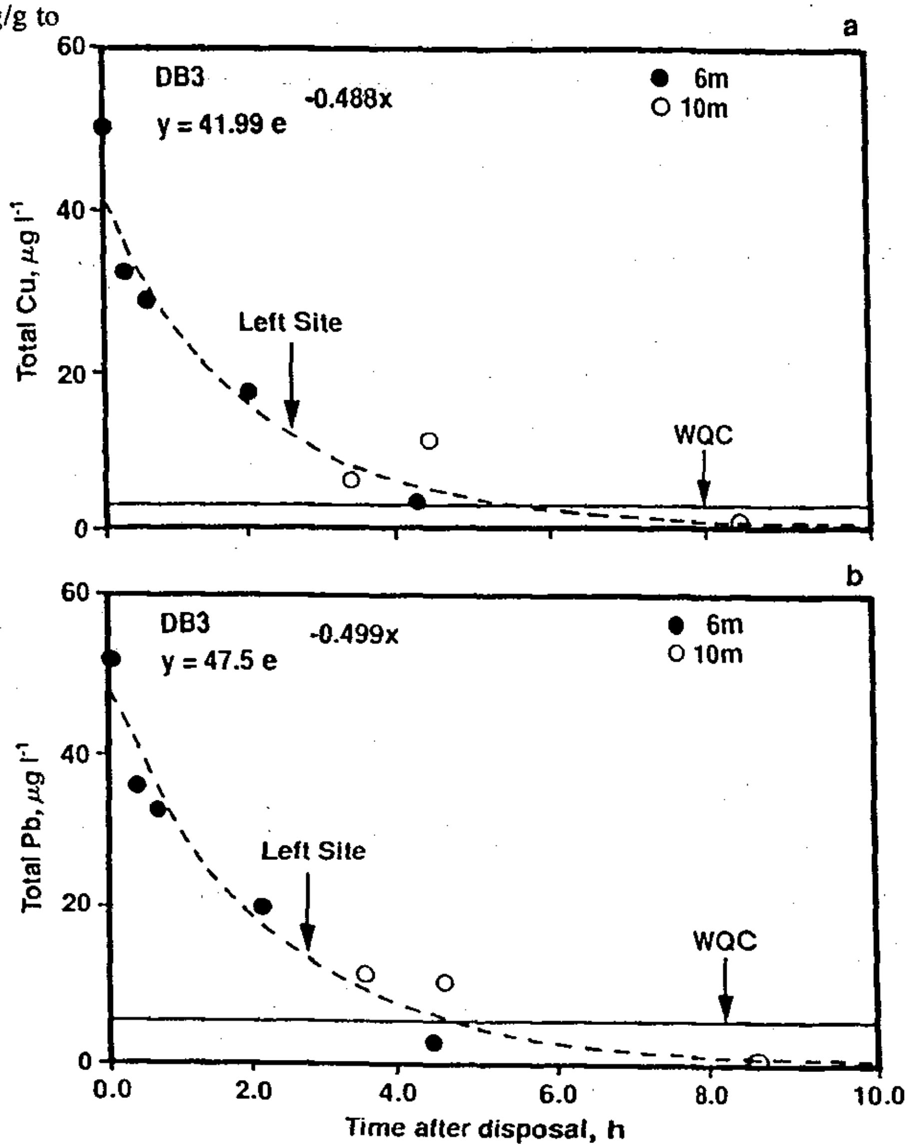


Figure 3-1. **A decrease in (a) copper (Cu) and (b) lead (Pb) concentrations was evident in plumes tracked in September 1987. Concentrations in the plume when it crossed the Site boundary are shown, as are the EPA chronic marine water quality criteria (WQC) for these metals.**

dumped at the 106-Mile Site (**Table 3-2**). This represents about 22% of the 1.5 million dry tons of sludge dumped at the Site between 1986 and 1992. Contaminant concentrations in the sludge during this period were used to calculate the input of selected sludge tracers from the dumping activity. The total input during the sediment trap period ranged from a low of 85 kg for total PCBs to ≈465,000 kg of coprostanol, a natural mammalian sterol. It was estimated that about 277,000 kg of zinc (Zn), 275,000 kg of copper (Cu), 22,600 kg of silver (Ag), and 71,000 kg of lead (Pb) were dumped during this period. These data were used to estimate the total metric tons of these sludge tracers dumped between 1986 and 1992.

$H_0$2: Disposal rates and operations are consistent with the requirements of the ocean dumping permits.

As part of the process to develop conditions for the permits required by the ODBA, EPA evaluated whether the dumping rates, in effect prior to the ODBA, would result in compliance with the requirements of the ocean dumping regulations. Based on the results presented below, EPA determined that disposal operations did result in compliance with the water quality requirements set forth in the ocean dumping regulations (**Figure 3-1**). As a result, new

Table 3-2. Summary of total monthly and cumulative loading of sewage sludge (dry tons) to the 106-Mile Site during two EPA sediment trap deployment periods, May to October 1990, and November 1990 to June 1991.

MONTH Year	MONTHLY Tons	CUMULATIVE Period 1	Period 2
05/90	6,057[a]	6,057	
06/90	31,195	37,252	
07/90	29,194	66,446	
08/90	31,529	97,975	
09/90	29,301	127,276	
10/90	32,794	160,070	
11/90	30,983		30,983
12/90	28,988		59,971
01/91	27,488		87,459
02/91	25,272		112,731
03/91[b]	16,388		129,119
04/91	12,912		142,031
05/91	13,393		155,424
06/91[c]	6,454		161,878

[a]Partial month; total for the month was 30,280
[b]Six New Jersey authorities stopped dumping by March 30, 1991
[c]Partial month; total for the month was 12,908

TOTAL FIRST PERIOD	160,070
TOTAL SECOND PERIOD	161,878
TOTAL BOTH PERIODS	321,948

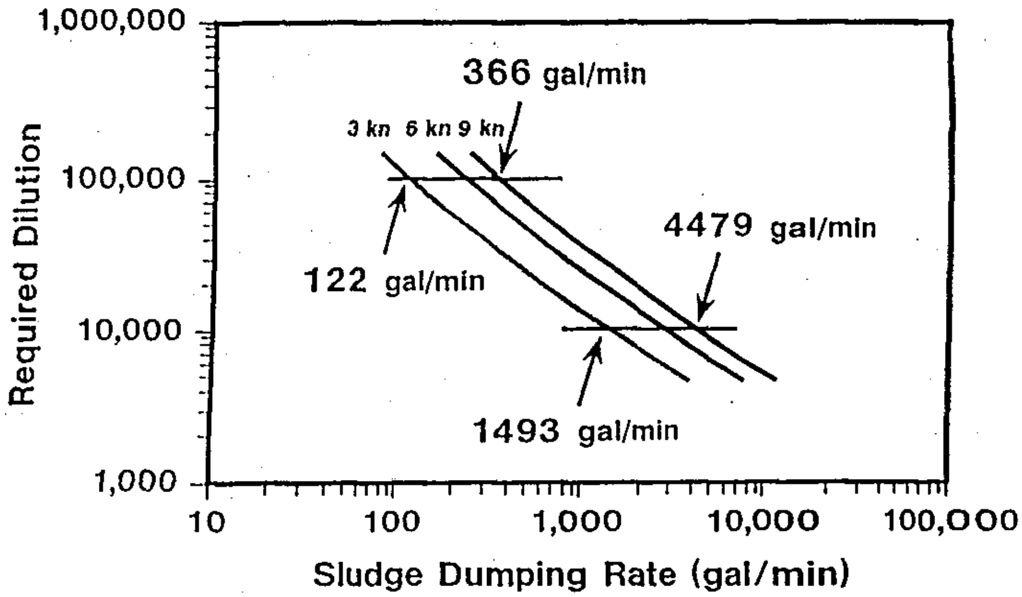


Figure 3-2. **Nomograph of sludge dumping rates (in gal/min) vs. sludge dilutions 4 h after dumping at the 106-Mile Site used to control dumping rates at the Site. Separate curves are given for the barge speeds of 3, 6, and 9 kn.**

permit conditions were established by EPA. In general, disposal operations were conducted in a manner that was consistent with the ocean dumping regulations and permits. The Ocean Dumping Surveillance System and shipriders were effective in ensuring that dumping rates and locations were as specified in the permits. In addition, the shiprider program effectively ensured that all sludge transfers made in the Harbor and in coastal waters, and that all dumping operations were conducted as required by the ocean disposal permits.

Dumping Rates

- Information on sludge dilution rates and vessel operations was used to develop a nomograph (EPA, 1992s) which showed the relationship between dumping rates and ability to meet the limiting permissible concentrations (LPC; **Figure 3-2**). According to the calculation, the disposal rate was to be less than 1000 gal/min for three of the permittees and less than 5000 gal/min for the remaining six permittees. Quarterly review of the permittee sludge characterization data and recalculation of allowable disposal rates ensured that dumping at the Site complied with EPA water quality criteria (WQC).

- In 1990-1991, following evaluation of the sludge bioassay results, EPA modified the discharge rates (established in August 1989) of several permittees (**Figure 3-3**). The lowest discharge rates were required of the LRSA and PVSA. MCUA had the highest allowable discharge rates. Except for WCDEF in New York and MCUA, PVSA, and LRSA in New Jersey, new discharge rates established in December 1990 were lower than the rates specified in the permits.

- The initial dilution (that was caused by the physical action of the wake during dumping) is an important parameter needed to set disposal rates in permit conditions. The permittees were required to determine these initial dilution rates for the different barge types that used the 106-Mile Site. A survey conducted by New York City found no difference in the initial dilution rate for barges that employed different dumping mechanisms and verified the initial dilution used in the permits (EA Engineering, Science, and Technology, Inc., 1991). Had the field studies verified that initial wake-induced dilution was, in fact, different, the permit condition would have allowed higher disposal rates for some types of barges.

Disposal Operations

- During the period that all nine permittees were discharging sludge at the 106-Mile Site, between 50 and 65 dumping missions were conducted each month. In December 1991,

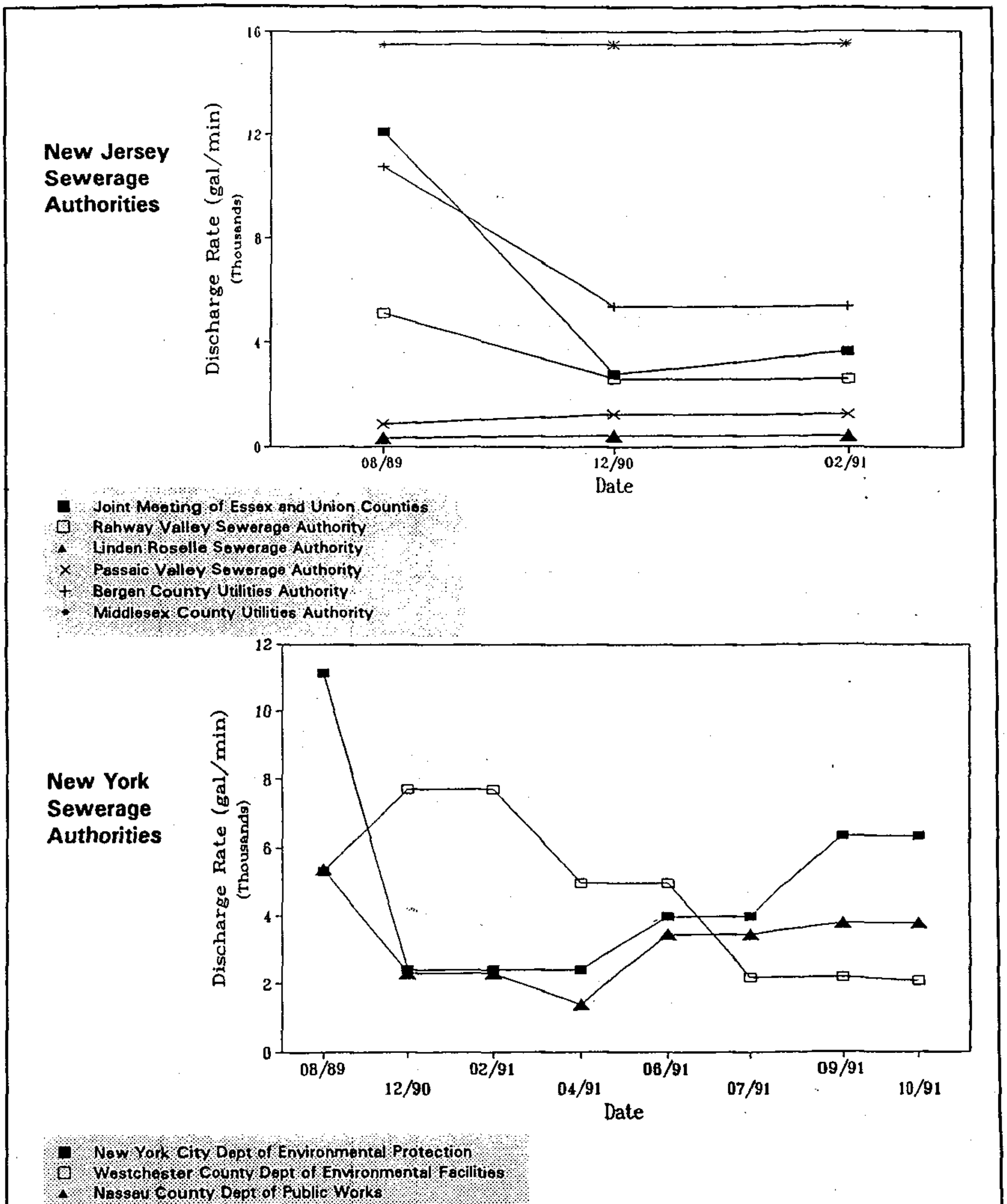


Figure 3-3. **EPA used the three-month averages of bioassay results to continuously adjust the dumping rates, for a vessel speed of 6 kn, specified for each sewerage authority.**

when ocean disposal of sewage sludge was terminated by the New Jersey permittees, the number of dumping missions was reduced to approximately 40 per month.

- Surveillance procedures were effective in identifying violations of the ocean dumping regulations and permit conditions. Administrative penalties issued by EPA to the permittees or towing companies ranged from $5,000 for discharging sludge outside the disposal site to $106,500 for a violation involving a sludge spill combined with lack of inspection and reporting. Settlements ranged from $4,000 to $50,000. Settlements subsequent to permit issuance totaled $214,200 against penalty assessments totaling $445,000.

- Dumping operations were consistently completed at the 106-Mile Site. The permits issued for the 106-Mile Site allowed for emergency dumping in certain operational situations or under certain atmospheric conditions (specifically, sustained winds of force 5) to provide equipment and barge crew safety. From August 1989 through May 1990, while the force-5 permit condition was in effect, 161 emergency dumps were attributed to such conditions. From June 1990 through June 1992, a total of 153 other emergency dumps occurred. These were primarily related to weather conditions at the 106-Mile Site. Illegal dumping was detected outside of the 106-Mile Site on one occasion.

3.2 Tier 2: Nearfield Fate and Short-Term Effects

Tier 2 monitoring included nearfield compliance, nearfield fate, and short-term effects studies. Monitoring at this level was intended to assess the short-term behavior, transport, and impact of sludge within the 106-Mile Site and in the area immediately surrounding the Site. Hypotheses H_o3 through H_o13 addressed the nearfield compliance, nearfield fate, and short-term effects of sludge disposal. Short-term effects were defined as those which occur within one day of sludge disposal. However, some hypotheses refer to a time period of 4 h because this is the initial mixing time allowed in the ocean dumping regulations. Tier 2 data were also used to develop and refine monitoring activities for farfield fate (Tier 3) and long-term effects (Tier 4) studies.

The major activities under Tier 2 were conducted between 1986 and 1990. After August 1990, no specific studies addressed hypotheses related to nearfield fate or short-term effects. After 1990, in response to public concerns, emphasis shifted to the farfield fate and potential long-term effects of the sludge.

3.2.1 Nearfield Compliance

H_o3: Concentrations of sludge and sludge constituents are below the permitted limiting permissible concentrations and water quality criteria outside the Site at all times.

H_o4: Concentrations of sludge and sludge constituents are below the permitted limiting permissible concentrations and water quality criteria within the Site 4 h after disposal.

H_o5: Pathogen or biological tracers of sewage sludge do not exceed ambient levels 4 h after disposal.

Early in the monitoring program, data indicated that sludge or sludge tracers were detected above relevant WQC outside of the Site boundaries and, on occasion, within the Site 4 h after disposal. To ensure that the WQC were met, EPA reduced barge dumping rates.

- EPA marine WQC for copper (Cu) and lead (Pb) were exceeded, thereby violating the requirements of the ocean dumping regulations, both within the Site 4 h after disposal and outside of the Site boundaries during the August/September 1987 survey (**Figure 3-1**) (EPA, 1992g) and during the September 1988 survey (EPA, 1989d; 1992i) (**Figure 3-4**). Overall, WQC were exceeded in approximately 50% of the plumes surveyed. These data established that the dumping rate of 15,500 gal/min initially set for sludge disposal resulted in concentrations of sludge constituents that frequently did not meet regulatory requirements (*i.e.*, exceeded marine WQC outside of the Site or 4 h after disposal).

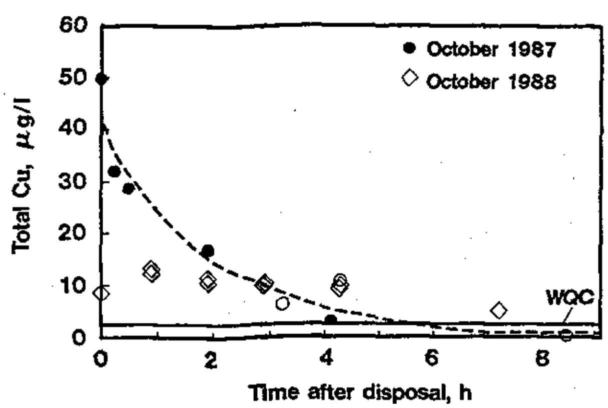


Figure 3-4. **Comparison of copper (Cu) dilution as a function of time for plumes surveyed in September 1987 and 1988. The EPA water quality criterion (WQC) for copper is included for comparison.**

- The August/September 1987 and September 1988 surveys established that the pathogen indicator *C. perfringens* exceeded ambient concentrations 4 h after dumping and also outside of the Site when sludge was dumped at a rate of 15,500 gal/min.

- Vertical profiles of turbidity in the area of the Site showed a consistent particle maximum in the pycnocline, resulting either from natural processes or from sludge disposal. This finding, combined with observations from the winter 1988 survey, prompted EPA to sample the pycnocline during the summer 1988 survey (EPA, 1992i). However, indications of sludge in the pycnocline particle maximum were not conclusive even though, during the survey, remnants of plumes, that had high concentrations of metals (**Figure 3-5**) and detectable concentrations of *C. perfringens*, were observed above the pycnocline in the Site, and to the southeast and northwest of the Site. Generally, neither the LPC nor WQC were exceeded unless the samples were obtained from within dispersing plumes.

- An increase in turbidity with associated increases in *C. perfringens* and metals concentrations at distances of 30 km southwest of the Site was observed during an October 1989 survey (Hunt *et al.*, 1992). Exceedances of marine WQC were not found.

3.2.2 Nearfield Fate

H_o6: Sludge particles do not settle in significant quantities beneath the seasonal pycnocline (50 m) or to the 50-m depth at any time within the Site boundaries or in an area adjacent to the Site.

In 1987, observations of sludge plume behavior suggested that sludge particles did not settle in significant quantities beneath the seasonal pycnocline. However, in 1989, more detailed studies determined that sludge particles settled below the pycnocline. Furthermore, direct measurements of sludge settling behavior from the deep-sea sediment trap program demonstrated unequivocally that a fraction of the sludge was reaching the seafloor within and near the Site.

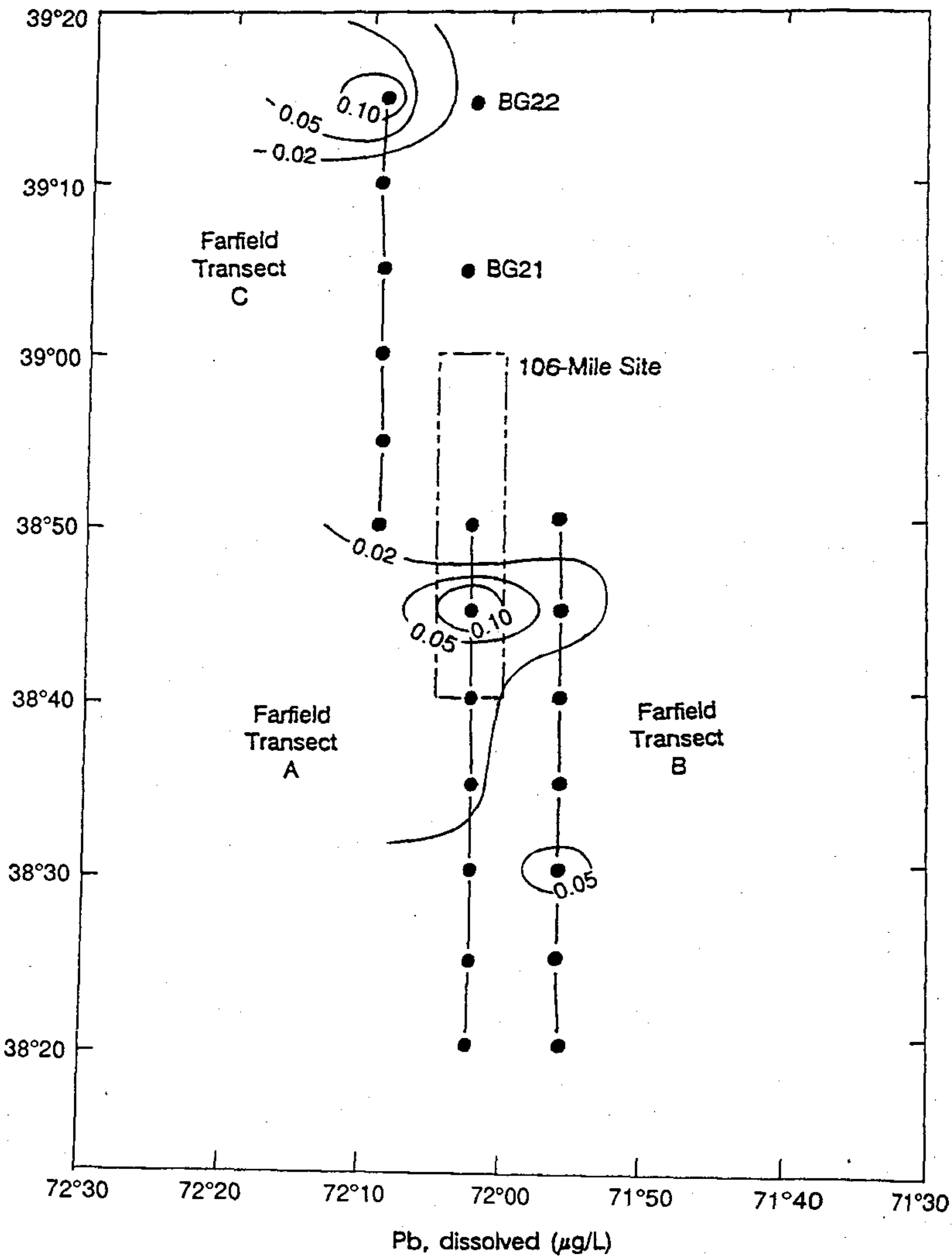


Figure 3-5. **Contour plot of dissolved lead (Pb) at the shallow particle maximum on the farfield transects — Summer 1988.**

Sediment Trap Program

- Initial observations made during 1987 and 1988 (EPA, 1992g,i; 1989c) indicated that most of the sludge particles did not settle rapidly and did not appear to penetrate the summer pycnocline in significant quantities during the first 8-12 h after dumping. Sludge generally remained in the upper 25 m of the water column. Profiling operations conducted in the summer of 1988 (EPA, 1992i) within and near the 106-Mile Site, but away from known plumes, detected evidence of sludge plumes at depths above 25 m. Settling of sludge particles below the pycnocline was clearly demonstrated during an October 1989 survey (Hunt *et al.*, 1992) and by the sediment trap program where sludge was detected in sediment traps located at 1000 m and within 250 m of the seafloor to a distance of at least 60 nmi (110 km) southwest of the Site (Hunt *et al.*, 1993; 1995a).

- Comparison of the sludge plume behavior in winter and summer indicated that sludge settling was not affected by seasonal factors (Redford *et al.*, 1992). As a result, dilution rather than settling appeared to be the major factor controlling the short-term dispersion of the sludge.

- All of the sewage sludge tracers measured during the sediment trap program showed similar trends with distance from the Site (EPA, 1992n). The decreasing gradients (at all three depths) for both concentration and flux with increasing distance from the Site (*e.g.*, LABs as presented in **Figure 3-6**) indicated that some of the sludge dumped at the Site settled through the water column and reached the sediments.

Laboratory Studies

- Because laboratory studies (Lavelle *et al.*, 1988) suggested that a fraction (<20%) of the sludge could settle at rates in excess of 0.3 cm/s, EPA conducted a study (Hunt *et al.*, 1992) as part of the sediment trap program to determine whether a rapidly settling component of sludge could be observed directly under the sludge plume shortly after disposal. Results showed that some components of sludge can settle at a rate on the order of m/h. Estimated settling rates (18-180 m/h) of large particles implied that these particles were likely to reach the seafloor within 1-13 days of disposal. Laboratory studies indicated that ≈13-20% of the sludge may be comprised of these large particles that are likely to rapidly settle to the seafloor.

- Data from EPA laboratory settling rate studies (Albro *et al.*, 1995; Bonner *et al.*, 1992) indicated that the bulk of sludge particles settled at rates of 1-2 m/day. These rates are too slow for this material to reach the seafloor in the vicinity of or to the southwest of the Site because water depths were generally greater than 2000 m and water advection would remove the particles from the area before they reached the seafloor.

- Using a 1:500 initial dilution, Bonner *et al.* (1992) predicted that 85% of the sludge would settle from the water column in 160 days (**Figure 3-7**). At a dilution of 1:500,000, more than 200 days passed before any sludge reached the benthos. Under the latter scenario, 95% of the sludge reached the bottom in 1100 days (3 years).

$H_0$7: The concentration of sludge constituents within the Site does not exceed the limiting permissible concentration or water quality criteria 4 h after disposal and is not detectable in the Site 1 day after disposal.

Based on the results of surveys conducted at the Site, sludge dumping at the rate of 15,500 gal/min resulted in violation of certain WQC levels 4 h after disposal. Revised dumping rates ensured that WQC were met at all times.

- Evidence from plume tracking studies conducted in 1987 and 1988 (EPA, 1988; 1992g; Redford *et al.*, 1992) showed that

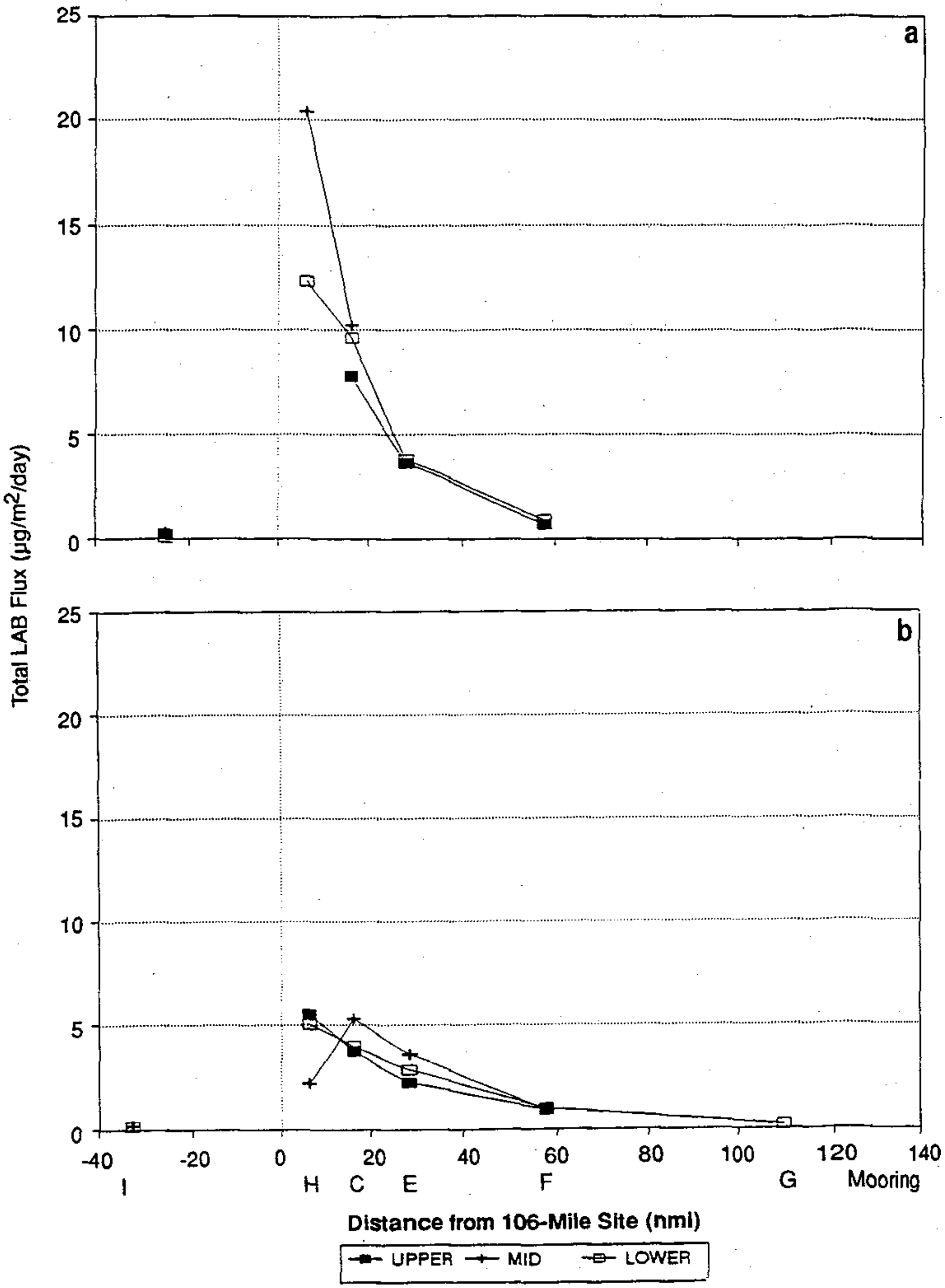


Figure 3-6. **Total LAB flux from the along-slope moorings. LAB flux decreased with distance from the 106-Mile Site.**

(a) First deployment period (May 1990 to November 1990)

(b) Second deployment period (November 1990 to June 1991)

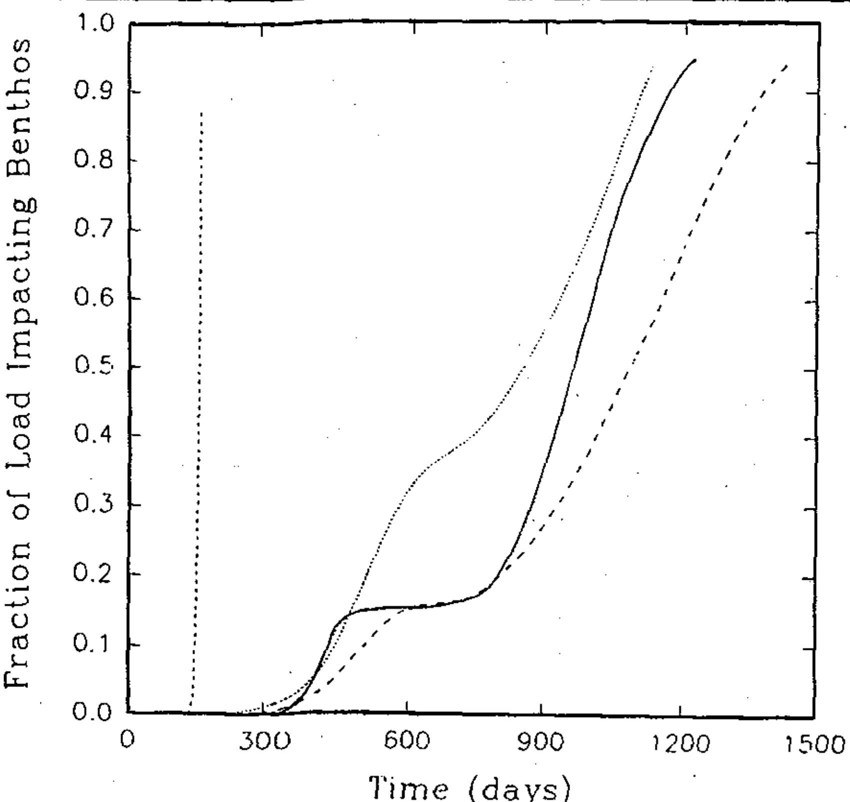


Figure 3-7. **Fraction of dumped sludge reaching the sediments as a function of time under various sludge dilution scenarios. The curves represent *various dilutions* of the sludge. From Bonner *et al.* (1992).**

----------	=	**1:500**
....	=	***1:500,000***
– – – –	=	**1:500,000 (discrete)**
....	=	**1:5,000,000**

exceedances of WQC for selected parameters were occurring 4 h after disposal.

- Samples collected from within the seasonal pycnocline in the Site showed high concentrations of selected metals that approached or exceeded the EPA marine WQC (EPA, 1992h) during this period. Vertical profiles of turbidity exhibited a subsurface maximum situated within the seasonal pycnocline. It could not be determined if this particulate maximum resulted from natural processes or was related to the disposal activities. Specific monitoring to determine if sludge could be found in this particle maximum was inconclusive.

H_o8: The concentration of sludge constituents at the Site boundary or in the area adjacent to the Site does not exceed the limiting permissible concentration or water quality criteria at any time and is not detectable 1 day after disposal.

Exceedances of WQC at the Site boundary were found during the 1987 and 1988 surveys. Dilution processes generally decreased concentrations to within two times the background levels in less than 1 day.

Plume Tracking Studies

- Data from the plume tracking operations (EPA, 1992g,h,i) showed that sludge may be transported out of the Site within a few hours of disposal and that the transport may be in any direction, depending upon the local current regime at the time of disposal. Data from the real-time current meter indicated that at least 90% of the time, surface currents were strong enough to transport sludge out of the disposal Site within 1 day.

- A 1988 EPA survey determined that, even though plumes may be transported out of the Site quickly, contaminant concentrations were not generally elevated in this region (EPA, 1992i). As described under hypotheses H_o3, H_o4, and H_o5, indications of sludge contamination were found several kilometers southeast and northwest of the Site during the various studies. The strongest indications of sludge in the area were associated with turbidity peaks located above the seasonal pycnocline.

- Studies conducted southwest of the Site in late summer 1989 (Hunt *et al.*, 1992) found evidence of elevated turbidity and detectable quantities of *C. perfringens* in samples from the surface and the pycnocline up to 40 km from the Site (**Figure 3-8**). However, WQC for metals and organic compounds were not exceeded in any of the samples. Concentrations were no more than two times the background for these samples (Hunt *et al.*, 1992).

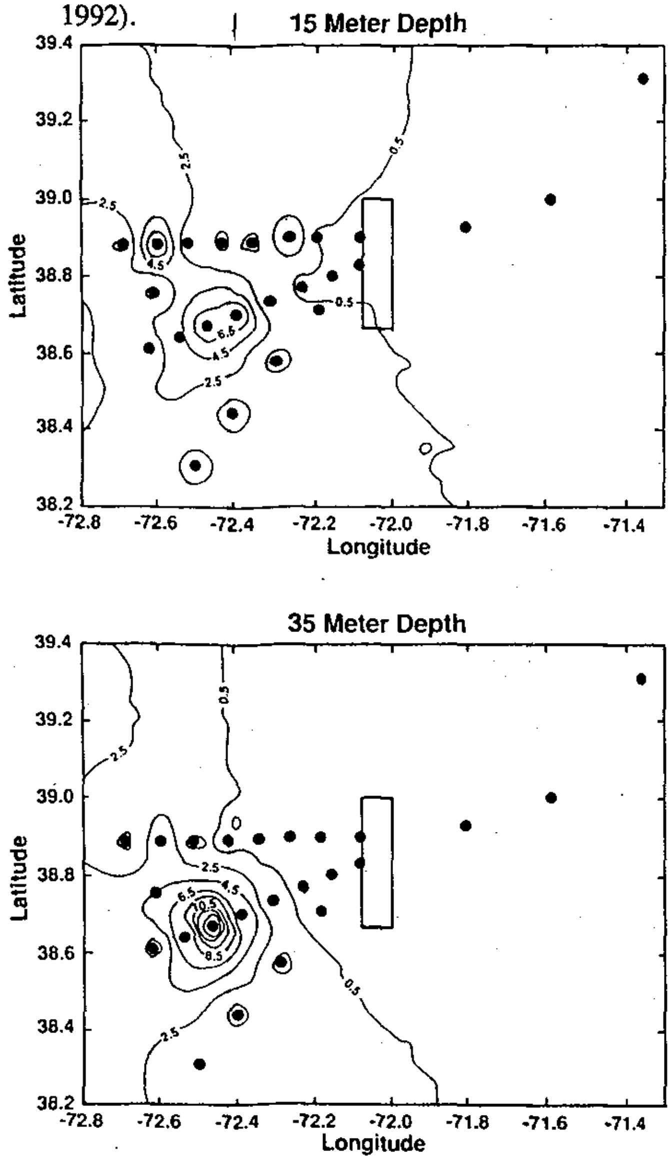


Figure 3-8. **Distributions of *Clostridium perfringens* in surface water near the 106-Mile Site in October 1989. *Elevated turbidity and detectable quantities of C. perfringens* were observed in samples from (a) the surface and (b) the pycnocline up to 40 km from the 106-Mile Site.**

$H_0$9: The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water nor a significant change in the pH of the seawater in the area.

No depletion in the dissolved oxygen content of seawater and no significant change in the pH of the seawater were observed.

- No significant depression of the dissolved oxygen content of seawater within plumes was observed during the fall 1987 survey (EPA, 1992g). Following disposal, minor decreases in dissolved oxygen were found within the plumes. The observed depression of oxygen was predicted by simple mixing models and was not the result of depletion caused by chemical or biological oxygen demand.

- The pH of seawater was not significantly altered in any of the plumes surveyed during the late summer of 1988 (EPA, 1992i). Evidence from the survey showed that the pH of seawater was not detectably altered in two of the three plumes surveyed. The pH in the third plume decreased by ≈ 0.2 immediately following disposal and rapidly recovered to ambient levels.

3.2.3 Short-Term Effects

$H_0$10: No significant biological effects in the water column are measurable within the Site within 1 day after disposal.

$H_0$11: No increase in primary productivity or any changes in planktonic biomass or species composition occurs.

$H_0$12: Sludge constituents do not accumulate in the surface microlayer in the vicinity of the Site.

$H_0$13: No evidence of short-term bioaccumulation of sludge constituents by commercially important species or important prey species found at or adjacent to the Site will be found within 1 day after disposal.

The data from the September 1988 survey (EPA, 1992i) were used to evaluate the short-term effects of sewage sludge disposal.

- Water samples taken in sludge plumes were toxic to sea urchin gametes from 0 to 3 h after disposal, but not 4 h after disposal (**Figure 3-9**). Sludge plumes were not observed to be toxic to calanoid copepods collected at the Site or to mysid shrimp 4 h after disposal.
- Observations of zooplankton and fish eggs for genetic abnormalities revealed no effects that could be attributed to sludge. However, the collection period was near the end of the reproductive season, thereby limiting the ability to determine effects.
- The samples collected for zooplankton and fish eggs unexpectedly contained floatable debris, including paper mulch, tar balls, and plastic pieces, pellets, spherules, and filaments. Ocean disposal of such debris is not permitted. After evaluating the characteristics of the material and information on the water masses in the area at the time of sampling, EPA could not determine whether the debris originated from sewage sludge or was associated with a streamer of continental shelf water intruding the Site. These results provided feedback to Tier 1 monitoring prompting EPA to initiate additional studies on floatable transport. EPA Region II developed methods for permittees to monitor floatable debris in sludge.

3.3 Tier 3: Farfield Fate

Tier 3 monitoring provided information about the transport and fate of sewage sludge after leaving the disposal site. The information was needed to predict and measure any potential transport of sludge constituents to shorelines, fisheries areas, or other biologically sensitive regions and to design studies of the long-term, farfield effects of sludge disposal (Tier 4). The null hypotheses $H_0$14 through $H_0$17 addressed Tier 3 monitoring.

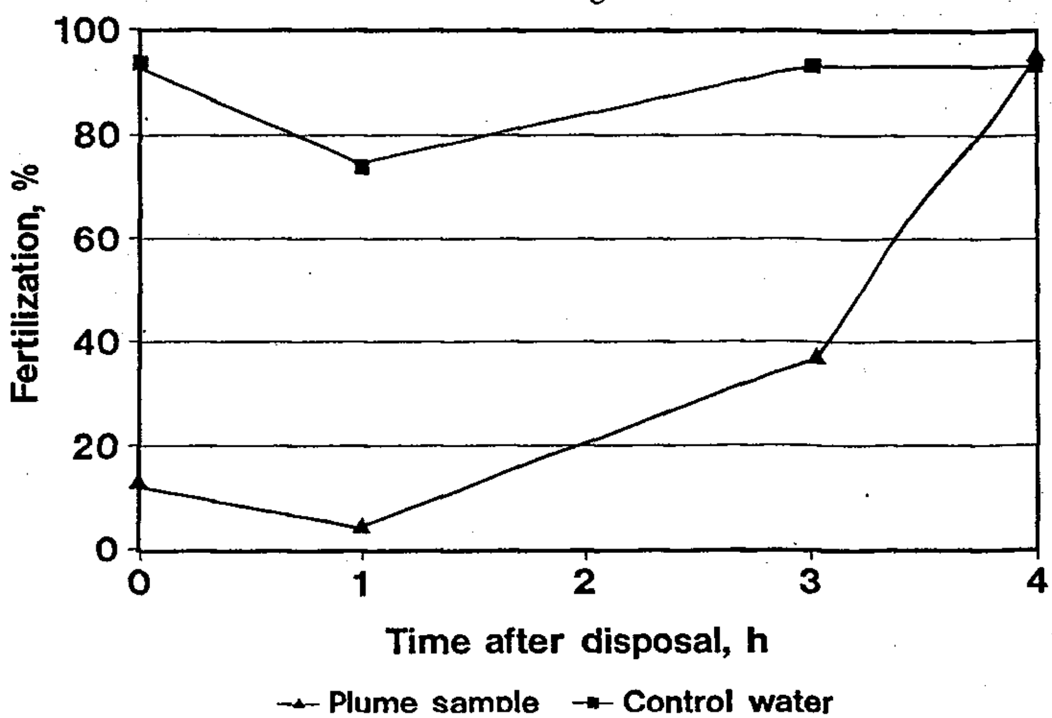


Figure 3-9. **Results from sea urchin fertilization tests conducted in October 1989. Control waters were obtained approximately 10 nm (19 km) north of the 106-Mile Site. *Samples taken in sludge plumes were toxic to sea urchin gametes up to 3 h after disposal, but not 4 h after disposal.***

H_o14: Significant amounts of sludge do not settle beneath the surface mixed layer outside the disposal site.

Evidence from the sediment trap program showed that sludge settled below the surface mixed layer outside the Site. Sludge was detected in sediment traps located at 1000 m and within 250 m of the seafloor to a distance of at least 60 nmi (110 km) southwest of the 106-Mile Site.

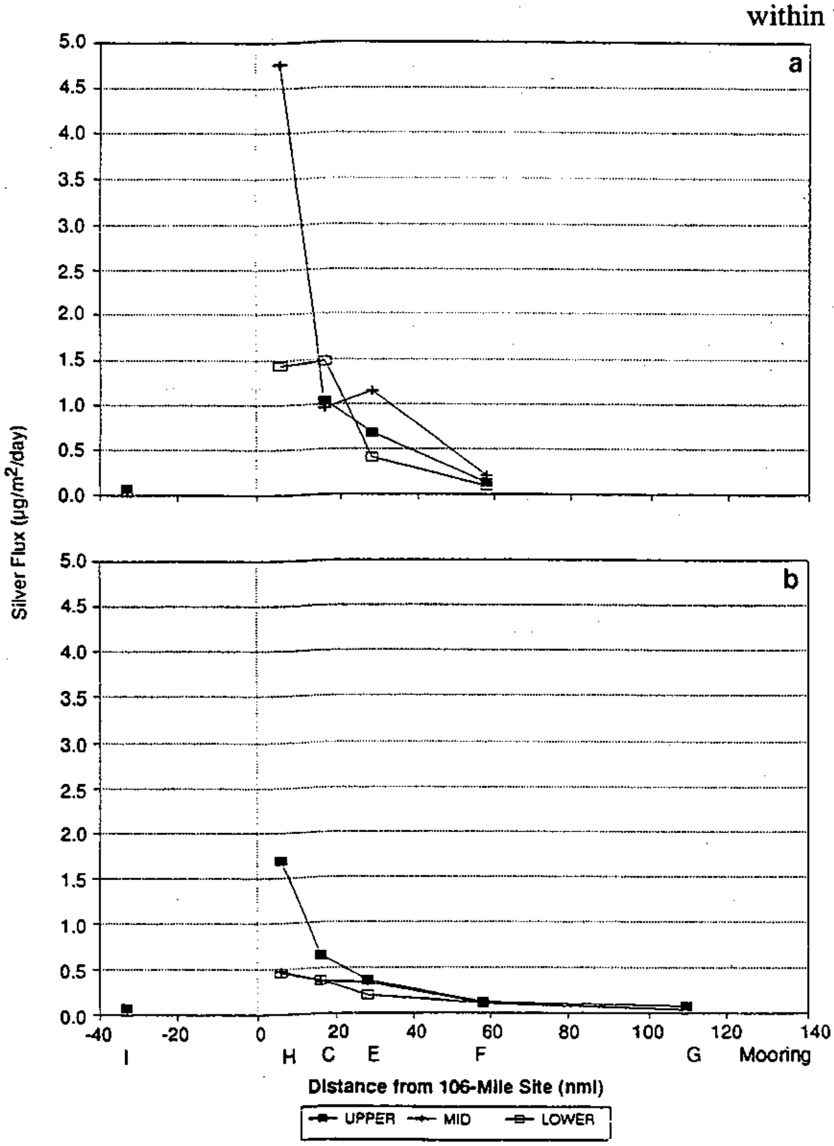


Figure 3-10. **Silver (Ag) flux from the moorings located along the continental slope. Silver flux decreased with distance from the 106-Mile Site during both deployment periods. Mooring I is a control mooring upstream of the 106-Mile Site.**

(a) First deployment period (May 1990 to November 1990)

(b) Second deployment period (November 1990 to June 1991)

- During the sediment trap program, silver, copper, lead, and chromium, and organic compounds (LABs, sterols, and PAHs) were found to be effective tracers of sludge fate, and showed similar patterns and trends with distance from the Site (**Figure 3-6** and **Figure 3-10**). Decreasing concentration and flux gradients with increasing distance from the Site were observed at all three trap depths (Hunt *et al.*, 1993). The highest flux of these tracers was found at the moorings located within 20 nmi of the Site; decreasing flux was observed with distance from the Site. Elevated concentrations of metals and organic compounds were found as far as 60 nmi downcurrent of the Site.

- The stable isotope ratios of carbon, nitrogen, and sulfur were also good tracers of the sludge. Each of these tracers showed that sludge was transported to depth in the ocean and that the fraction of sludge in the sediment traps decreased with distance from the Site (**Figure 3-11**) (Hunt *et al.*, 1993, 1995a; EPA, 1992n). Isotope ratios from the three moorings within 28 nmi of the Site approached the isotopic ratio of the sludge dumped at the Site. Contaminant concentrations and isotope ratios returned to background levels at distances greater than 60 nmi from the Site.

- Relative to background concentrations, the chemical tracers in the sediment traps downcurrent of the Site showed a range in enrichment caused by the sludge disposal (Hunt *et al.*, 1993). The maximum enrichments were between 50 and 100 times the background for silver and total LABs, respectively. Maximum enrichments factors for copper,

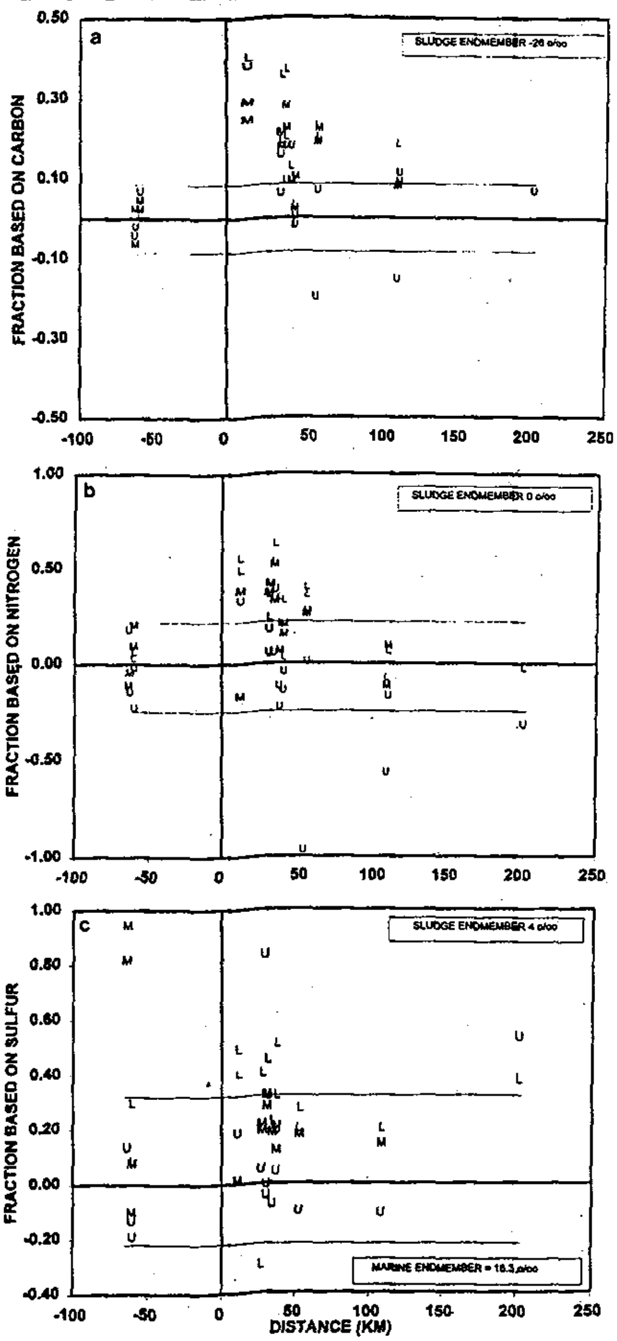


Figure 3-11. **Fraction of sludge in sediment traps from the vicinity of the 106-Mile Site based on the stable isotope data. All traps from both deployment periods are included in the data. All three isotopes show that the fraction of sludge in the traps decreases with distance from the 106-Mile Site. Symbols indicate traps located in the upper (U), mid (M), and lowest (L) depths of the water column. Values between light horizontal lines are typical of marine particulate matter. Those outside of these lines are influenced by the sludge dumping.**
(a) Carbon (b) Nitrogen (c) Sulfur

total PAHs, and coprostanol were 10-20 times the background. By using the enrichment factors, sludge was detected at distances as far as 100 km from the Site.

$H_0$15a: Ocean currents do not transport sludge to any adjacent shoreline, beach, marine sanctuary, fishery, or shellfishery.

$H_0$15b: Ocean currents do not transport sludge onto the continental shelf.

Evidence from the satellite-tracked drifter program, probability modeling, numerical modeling, visitation frequency analysis, and persistence analysis revealed that sludge is not likely transported eastward of the shelf/slope break.

Satellite-Tracked Drifter Studies

- The drifters deployed during the satellite-tracked surface-layer drifter program showed that slope water did not cross the shelf/slope front (Dragos, 1993; Burch *et al.*, 1993). This strongly implies that sludge dumped at the 106-Mile Site was not transported into coastal areas along the eastern seaboard nor to locations of significant fish and shellfish harvesting (**Figure 3-12**). Drifters were generally carried southwest from the Site until they reached the north wall of the Gulf Stream. Once entrained in Gulf Stream flow, the drifters moved rapidly eastward, following the meanders and eddies of the Stream as it carried them out to the north mid-Atlantic (Dragos, 1993; Dragos *et al.*, 1995; Berger *et al.*, 1995).

- A major oceanographic feature that could affect sludge transport onto the shelf was warm-core rings (Berger *et al.*, 1995). Warm core rings could only transport sludge to the outer edge of the continental shelf along a narrow strip ($\approx$20 nmi) running to the southwest of the 106-Mile Site. Such transport would account for less than 1% of the discharged sludge reaching this area

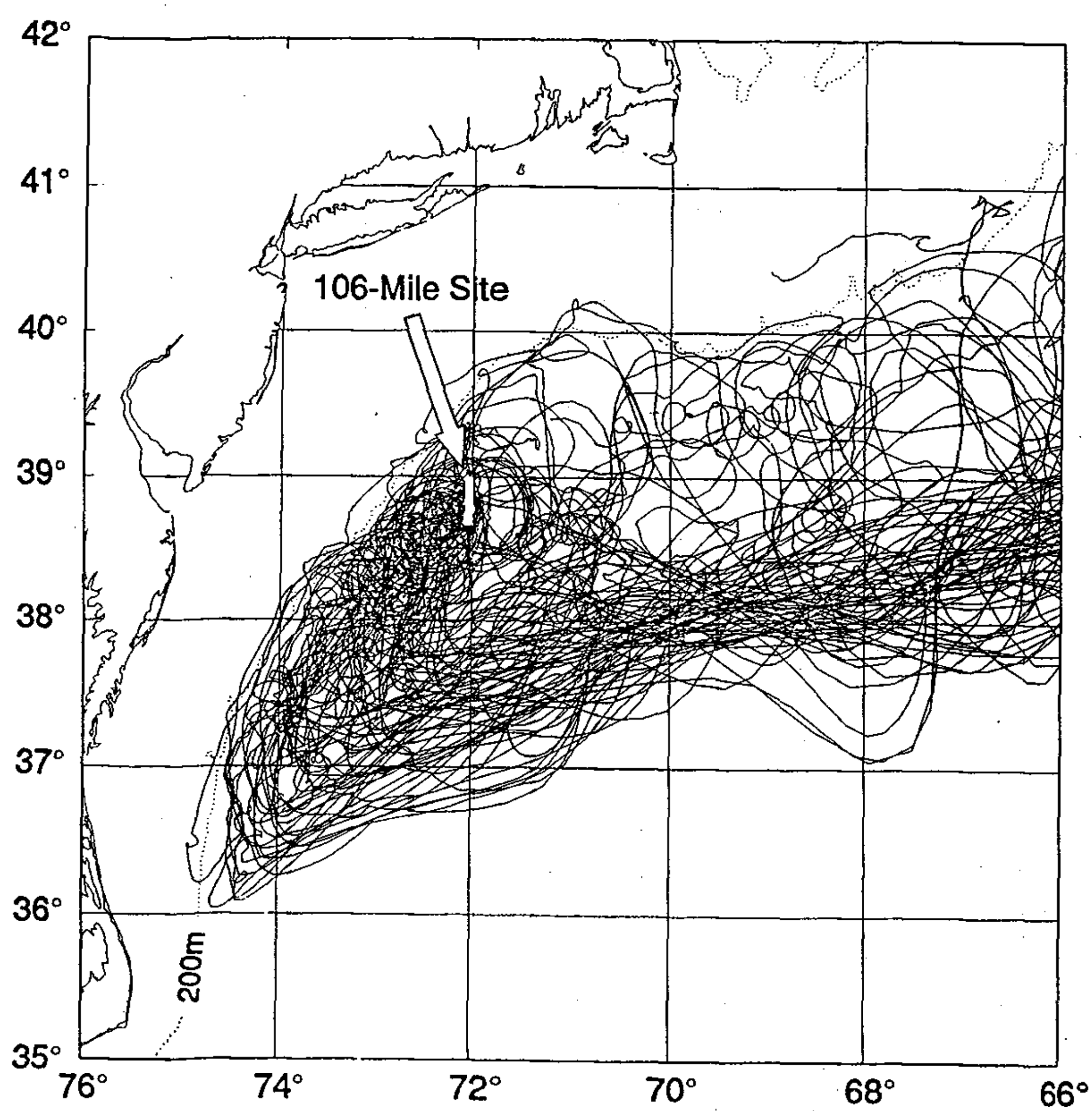


Figure 3-12. **Trajectories of 66 satellite-tracked drifting buoys released at the 106-Mile Site between October 1989 and October 1992 shown in the region of the Mid-Atlantic Bight. No drifters moved to the continental shelf.**

(Churchill and Aikman, 1992; Churchill and Aikman, 1995).

Sediment

- To the extent that *C. perfringens* spores behave as sewage sludge tracers, *C. perfringens* data from sediments sampled in 1991 implied that spores dumped at the Site were not deposited on the continental slope or shelf but were deposited at least 100-150 km to the southwest of the Site (**Figure 3-13**), indicating that sludge dumped at the Site did not move onto the shelf (White *et al.*, 1993). These data support the EPA sewage sludge mass flux model (Burch *et al.*, 1993) and the Fry and Butman (1991) model which predict a flux of $\approx$60 mg of sludge/m^2/day at the Site, decreasing to $\approx$25 and $\approx$1 mg/m^2/day at distances of 50 km and 350 km, respectively, to the southwest of the Site.

Sediment Trap Data

- For several tracers, transport of sludge towards the continental shelf was evident at depth ($\approx$1000 m); however, transport onto the shelf was not significant based on the sediment trap data (EPA, 1992n; Hunt *et al.*, 1995a). The only sludge tracer to show any significant transport towards the continental shelf was xylem tracheids (plant cells that conduct water in plant stems used to track sewage distribution). All other sludge tracer data implied that sludge was transported primarily in a southwesterly direction along the continental rise. The maximum area of sludge flux was located within 30-40 nmi of the Site; a significant flux was measured at 60 nmi from the Site. Evidence for sludge deposition at distances as great as 120 nmi from the Site was not clear from the sediment trap data.

- The sludge mass flux estimates (**Figure 3-14**) resulting from the numerical sludge transport model (Isaji *et al.*, 1995) were in agreement with previous simulations performed by Fry and Butman (1991). Both models predict a maximum seabed flux of $\approx$60 mg/m^2/day southwest (downstream) of the Site, decreasing to about 20 and 2 mg/m^2/day at distances of 50 km and 350 km southwest of the Site, respectively. The material deposited on the seabed was dominated by particles with higher settling velocities and was confined to the Slope Sea. Little material was predicted to penetrate onto the shelf. Slower settling particles tended to be transport to the Gulf Stream off Cape Hatteras and generally exited the study area. Similar results were achieved using large-scale three-dimensional circulation models (Patchen and Herring, 1995).

Modeling Studies

- Probability modeling and visitation frequency analysis showed that a small fraction of the slowly settling sludge could be transported towards the continental shelf (Churchill and Aikman, 1995). This transport is likely associated with slope water intrusions within the seasonal pycnocline and transport was found to be confined primarily to depths below the surface mixed layer. The conditions under which currents could transport sludge to the continental shelf occurred at a low frequency and were of short duration.

- Persistence analysis showed that the likelihood of sludge transport towards the continental shelf and Hudson River Canyon area was small (Hunt *et al.*, 1993). On-shelf flows were generally episodic and of short duration particularly when compared with the transit time required to move sludge onto the shelf and into the Hudson River Canyon area.

- The sludge mass flux estimates resulting from the numerical sludge transport model (Isaji *et al.*, 1995) predicted that little material would penetrate onto the shelf.

$H_0$16a: Recirculation of slope water through the 106-Mile Site is not significant.

Recirculation of slope water through the 106-Mile Site was not determined to be significant.

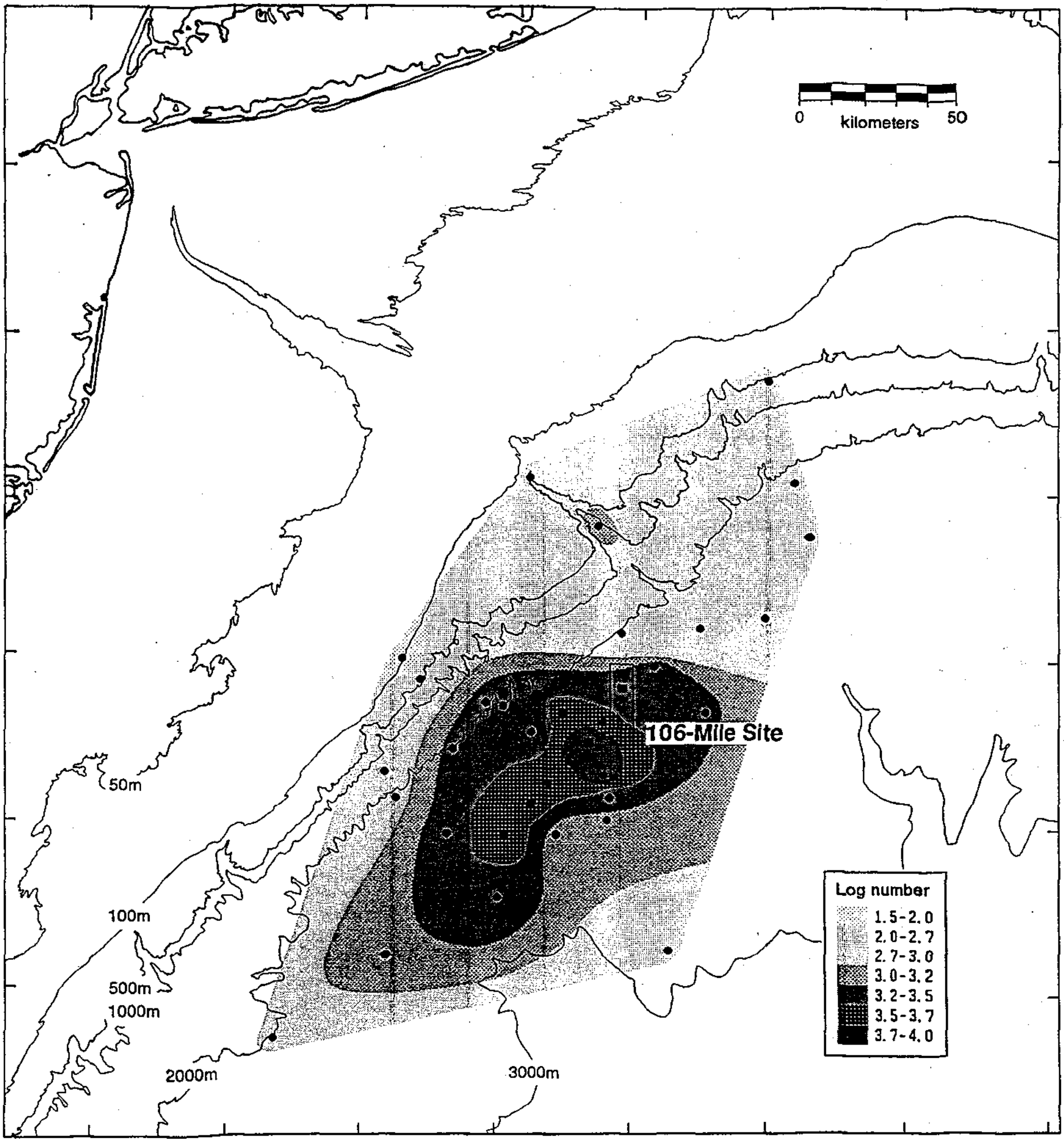


Figure 3-13. ***Clostridium perfringens*** **spores (log number g^{-1} dry weight) in the top 0.5 cm of sediment. The depositional footprint demonstrates a clear *C. perfringens* signal extending at least 100-150 km to the southwest of the Site and covering a total area of $\approx 10^4$ km^2. The rectangle delineates the area of the 106-Mile Site. From White *et al.* (1993).**

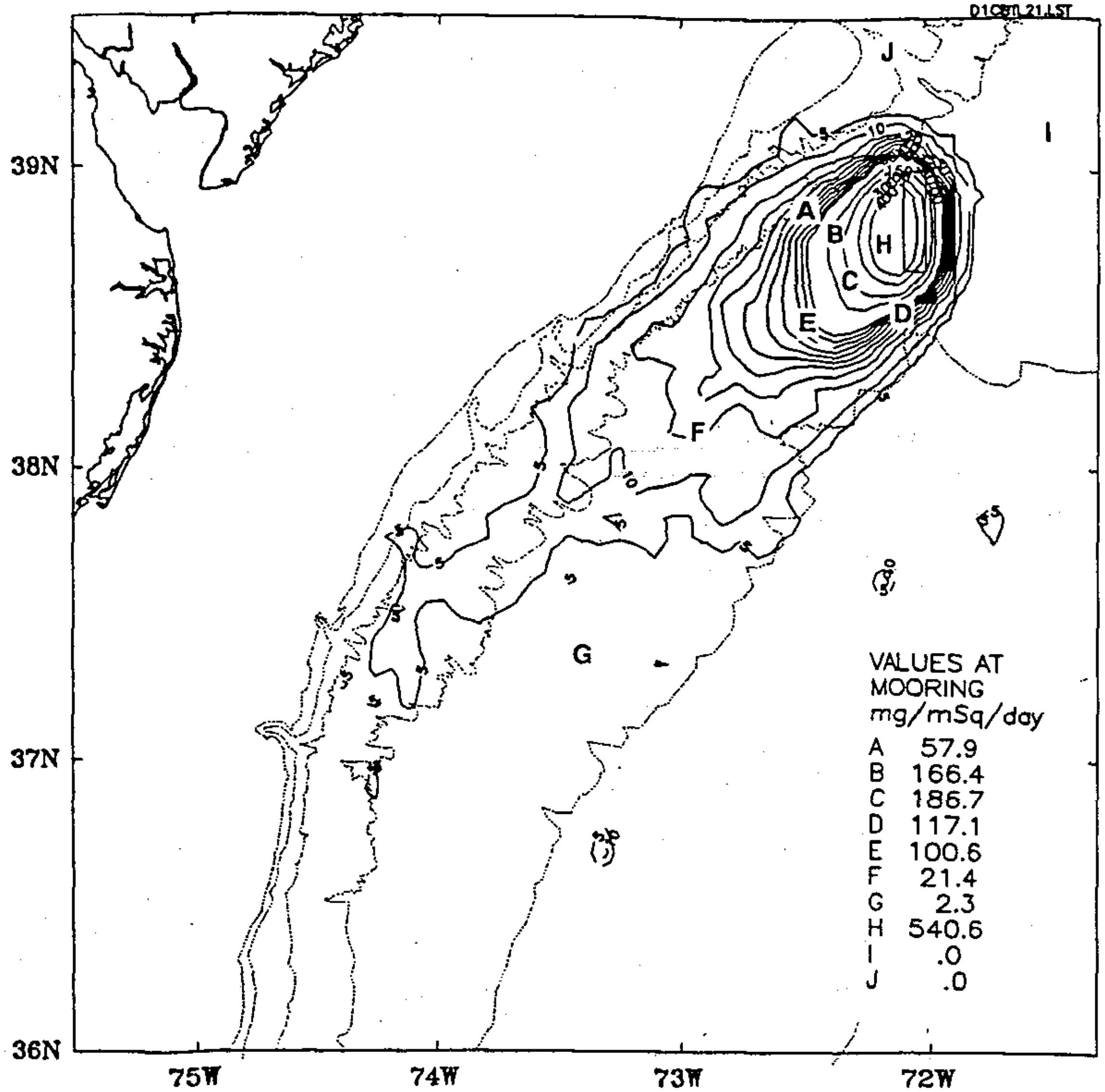


Figure 3-14a. **Estimated sewage sludge mass flux (mg/m²/day) at a depth of 100 m during the first deployment period. The EPA mooring sites are noted by letters enclosed in circles.**

- The drifter studies (Dragos, 1993; Dragos *et al.*, 1995) clearly showed that recirculation through the Site did occur, primarily as part of the gyre-like circulation that constitutes the long-term flow pattern of currents in the upper layers (0-1000 m) of the water column in the western Slope Sea (Csanady and Hamilton, 1988).

- Between 20 to 30% of the current flow through the Site appeared to recirculate, with an average recirculation time near 2 months (Burch *et al.*, 1993). Shorter period recirculations (with periods on the order of one week) also occurred in association with warm-core rings that passed through the Site. However, model and mass balance estimates indicated that sludge concentrations in recirculated water were well below existing background concentrations for suspended solids or sludge chemical contaminants of concern. The highest potential concentrations occurred when a warm-core ring occupied the Site for 15 days, when potential maximum

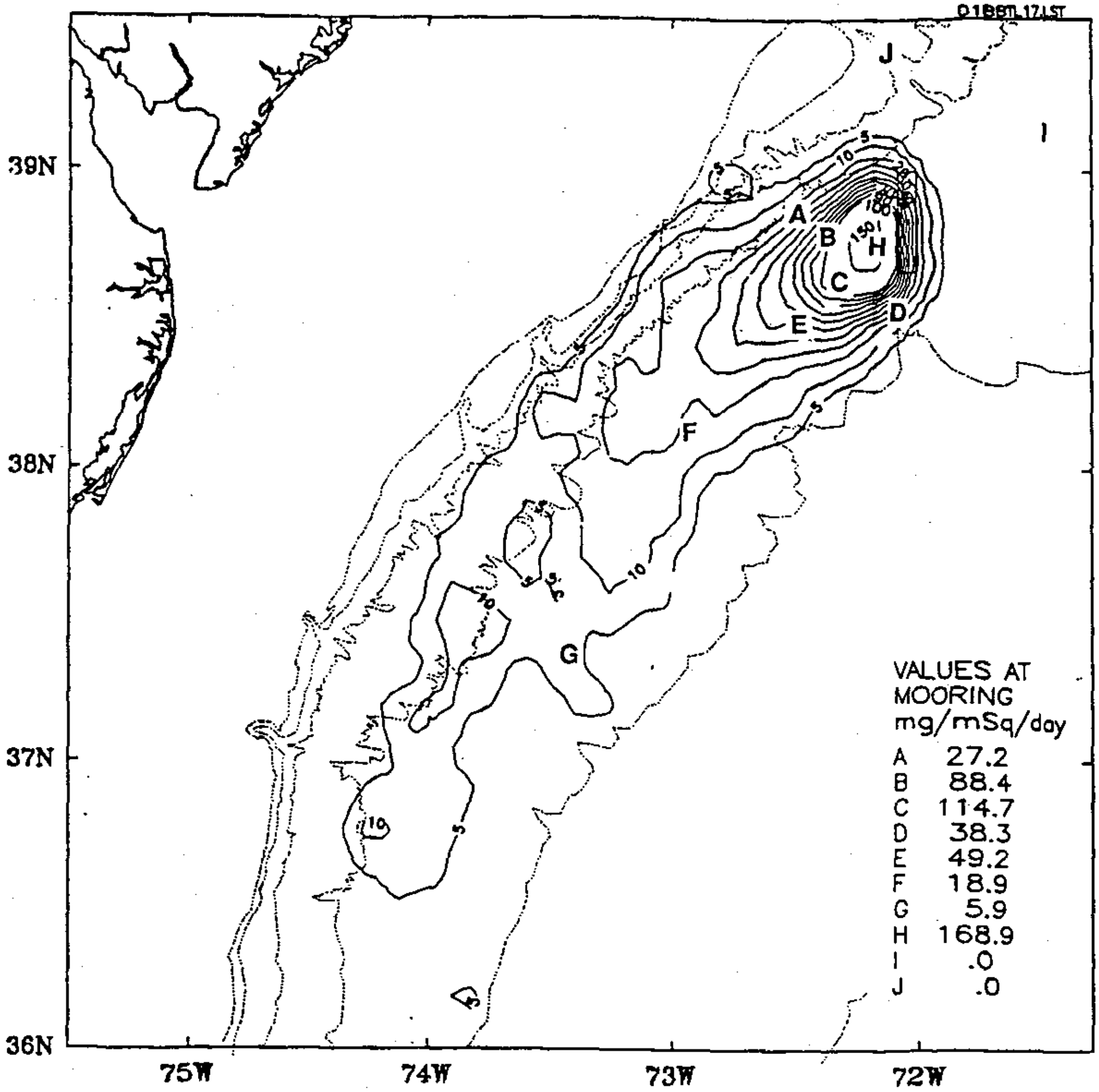


Figure 3-14b. **Estimated sewage sludge mass flux (mg/m²/day) at the seabed during the first deployment period. The EPA mooring sites are noted by letters enclosed in circles.**

sludge concentrations in recirculated water could reach an approximate level of 20 ppb, a value that is still ten times less than the existing ambient background suspended particle concentrations.

$H_0$16b: Concentrations of sludge constituents dumped at the 106-Mile Site that are associated with any recirculating slope water do not exceed EPA chronic marine water quality standards.

No direct measures for sludge constituents in recirculating water were made. However, concentrations of metals and other chemicals at reference sites to the northeast of the Site did not show any abnormal concentrations between 1987 and 1989. Furthermore, modeling studies showed that long-term accumulations of sludge in the western Slope Sea would not result in detectable concentrations of sludge constituents above the existing ambient background levels. Thus, no exceedences of marine WQC were expected.

H_017a: Significant amounts of sludge particles do not settle to the seafloor in the vicinity of the Site or in the region predicted as a plausible settling region.

Sludge-derived particles and associated contaminants were found to settle to the seafloor in significant amounts in areas southwest of the 106-Mile Site. Evidence from both the sediment trap program and sediment samples collected in and near the Site showed that sludge reached the seafloor southwest of the Site but not on the continental shelf.

- Measurement of the stable isotopes of nitrogen, carbon, and sulfur in organic matter collected by the sediment traps consistently indicated that the stable isotope ratios were shifted away from values typical of marine organic matter and towards those of the sewage sludge. The shift was most evident immediately west of the 106-Mile Site, but was detectable within 60 km to the southwest of the disposal Site. In addition, sewage sludge tracer data consistently indicated that an area within 30 nmi southwest of the Site received the maximum flux of sludge components (and by extension deposition) (EPA, 1992n; Hunt *et al.,* 1993; 1995a). Detectable levels of sludge constituents were consistently found at least 60 nmi southwest of the Site and 110 nmi southwest of the Site through measurement of organic contaminants (Hunt *et al.,* 1993). Transport of the sludge in the cross-slope direction was confined to a relatively narrow distance ($\approx$20 nmi).

- Van Dover *et al.* (1992) measured stable isotope ratios in opportunistic organisms collected in the vicinity of the Site and concluded that sewage-derived organic matter had reached the seafloor and entered the benthic food web as a result of consumption by surface deposit feeders such as the sea urchin *E. affinis.*

- At the broadest level of evaluation and interpretation, all of the sewage sludge tracers measured during the sediment trap program showed similar patterns and trends with distance from the Site and across the rise (EPA, 1992n). The decreasing gradients (at all three depths) for both tracer concentration and flux with distance from the Site **(Figure 3-6 and Figure 3-10)** indicated that a fraction of the sludge dumped at the Site settled through the water column and reached the sediments (Hunt *et al.,* 1993; 1995b).

- Estimates of the amount of sludge reaching the seafloor varied among the sludge tracers; the highest fraction reaching the sediments was estimated for total LABs, total PAHs, and lead; it was estimated that about 30% of these tracers released at the Site were deposited on the seafloor. The tracers silver and copper showed the lowest total deposition of 5 and 10%, respectively. The fraction estimated to reach the seafloor was independent of the settling rate scenario used to model the depositional footprint of the sludge.

H_017b: Organic, inorganic, and bacterial contaminants that are present in sewage sludge discharged at the 106-Mile Site do not measurably increase concentrations of contaminants in the sediment within the expected dispersion area or reference areas.

Sediment studies found that the concentrations of organic and inorganic contaminants increased in the area immediately to the southwest of the Site. Broad-scale regional increases in contaminants in the sediments were not evident and the observed patterns did not reflect projected distributions based on modeled deposition patterns. Distribution of the sewage tracer *C. perfringens* showed a distinct pattern to the southwest of the Site, similar to modeled sludge deposition patterns. Although broad-scale background concentrations of *C. perfringens* were evident, locally elevated concentrations were associated with offshore transport of anthropogenic materials. Transport of contaminants and bacterial indicators onto the continental shelf was not detected. The levels of some contaminants in the sediments near the Site decreased within one year of the cessation of sludge dumping.

- Bothner *et al.* (1991; 1994) found that the general distribution of sewage sludge tracers in sediments near the 106-Mile Site agreed with predictions of Fry and Butman (1991). The distribution of silver, *C. perfringens*, coprostanol, and LABs indicated that sludge particles were reaching the seafloor in measurable quantities immediately west of the Site. Elevated concentrations of silver in surficial sediments were found as far as 38 km west of the Site. The maximum value (0.57 ppm) was 16 times higher than in the control area sediments.

- Concentrations of *C. perfringens* in the sediments southwest of the Site (**Figure 3-13**) (White *et al.*, 1993; Draxler *et al.*, 1995) were elevated and showed a pattern similar to modeled sludge deposition patterns (**Figure 3-14**). The counts of *C. perfringens* in sediment samples collected within and to the southwest of the 106-Mile Site were significantly elevated ($P<0.01$) compared with reference stations of similar depth, topography, and distance from the continental shelf; this indicated that the benthic environment was contaminated by sewage dumping at the Site (Hill *et al.*, 1993; White *et al.*, 1993). Low counts of *C. perfringens* in sediment samples collected at stations between the base of the continental shelf and the Site indicated that coastal runoff was not a significant source of contamination. Elevated counts (up to two orders of magnitude) were observed in sediment samples as far as 150 km to the southwest of the Site. Low counts were obtained for samples from stations to the east of the 106-Mile Site. This distribution is consistent with projected patterns of sludge dispersal based on previous model predictions, and indicated that sludge was accumulating in the benthic environment and encompassed an area of ≈ 104 km^2.

- Concentrations of PAHs, PCBs, and silver in sediments collected immediately west (within 10 km) of the Site were elevated in the upper 0.5 cm of the sediments in October 1991 (Draxler *et al.*, 1995) (**Figure 3-15**). The areas of the high contaminant concentrations were generally small and did not show the gradients observed for *C. perfringens* or tracers from the sediment trap program. Elevated levels of other contaminants were not found in the vicinity of the Site or in the southwest direction.

- Analyses of sediments collected from the continental shelf did not reveal significant concentrations of sludge-related contaminants (Draxler *et al.*, 1995). The distribution patterns observed for the contaminants generally suggested other sources or transport histories in these areas. Notable were high contaminant concentrations in the Hudson Canyon which were associated with high concentrations of organic carbon and sewage tracers, suggestive of shoreward sources.

- A July 1992 re-sampling and analysis of sediments from the areas sampled in 1989 found that concentrations of silver, PAHs, and PCBs remained elevated near the 106-Mile Site (Lamoureux *et al.*, 1995). Concentrations of these contaminants were similar to those measured in 1989. However, LAB concentrations were one-half to one-third of the concentrations reported in 1989, and concentrations were depleted relative to silver in the sewage sludge and sediment trap material. These data suggested that LABs were being degraded and that some transport of the deposited sewage sludge was occurring.

- Extensive sampling in the heads of submarine canyons along the entire mid-Atlantic shelf from the Baltimore Canyon to Georges Bank between 1990 and 1992 found evidence of contaminant and sewage tracer inputs to the outer continental shelf (Cooper, 1993; Baker *et al.*, 1992; Small *et al.*, 1991; Sawyer *et al.*, 1995). However, gradients towards the 106-Mile Site were not evident and sources

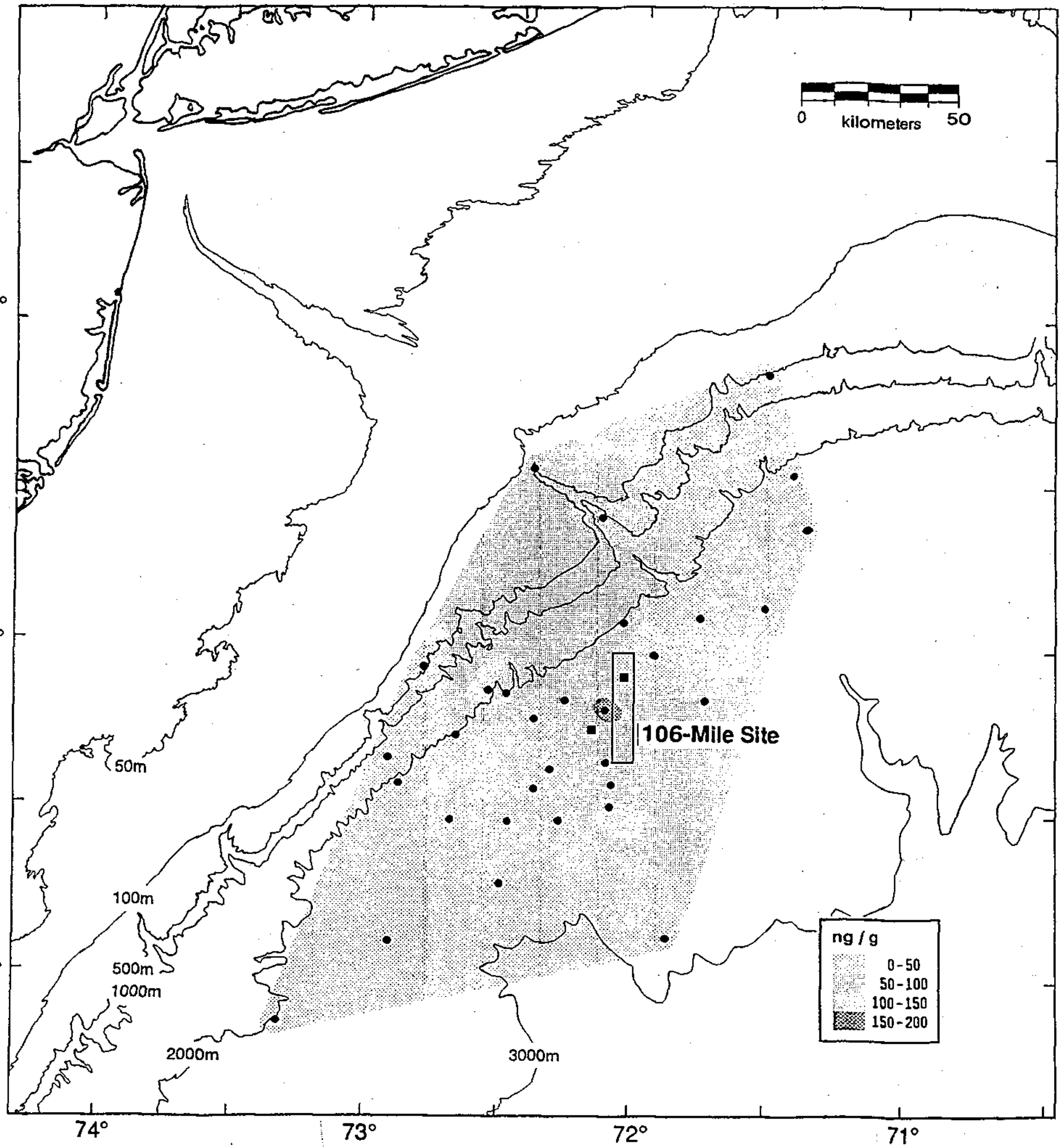


Figure 3-15a. **Elevated contaminant concentrations in surface sediments were found near the 106-Mile Site. High-molecular-weight PAHs.**

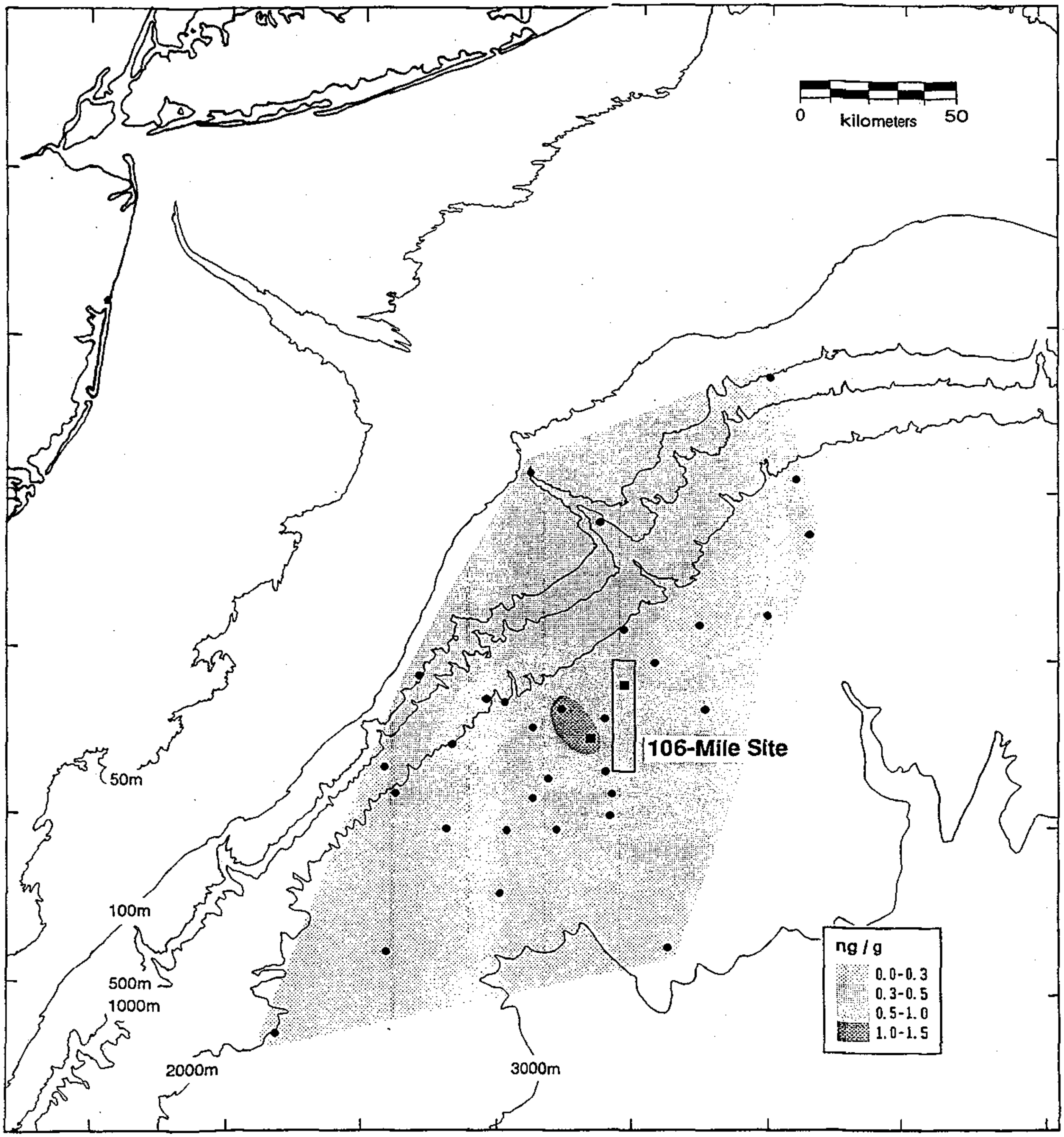


Figure 3-15b. **Elevated contaminant concentrations in surface sediments were found near the 106-Mile Site. PCBs.**

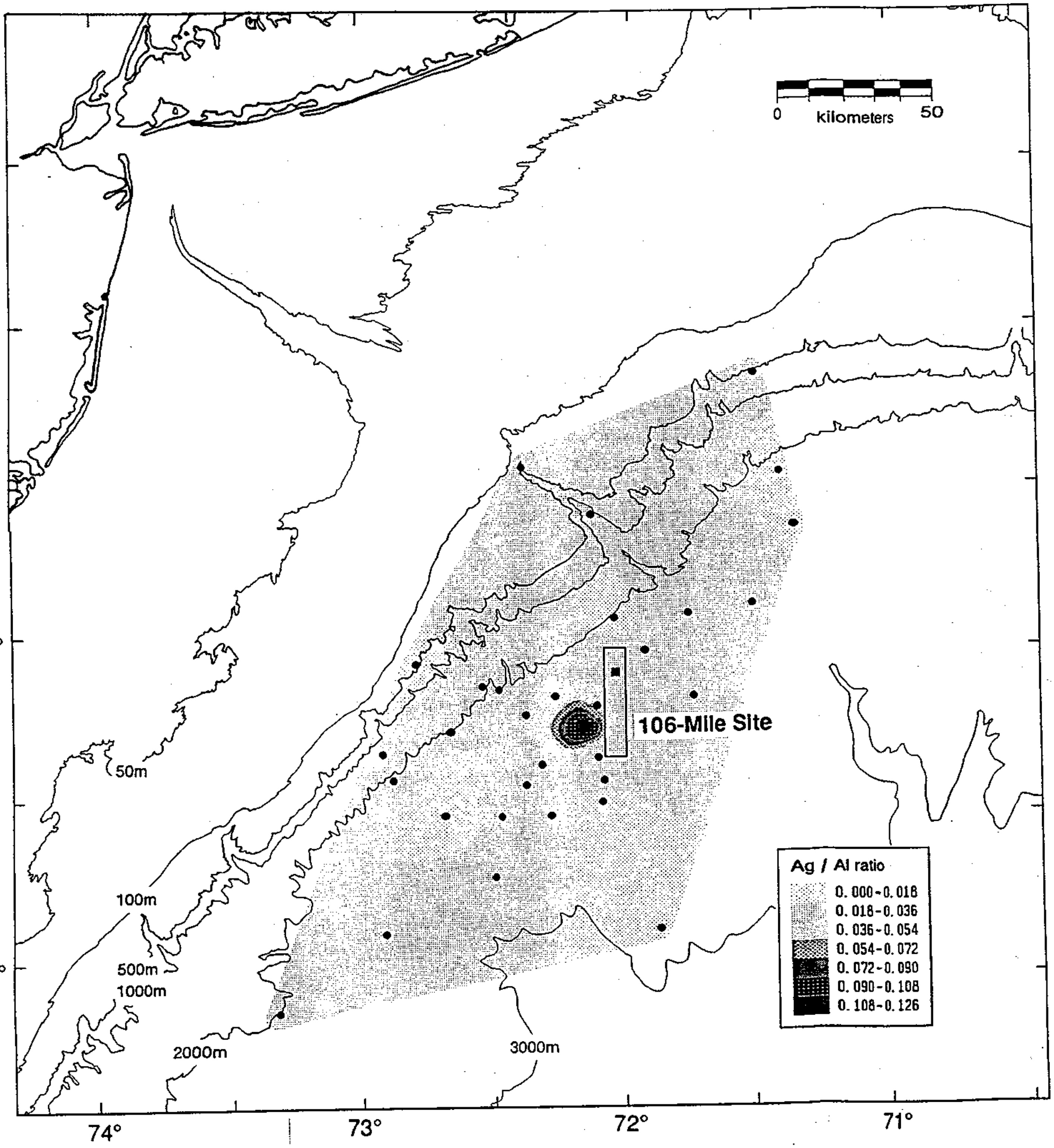


Figure 3-15c. **Elevated contaminant concentrations in surface sediments were found near the 106-Mile Site. Ratio of silver to aluminum (Ag/Al).**

could not be linked to sewage sludge disposal at the 106-Mile Site. The increased concentrations were suspected to result from offshore transport of contaminants and atmospheric inputs.

3.4 Tier 4: Long-Term Effects

Tier 4 studies assessed whether there were long-term effects from sludge disposal at the 106-Mile Site. Studies conducted under Tier 4 included endangered species observations at sea; surveys of midwater fish for evidence of bioaccumulation of chemical contaminants; surveys of epibenthic organisms for cytochrome P-450E enzyme induction; histopathological/biochemical analyses; assessments of ichthyoplankton; evaluations on the prevalence of chitinoclasia shell disease, metals, and organic contaminants in commercial fish species, red crabs, and lobsters; and evaluation of benthic and microbiological community structure, and fisheries landings. Hypotheses $H_0$18 through $H_0$29 evaluate the possibility of such effects on major groups of living marine resources.

$H_0$18: Sludge constituents have no significant long-term effect on the distribution of endangered species in the vicinity of the Site.

No apparent adverse effects to endangered species were observed. Observations suggested that the Site was in the migratory route for endangered species, but was not in a breeding or nursery ground.

- From the onset of monitoring through 1989, EPA included trained observers of marine mammals, reptiles, and birds on all surveys related to the 106-Mile Site. The observers recorded the presence, number, and behavior of all species of marine mammals, reptiles, or birds sighted along the survey track. Data from sighting made between 1985 and 1989 in the potential area of influence are presented in **Table 3-3**. Two endangered and threatened mammals, the fin and the sperm whale, were sighted. Only two of three endangered and threatened turtle species, the leatherback and the loggerhead turtle, were sighted. Numerous dolphins and unidentified whales were also observed. Seabirds were observed during every survey (EPA/NOAA, 1992). Details of marine mammal, turtle, and seabird sightings are described in EPA (1992c).
- Based on observations of marine mammals, turtles, and birds identified in the vicinity of the Site and downcurrent of the Site, sludge disposal had no apparent effects on endangered species. Comparing data from surveys before the start of sludge dumping (Payne *et al.*, 1984) through 1989 did not show any change in the endangered species data.

$H_0$19: Sludge constituents do not accumulate in the tissues of commercially important species resident in the shelf/slope areas adjacent to the Site.

Data from studies of commercially important species collected in the continental shelf/slope canyons indicated that sludge dumping at the 106-Mile Site was not the prime source of chemical contamination found in these species.

- Concentrations of metals in the muscle of tilefish *(L. chamaeleonticeps)*, the only commercially important deep-water finfish in the mid-Atlantic Bight, collected between 1990 and 1992 in Hudson, Lydonia, and Atlantis Canyons, were generally low, often below detection limits (NOAA, 1992). Concentrations were generally higher in liver tissue than in muscle. No clear patterns were evident to the north and south of the 106-Mile Site (Steimle *et al.*, 1995). The metal concentrations found during this study were similar to those reported for the tilefish in

Table 3-3. Sightings of mammals, turtles, and seabirds in the 106-Mile Site area of potential influence.

Date	Number of Sightings: Mammals	Turtles	Seabirds[a]
<u>1985</u>			
6-16 Nov	2 fin whales 260 dolphin *spp.*	0	11
9-19 Nov	907 dolphin *spp.*	0	17
<u>1986</u>			
22-27 Aug, 15-20 Sep	0	0	12
<u>1987</u>			
7-24 Jul	4 fin whales 131 dolphin *spp.*	8 leatherback 1 loggerhead	12
29 Aug—5 Sep	6 sperm whales 4 fin whales 1 Balaeonptera *spp.* 538-792 dolphin *spp.*	0	3
<u>1988</u>			
1-5 Mar	3 fin whales[b] 14 additional cetaceans[c]	0	5
9-20 Sep	2 sperm whales 7 fin whales 1 whale *spp.* 101 dolphin *spp.*	0	8
<u>1989</u>			
18-30 Oct	3 large whales *spp.* 287 dolphin *spp.*	2 leatherback	12

[a]Species of birds observed.
[b]Two fin whales were observed near the 106-Mile Site; one was observed within the boundaries of the Site.
[c]Includes bottlenose dolphins and pilot whales.

these canyons from 1981 to 1982, before sludge was dumped at the 106-Mile Site.

- The concentrations of organic contaminants in tilefish were lower than the other megafaunal finfish analyzed from other collections (NOAA, 1992). Total mean pesticide concentrations in liver ranged from 0.4 to 0.7 ppm; total PCB concentrations were similar. In all samples of tilefish muscle, concentrations of pesticides and PCBs were lower than 0.2 ppm and were not higher in the 1990-1992 period than in the 1981-1982 period (**Figure 3-16**). Individual pesticides and DDT compounds were found in higher concentrations to the north of the 106-Mile Site (Steimle *et al.*, 1995). No evidence was found that linked sludge disposal at the 106-Mile Site to the pesticide concentrations.

- Samples of lobster *(H. americanus)* hepatopancreas collected in 1990-1992 from submarine canyons between New York and Virginia had concentrations of total pesticides ranging from 0.12 to 14 ppm and PCB concentrations between 0.75 and 3.5 ppm; lowest concentrations were found in Lydonia Canyon lobsters and highest concentrations

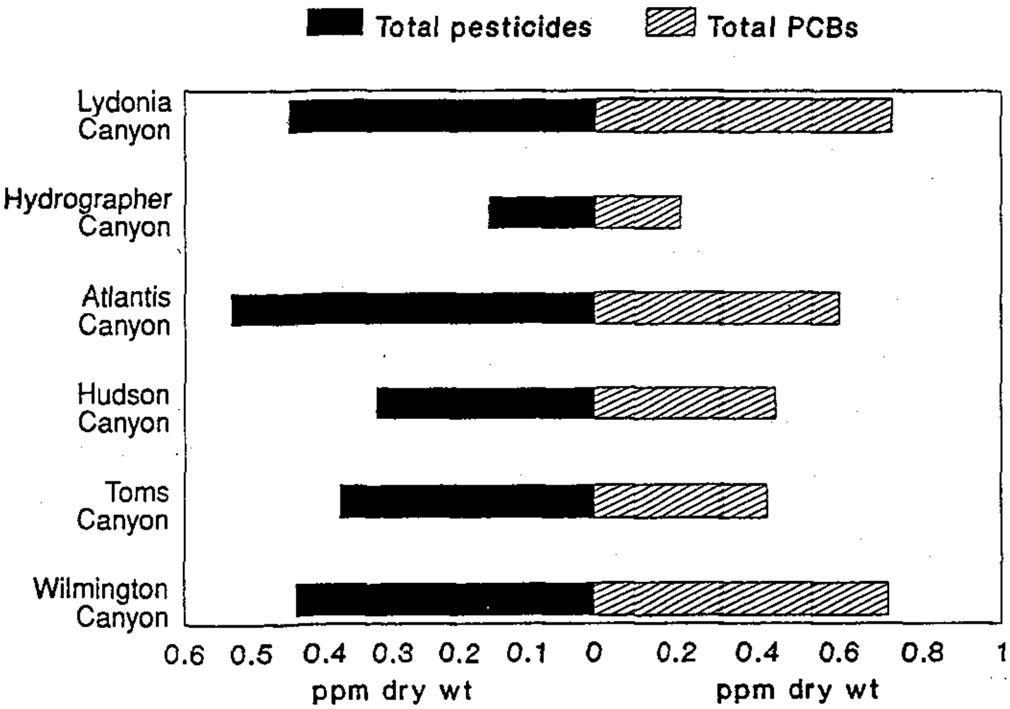


Figure 3-16. **Mean concentrations of total pesticides and total PCBs in tilefish livers collected from various canyons between 1990 and 1992.**

Benthic metabolism, as measured by oxygen consumption rates of the sediments, was elevated in areas known to receive sewage sludge. Changes in the bacterial and benthic community structures in and near the 106-Mile Site were noted during several studies. There were no apparent impacts of sludge disposal on the benthic communities in the heads of canyons on the outer continental shelf or on the deepwater demersal fish community.

were in lobsters from Norfolk Canyon (NOAA, 1992). Total mean pesticide concentrations ranged from 0.75 ppm in lobsters from Lydonia Canyon to 2.7 ppm in lobsters from Norfolk Canyon. A comparison of organic chemical contamination of hepatopancreas from lobster with and without shell disease revealed no significant differences among sampling sites or between healthy and diseased animals (**Figure 3-17**).

- Contaminant levels in the edible tissue and hepatopancreas of red crabs sampled between 1990 and 1992 from the heads of submarine canyons (700 m) on the continental shelf did not identify any gradients related to sludge disposal at the 106-Mile Site (Feeley, 1993; Cooper, 1993).

H_o20: Benthic metabolism, populations, and/or communities do not change significantly because of sludge disposal.

Benthic Metabolism

- In 1992, sediment oxygen consumption was elevated by more than a factor of two southwest of the Site, in the area predicted to receive the highest deposition of sludge relative to reference areas (Sayles *et al.*, 1995). A decreasing gradient in oxygen consumption rates extended 95 km to the southwest of the Site (**Figure 3-18**). Relative to references areas unimpacted by sewage sludge disposal, the higher consumption rates are indicative of additional input of organic carbon to the sediments and subsequent oxidation by natural processes.

- Relative to the reference area sediments, the aerobic zone in the sediments near the Site was reduced by one-half to one-third (from ≈6 cm to 2-3 cm depth).

- In 1993, one year after disposal stopped, the oxygen consumption rates near the 106-Mile Site returned to background levels. The

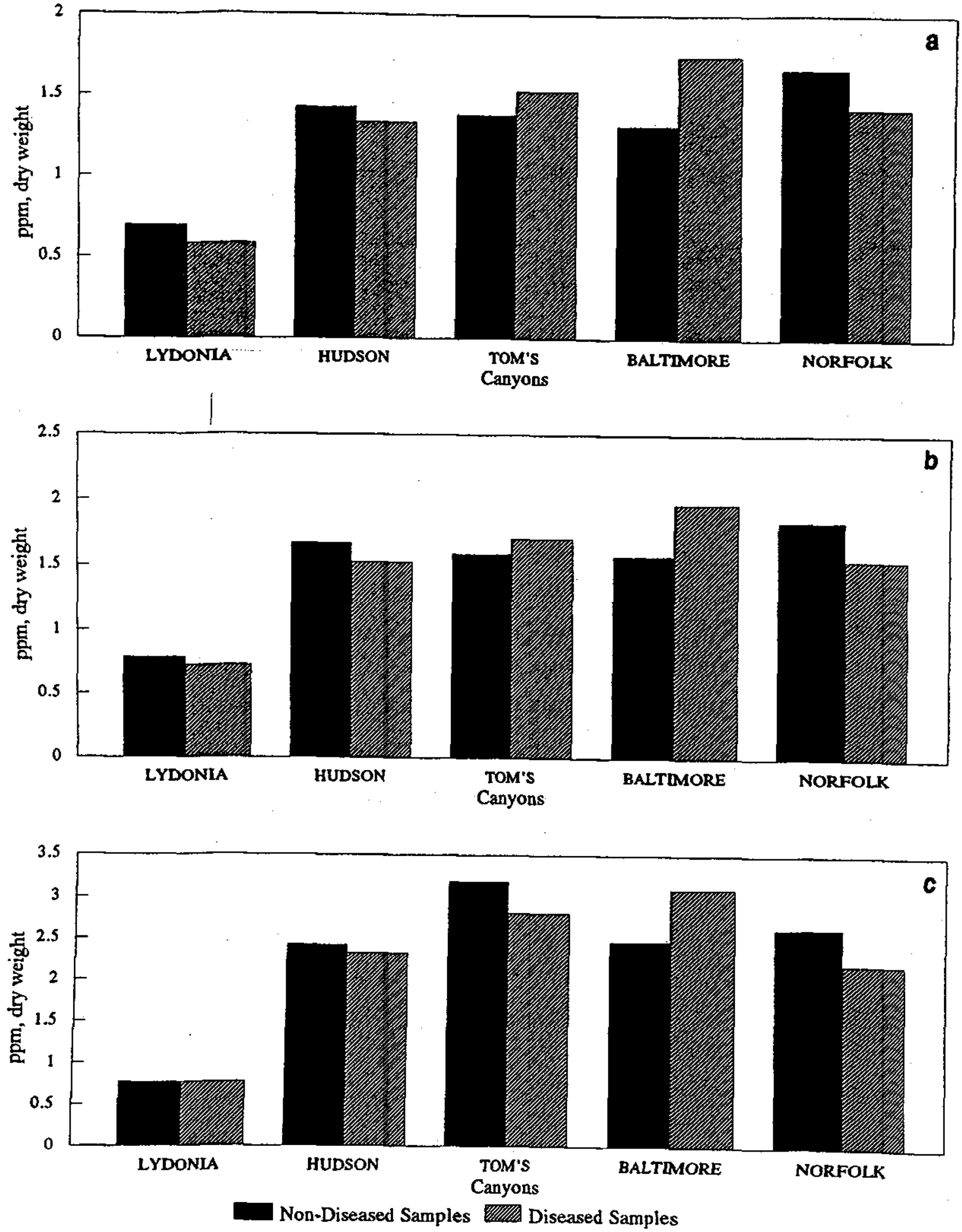


Figure 3-17. **Total mean concentrations of (a) DDTs, (b) chlorinated pesticides, and (c) PCBs in lobster hepatopancreas by sample site. There were no significant differences in contaminant concentrations among sampling sites or between healthy and diseased animals. LC = Lydonia Canyon; HC = Hudson Canyon; TC = Tom's Canyon; BC = Baltimore Canyon; NC = Norfork Canyon.**

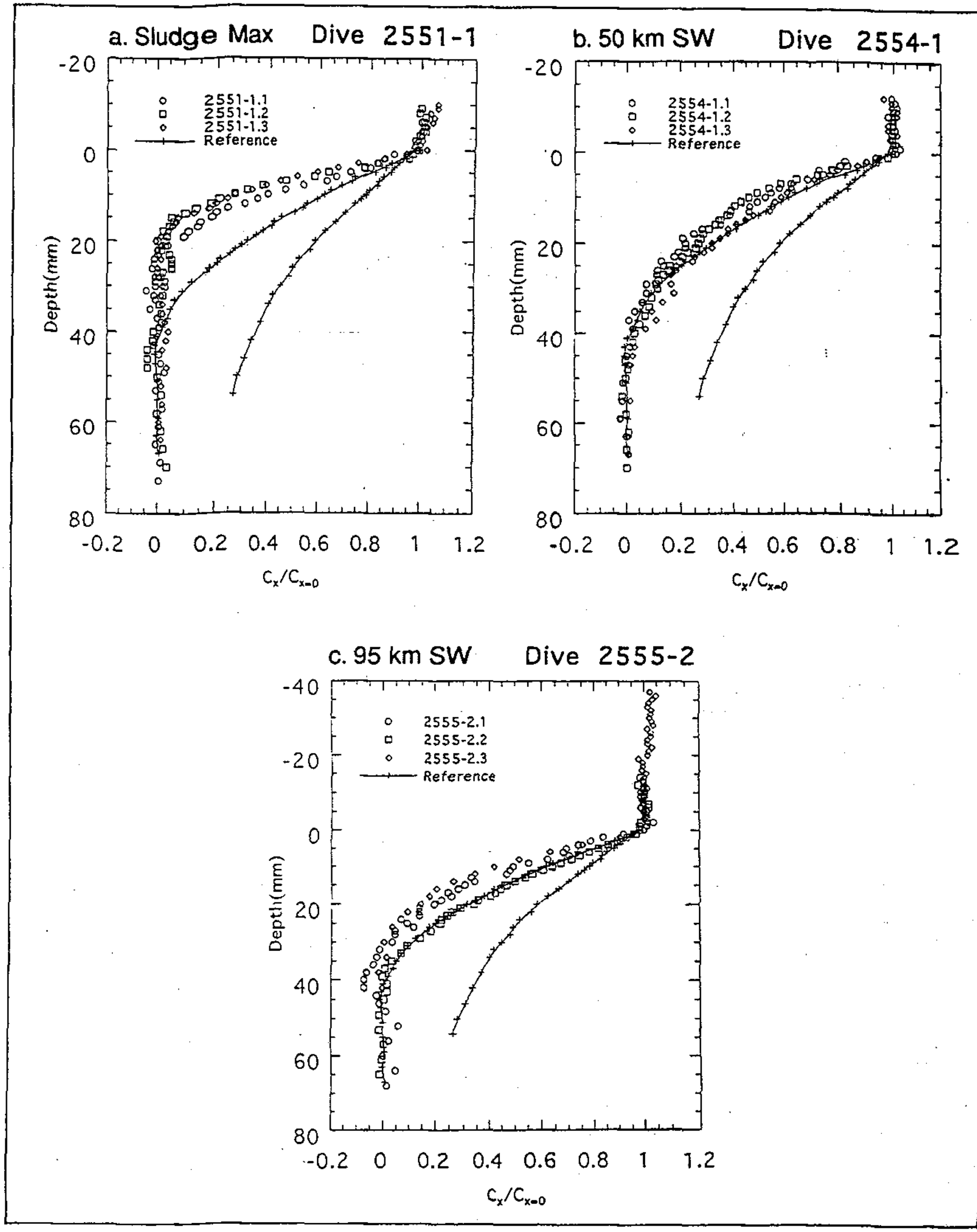


Figure 3-18. **Sediment oxygen profiles sampled in the vicinity of the 106-Mile Site in 1992 (open symbols) showed a gradient of impact relative to reference locations (+ symbols).**

decreased rate of oxygen consumption was attributed to oxidation of the organic matter. The half life for the carbon added to the sediment of this environment was estimated at 3-6 years. In addition, one year after disposal stopped, the depth of the aerobic zone in sediments immediately adjacent to the Site returned to depths typical of reference areas.

- In 1993, oxygen consumption rates remained elevated 95 km from the Site (**Figure 3-19**). Along-slope transport of sediments towards the southwest may also have been responsible for the continued high consumption rates at the 95-km distance.

- Use of the stable isotope ratios of carbon, nitrogen, and sulfur as tracers of sewage-derived organic material, indicated that sludge reaches the seafloor and enters the benthic food web through the grazing activity of the sea urchin *E. affinis*, an opportunistic deposit feeder attracted to aggregations of plankton-derived organic material (Van Dover *et al.*, 1992).

Deep-Sea Benthic Studies

- Two species of polychaete worm, not found previously in continental slope and rise sediments, were abundant at locations west of the Site (Bothner and Grassle, 1992; Grassle, 1991b). The presence of these species was attributed to the input of organic carbon from sludge disposal. Other results from this benthic study were not available at the time that this summary report was prepared (mid 1995).

- The polychaete community apparently changed in response to the increased sludge content of the bottom sediments. Although the sludge accumulation rates southwest of the Site were low (60 mg/m^2/day), the estimated influx of sludge represents only a doubling of the rate at which organic material reaches the seafloor (Grassle, 1991a).

Canyon Benthic Studies

- Extensive video surveys at a depth of 700 m showed that the community structure and species abundances in the outer continental shelf canyons were consistent (Cooper *et al.*, 1992). Also, the behavior and habitat associations of the animal populations in the canyons were consistent and did not appear to be affected by sludge dumping.

Deep-Sea Bacterial Community Study

- The autochthonous bacterial community in the near-bottom waters at the Site was replaced by a bacterial community that was poorly adapted to the *in-situ* conditions (Straube *et al.*, 1991). The bacterial community of the Site contained few cold-adapted species when compared with the bacterial community at a reference site. Bacterial growth was strongly inhibited by the *in-situ* hydrostatic pressure (250 atm) at the Site.

Canyon Bacterial Community Studies

- Between 1990 and 1993, sediment samples from the 200- to 700-m depth in the Hudson Canyon were tested for bacterial indicators of sewage sludge. All 24 sites sampled were positive for *Clostridium perfringens*, the concentrations of which ranged from 540 to 28,000 spores per 100 g sediment (Sawyer *et al.*, 1995). Three species of Acanthamoeba were found at one or two sites each year. Three other genera of cyst-forming amoeba were also found, but less often. The data indicate that this region of the Hudson Canyon had received sewage wastes but the data did not reveal whether sewage sludge disposal at the 106-Mile Site was directly responsible.

Demersal Fish Community Study

- The community structure of demersal fish collected in 1990 and 1991 was similar to the community sampled between 1973 and 1978 (Musick *et al.*, 1995). Species richness, dominant species, numerical abundance

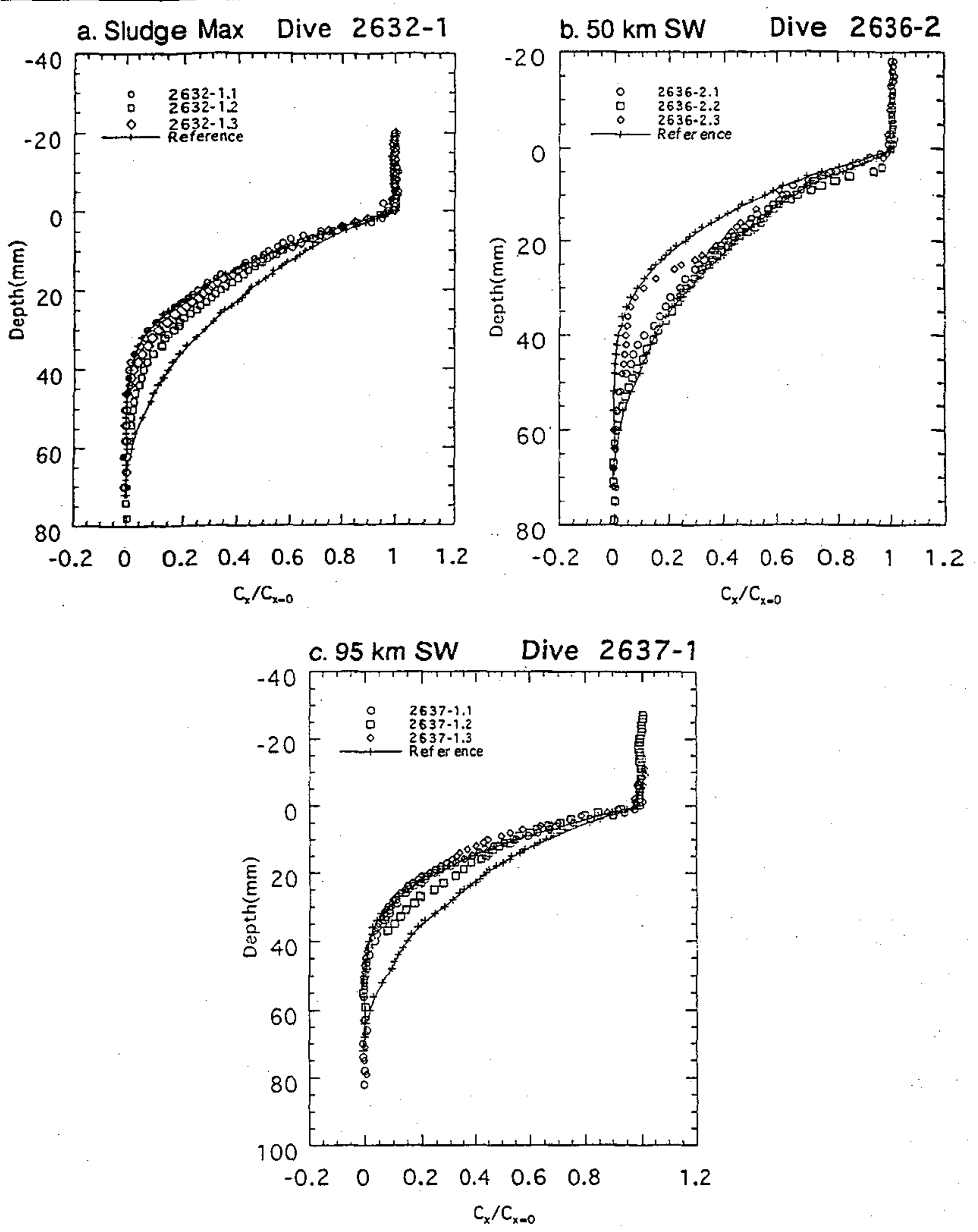


Figure 3-19. **Sediment oxygen profiles sampled in the vicinity of the 106-Mile Site in 1993 did not show the gradient observed in 1992.**

(**Figure 3-20**), and depth distributions were similar during both sampling periods. No significant differences in biomass were found among stations near and downstream of the Site. Changes in the demersal fish community resulting from sewage sludge disposal at the 106-Mile Site could not be detected.

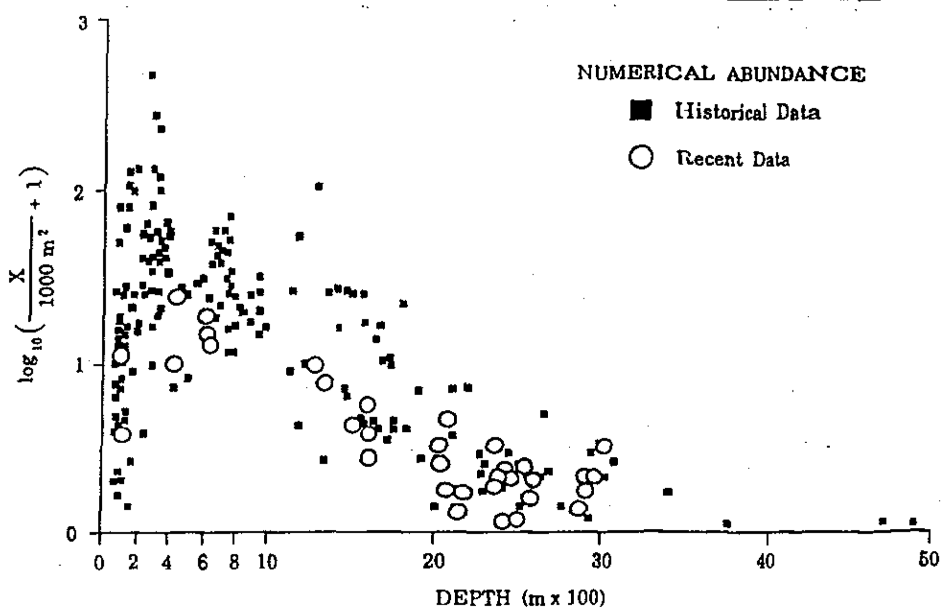


Figure 20. **Comparison of historical demersal fish abundance to abundance during sludge disposal found no significant changes (from Musick *et al.*, 1995).**

$H_0$21: Sludge disposal has no effect on the sensitive eggs and larval stages of indigenous animals.

$H_0$22: Sludge disposal has no measurable long-term impact on offshore plankton.

These hypotheses were not directly addressed by EPA between 1988 and August 1990, and they were not evaluated by EPA or NOAA between August 1990 and October 1991. In the absence of extensive long-term sampling, effects on plankton communities are difficult to assess. EPA and NOAA resources were focused on issues that were more directly related to contaminants in marine resources and effects on human health.

- Data from the sediment trap program (Hunt *et al.*, 1993) suggested, but could not demonstrate, that the sludge may have affected primary production in surface water.

$H_0$23: Pathogen or biological tracers of sewage sludge do not increase in the water column or biota as a result of sludge disposal.

Tracers were confirmed in the water column both inside and outside the 106-Mile Site. The concentrations of these substances were below the concentrations found in the sludge. No follow-up studies were conducted to determine whether virulent contaminants survived in sludge plumes.

- During the October 1991 survey (Hunt *et al.*, 1992), the spatial distribution of *C. perfringens* indicated heterogeneity in the distribution of the spores and suggested that the discharge of sludge does not result in a general area-wide increase in sludge-related bacteria. Rather, the *C. perfringens* distribution appeared to be related to specific dumping events and the physical transport of the surface water within the Site that received the sludge.

- *C. perfringens* data confirmed the movement of the sludge to the southwest of the Site. Elevated *C. perfringens* counts occurred at a number of stations removed from the Site (**Figure 3-8;** Hunt *et al.*, 1992). Detectable concentrations were found in near-surface waters (to 35 m) at locations as far as 4 km downstream of the Site and in samples collected below the pycnocline.

- Between 1990 and 1993, bottom water samples collected from the 200- to 700-m depth in the Hudson Canyon were tested for bacterial indicators of sewage sludge. Water from 14 of 24 sites contained the marine ciliate *Uronema* sp. and cyst-forming flagellate *H. obovata* which could only be cultured in freshwater media. Identification of these species further supported the input of sewage to the area but could not identify the 106-Mile Site as the source.

H_o24: There are no detectable differences in the body burdens of sludge contaminants in midwater fishes in the immediate vicinity of the 106-Mile Site compared to a broad area surrounding the dumpsite.

Evidence from EPA and NOAA midwater fish and plankton analyses did not reveal any significant broad-scale differences in body burdens of sludge contaminants related to geographical distribution. However, occasional elevation of some metals in the myctophid *Benthosema glaciale* and in plankton material from the western boundary of the Site suggest short-term exposure to sludge.

Midwater Fish Studies

- Body burdens of PCBs and pesticides were low, but detectable, in fish belonging primarily to the families Myctophidae (lantern fish) and Sternoptychidae (hatchet fish) from stations within, to the northeast of, and to the southwest of the Site, and from a reference site in the Sargasso Sea (EPA, 1992r). These data were insufficient to determine whether the contaminants originated from sludge or from one of the other possible sources. Concentrations of metals in fish tissues suggested that one Myctophidae species collected within the Site concentrated several metals that are also found in sludge (Zdanowicz *et al.*, 1990).

- In 1990, the distribution of metal concentrations in midwater fish collected by NOAA showed elevated levels of individual metals in fish from isolated stations scattered over a large area. However, the elevated concentrations could not be directly attributed to the sludge dumping (NOAA, 1992). More than one-half of all lead measurements were below the detection limits. Detectable concentrations of silver, cadmium, copper, lead, zinc, mercury, and iron were lower than some values measured at the NOAA stations during the preliminary study in 1989.

- Midwater fish and their prey in the area southwest of the 106-Mile Site were collected during the August 1991 midwater fish survey conducted by NOAA. Samples of plankton, collected by Bongo tows and stomach-content analysis of fish from the same stations, provided prey information. Significantly elevated concentrations of metals were found in specimens from several stations located on the western boundary of the Site (**Figure 3-21**; Zdanowicz *et al.*, 1995). Higher concentrations farther southwest were not observed. The high values detected in fish near the Site were thought to result from injection of particles and plankton that were high in metal concentrations (**Figure 3-22**) but that were later depurated. Definitive linkage of the high concentrations of metals in fish to sludge dumping could not be made and any increases in concentrations were thought to be temporary.

Zooplankton Studies

- Concentrations of metals in zooplankton samples from the vicinity of the Site were not highly elevated relative to the concentrations in other areas, and showed little evidence of contamination due to sludge dumping (NOAA, 1992).

- Concentrations of organic contaminants were lower in zooplankton than in midwater fish and ranged from concentrations that were below detection limits to the low ppb range. There was no apparent similarity in the distribution of contaminants in zooplankton and fish. Statistical analysis suggested that the concentrations of organic contaminants for a

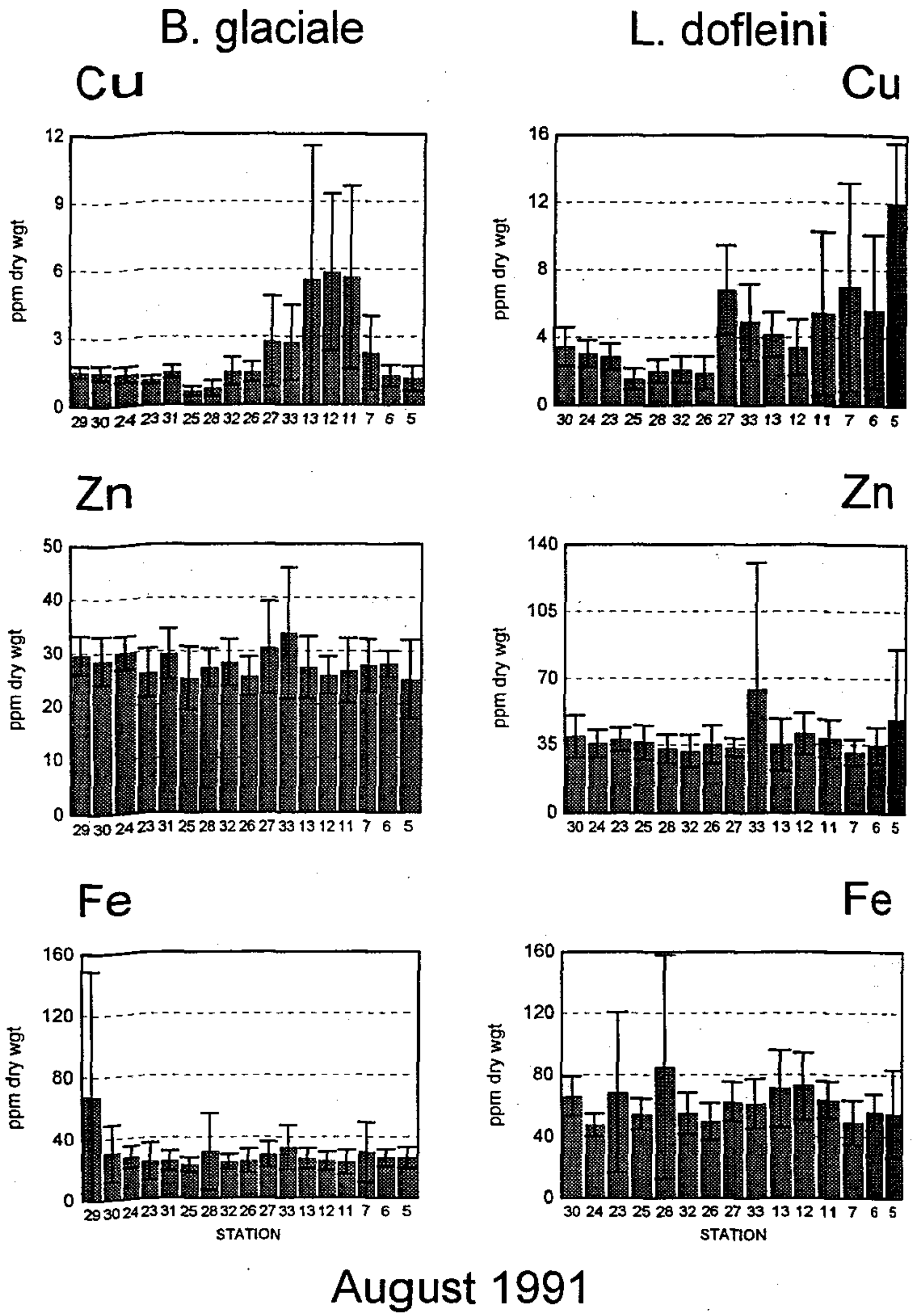


Figure 3-21. **Metal concentrations in midwater fish species collected in 1991 showed sporadic elevations (from Zdanowicz *et al.*, 1995).**

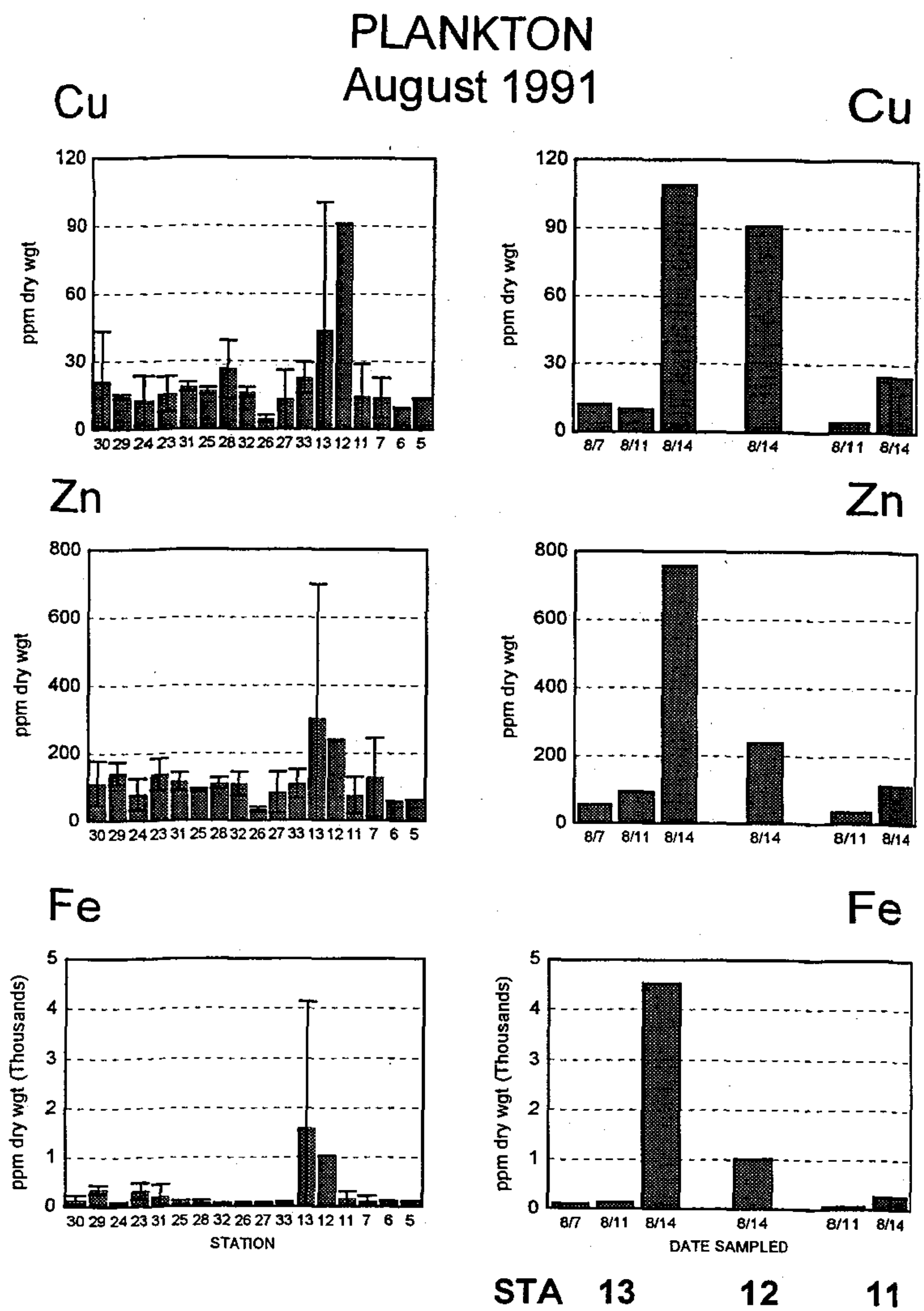


Figure 3-22. **Metal concentrations in phytoplankton collected in 1991 showed sporadic elevations (from Zdanowicz *et al.*, 1995).**

given species of fish did not vary significantly from one station to another (NOAA, 1992).

H_o25: The prevalence of shell disease exhibited by commercially important crustaceans is not significantly different in collections of commercially valuable American lobsters and red crabs, off New Jersey, adjacent to and downstream from the 106-Mile Site, from those in collections off Georges Bank and southern New England.

An extensive data set for chitinoclasia shell disease in lobsters and red crabs resident on the continental shelf and canyons suggested that this disease was common to all populations sampled. Prevalence of chitinoclasia shell disease was significantly different in lobsters collected from areas of potential sludge influence. A definitive cause-and-effect relationship could not be established for the 106-Mile Site because of the likely influence from other sources, notably the former 12-Mile Site. No cause-and-effect linkage could be established between sludge dumping the 106-Mile Site and incidence of shell disease in red crabs.

Commercial Catch Inspection

- Examination of more than 15,000 lobsters collected from 9 canyons for signs of chitinoclasia revealed that 7.9% of the population had lesions (Ziskowski *et al.*, 1995). Occurrence of shell lesions was independent of carapace length, although female lobsters were more affected than males. Disease prevalences in female lobsters from areas potentially affected by sludge dispersion were significantly higher than lobsters from areas outside of this potential influence and statistical analysis suggested that female lobsters from the canyons most likely to be influenced by dumping at the 106-Mile Site had a higher prevalence of disease. An equally strong relationship for the former 12-Mile Site was also found. Because of this, a cause-and-effect relationship to disposal operations at the 106-Mile Site could not be established.

NOAA NMFS Groundfish Survey

- Results from commercial catch inspections were supplemented with data collected by NOAA NMFS in 1990 (fall) and 1991 (spring and fall) during groundfish surveys at shelf stations north of the area influenced by the Site. Of the 460 specimens examined, shell lesions were only found in 6% (NOAA, 1992), which was not statistically different than for the commercial catch observations.

Commercial Catch Observer Program

- From January 1989 to December 1991, observations of chitinoclasia prevalence and severity in lobsters collected from fish trawls and pots on the continental shelf between the Gulf of Maine and Virginia(**Figures 3-23 and 3-24**) indicated that disease prevalence was low; 2.6% (20 of 764 specimens) of lobsters caught in trawls and 1.8% (62 of 3420 specimens) of lobsters caught in pots were affected (Wilk *et al.*, 1995).

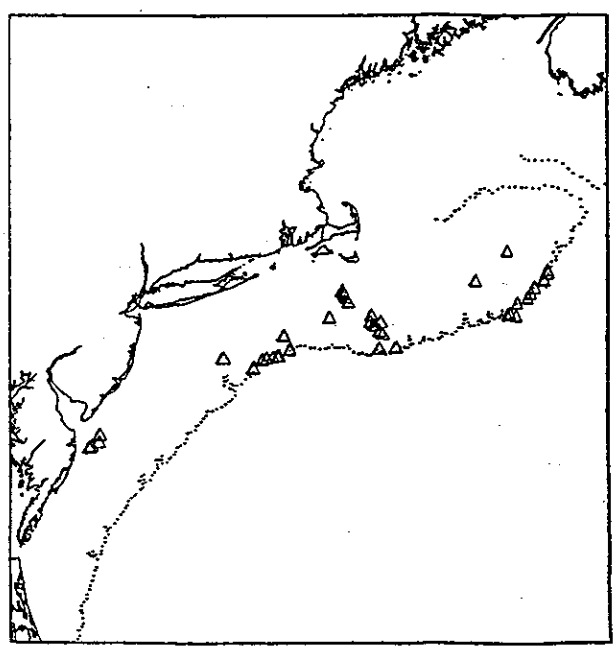


***Figure 3-23.* 106-Mile Site chitinoclasia study locations of lobster pot hauls containing American lobsters *(Homarus americanus)* with positive pathology.**

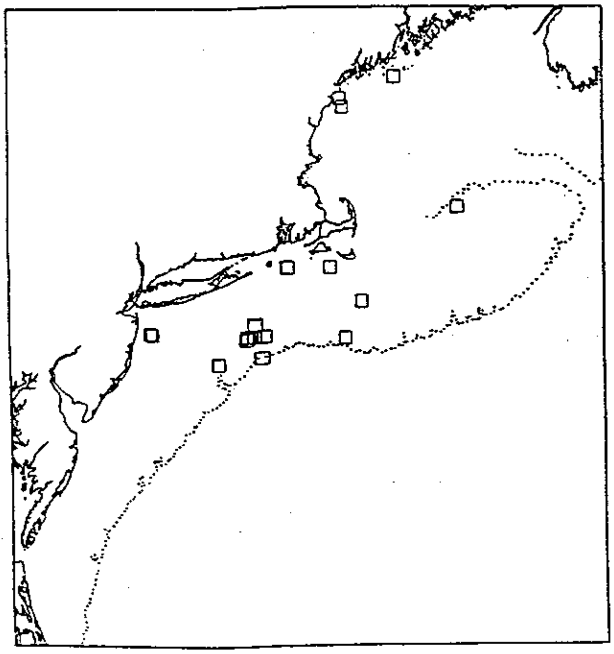


Figure 3-24. **106-Mile Site chitinoclasia study location of lobster pot tows containing American lobsters *(Homarus americanus)* with positive pathology.**

Red Crab Study

- Red crabs collected from 14 sites on the continental shelf break showed high incidence of shell blackening (95% of medium-size male crabs). The incidence ranged from 67 to 100%. On a scale of 1 to 5, the mean severity index was 2.54 and ranged from 2 to 3.3. No significant trends were found between the incidence of the disease and distance from the 106-Mile Site (Feeley, 1993; Feeley *et al.*, 1991; Cooper, 1993).

$H_0$26: Body burdens of trace metals, polynuclear aromatic hydrocarbons (PAH), and polychlorinated biphenyls (PCBs) and pesticides are not significantly different in collections of commercially valuable American lobsters and red crabs, off New Jersey, adjacent to and downstream from the 106-Mile Site, from those in collections off Georges Bank and southern New England.

Sludge dumping at the 106-Mile Site did not adversely affect the contaminant levels in these two commercially valuable species.

Lobster Study

- Trace metal concentrations in commercially valuable lobster collected from submarine canyons on the continental margin were low (NOAA, 1992). Organic contaminants were also found in low concentrations with no significant differences between sampling sites. Comparison with historical data indicated that concentrations did not change significantly between 1982 and 1990.

Red Crab Study

- Concentrations of contaminants in red crabs *(Chaceon quinquidens)*, collected in an area from Baltimore to Georges Canyon, were highly variable among the individuals collected from each site, masking any inter-site variation (Baker *et al.*, 1992). Total PCB concentrations in hepatopancreas tissue ranged from 28 to 1452 ng/g-wet. When the contaminant concentration was correlated with tissue lipid content, it was suggested that physiological variations among the crabs were responsible for the extremely variable concentrations of contaminants.

- Metal and PCB concentrations in large male red crabs from the West Hudson Canyon were not significantly higher than in Veatch Canyon, areas west of Veatch Canyon, or Baltimore Canyon (Feeley, 1993). Arsenic and zinc concentrations were significantly higher in Baltimore Canyon compared with Veatch Canyon. Only arsenic and mercury concentrations increased with animal size. The increased metal concentrations could not be related to sludge dumping at the 106-Mile Site.

$H_0$27: There is no difference in the chemical body burdens in American lobsters and red crabs showing evidence of shell disease and lobsters and crabs without substantial shell disease manifestations.

No significant differences were observed in the organic contaminant concentrations of lobsters with and without shell disease. The incidence of shell disease in male red crabs was correlated to copper in the hepatopancreas and to mercury in muscle tissue.

- During the period of August 1990-1991, concentrations of total pesticides in hepatopancreas of lobsters from submarine canyons between New York and Virginia ranged between 0.12 and 14 ppm, and PCB concentrations ranged between 0.75 and 3.5 ppm. A comparison of organic chemical contamination of hepatopancreas from lobsters with and without shell disease revealed no significant differences among sampling sites or between healthy and diseased animals (NOAA, 1992). Analysis of selected lobster muscle showed very low concentrations of contaminants in edible tissues.

- Metal concentrations in lobster collected from the commercial fishery were apparently not related to the presence or absence of disease (NOAA, 1992). Concentrations in muscle tissues were low, often below the level of detection, except for mercury, which reached a concentration of 3.5 ppm (dry weight) in one specimen. In hepatopancreas tissue, mean concentrations of cadmium, copper, and silver were much higher, reaching values as high as 82.0, 1939, and 15.5 ppm (dry weight), respectively.

- Concentrations of copper in male red crab hepatopancreas were positively correlated with shell disease and size of the individuals (Feeley, 1993). Similarly, mercury concentrations in crab muscle tissue were significantly correlated with shell disease.

$H_0$28: Body burdens of sludge-related contaminants in epibenthic megafauna are not detectably different in animals found in the vicinity of the 106-Mile Site and from those animals found in reference areas.

Evidence from NOAA studies indicated that body burdens of sludge-related contaminants in epibenthic megafauna were not different in animals collected from different areas.

- Steinhauer *et al.* (1995) determined that the organic and inorganic tissue contaminant concentrations in six bottom fish (three blue hake, *Antimora rostrata*; two grenadier, *Coryphaenoides aramatus*; and one cutthroat eel, *Synaphobrachus kaupi*) collected near the Site were similar to those found previously along the eastern North Atlantic continental slope. In liver, arsenic, zinc, and copper were all elevated compared to the other elements. In muscle tissue, arsenic and zinc were found at much higher concentrations than other elements measured (silver, cadmium, lead, copper, and mercury). PCB and DDT (as DDT, DDE, and DDD) were found in all samples. Concentrations of PAHs were negligible in all samples. No significant differences in contaminant concentrations were observed between fish caught at the northern boundary of the Site and those caught 10 nmi east of the Site. Elevated levels of hepatic cytochrome P4501A were detected in grenadiers and in the cutthroat eel, but not in the blue hake. None of the fish examined had any histopathological lesions of the type normally associated with chronic or severe exposure to chemical contaminants.

- Concentrations of metals in the tissue and livers of 13 species of deep-water finfish (more than 600 individual fish) and 2 species of shrimp (128 individuals), collected in 1991 and 1992 from areas within the potential influence of sludge dumping at the 106-Mile Site, were consistent with previously reported concentrations in similar organisms in other regions of the world (Sennefelder *et al.*, 1995). Few instances of elevated metals were found and no pattern of metal concentrations relative to distance from the 106-Mile Site could be identified.

- The level of organic contaminants in individual megafaunal specimens varied widely (NOAA, 1992). however, clear association between the levels of organic contaminants and disposal at the 106-Mile Site could not be established.

$H_0$29: The distribution or abundance of the dominant commercially exploited fisheries is not influenced by sludge disposal at the 106-Mile Site.

Effects of sewage sludge disposal cannot be excluded as factors measurably affecting fishery resource abundance and composition. Data are inadequate to determine whether natural causes, fishing pressures, sludge disposal, other unknown factors, or a combination of factors were responsible for the observed population fluctuations.

- Species abundances of silver hake *(Merluccius bilinearis)*, red hake *(Urophycis chuss)*, summer flounder *(Paralichthys dentatus)*, goosefish *(Lophius americanus)*, and black sea bass *(Centropristis striata)* declined significantly over temporal and spatial (north to south) scales during the period that sludge was disposed at the Site (Chang, 1993). The cause of the reduced abundance of these species was unclear; natural factors may have been responsible for fluctuations in the population.

4.0 SITE MANAGEMENT

Throughout the history of sludge disposal at the 106-Mile Site, EPA, NOAA, and the USCG adhered to Federal, state, and local statutes and regulations that govern disposal of the sludge in the ocean. A substantial amount of Federal, state, and local funds was spent to ensure that the environment was protected, that disposal was conducted within the conditions established by the ocean dumping regulations and disposal permits, and the fate and effects of the sludge were determined. This section highlights significant Federal management actions that were completed during the period that the 106-Mile Site was used for sludge disposal. A summary of management actions relative to various statutory, regulatory, and permit conditions, and recommendations for future researchers and managers relative to large multidisciplinary monitoring programs are presented.

4.1 Summary of Management Actions

4.1.1 Tier 1 Management Actions

Waste Characteristics

In 1989, EPA evaluated the type of measurements, reporting frequency, and data for sludge characteristics monitoring established in 1984. This evaluation determined that the data and reporting requirements were inadequate and, as a result, new program-specific requirements for sludge characteristics monitoring were developed. These requirements were included as part of the permits issued for sewage sludge disposal in August 1989. These new permit conditions required modified sampling methods and required that all analyses be conducted under EPA-approved quality assurance plans. The revised permits specified the analytical methods, method detection limits, number and type of parameters to be monitored, frequency of monitoring, and quality control requirements.

The direct linkage of sludge quality to sludge disposal rates provided EPA with a tool for frequent adjustment of the sludge disposal rates in response to changes in sludge quality. In addition, identification of specific sludge tracers resulted in further sludge characterization necessary to ensure that appropriate data were available for the studies being conducted under Tiers 3 and 4.

Disposal Operations

In response to concerns of short dumping at the Site and public concerns over sludge transfer in the Harbor, EPA determined that surveillance of all dumping activities was necessary. As a result, a cradle-to-grave manifest, seal system, and shiprider program was established. This program supplemented the ODSS established by the USCG and focused on the activities within the Harbor. These surveillance procedures were effective in identifying violations to the ocean dumping regulations and permit conditions. Permit conditions specified allowable dumping rates and designated tracklines for dumping. From August 1989 through 1992, EPA reviewed the sludge characterization data submitted by the permittees and adjusted disposal rates at the 106-Mile Site as necessary to ensure that the requirements of the ocean dumping regulations were met. Administrative penalties of $445,000 were assessed as of October 1991 for violations of permit conditions with settlements exceeding $214,000.

4.1.2 Tier 2 Management Actions

Nearfield Compliance
During the period from 1988 through 1990, the results from nearfield-fate monitoring established that, under the conditions initially set for sludge disposal (*i.e.*, a dumping rate of 15,500 gal/min), concentrations of sludge constituents frequently did not meet regulatory requirements. As a result, the permittee dumping rates were lowered to ensure that WQC were met at all times and that levels of pathogens in the water column were reduced.

Short-Term Effects
Because floatable debris was discovered in plankton samples collected in 1989, an increased effort to assess the sources of this material was initiated. Also, more stringent requirements for monitoring this material were imposed on the sewerage authorities.

4.1.3 Tier 3 and Tier 4 Management Actions

Management actions under Tiers 3 and 4 of the joint Monitoring Plan specifically included implementation of the 106-Mile Site monitoring program in response to the ocean dumping regulations and the specific requirements of the ODBA. Because ocean dumping of sludge was stopped in 1992 by Federal statute, no specific long-term management actions relative to the Site were necessary. However, the results of the monitoring program summarized in the previous sections of this report were adequate for EPA and other responsible agencies to make informed decisions regarding the continuation of sludge disposal at the Site. Furthermore, the results have added significantly to the understanding of many issues related to the transport, fate, and effects of sewage sludge disposal in deep-water environments. The data developed under this monitoring program and the conclusions drawn have also contributed meaningful information towards improved understanding of the transport processes affecting the fate of sludge disposed in the ocean. Thus, the information returned during the program provides a significant data set that is invaluable for evaluating any future requests for ocean disposal of similar wastes.

As required by the ODBA, the overall program effectively implemented both traditional and state-of the-art monitoring methods during the assessment of fate and effect. Effective integration of the 106-Mile Site monitoring program with other ongoing monitoring and research programs was also achieved.

Several components of the program clearly demonstrated that sewage sludge was not transported across the continental shelf and that sludge did not reach the coastal beaches or important areas for commercial fisheries. The monitoring program also provided considerable insight into the frequency and prevalence of chitinoclasia shellfish disease in the greater New York Bight region, and was able to demonstrate that sewage sludge disposal at the 106-Mile Site did not influence the prevalence of this disease.

4.2 Recommendations

The following set of recommendations was derived from the various technical and management actions undertaken during the 106-Mile Site monitoring program. These recommendations provide future researchers and managers with a summary of the lessons learned from the monitoring program. The recommendations will hopefully benefit future studies of this type so that future programs are even more effective in addressing waste disposal management.

The successes of the 106-Mile Site monitoring program overall, and specifically the sediment trap program, can be attributed to the early use of all available information regarding the physical oceanographic regimes near the Site and all available sludge transport models. Placement of the sediment trap moorings was nearly ideal and cost-effectively confirmed the transport of the sludge. The data set was sufficiently robust to allow evaluation of tracer-specific transport behavior and identification of possible secondary processes associated with the sludge transport. The use of satellite communications systems and remotely acquired data effectively contributed to the understanding of surface ocean processes and demonstrated that the sewage sludge did not reach the shorelines of the region. Clearly, inclusion of such technology in future programs is warranted, if the issues being addressed by a monitoring program require this approach.

Although the overall monitoring program was highly successful, several aspects of the program could have been improved. Suggested improvements are discussed below.

The ability to provide unequivocal estimates of sludge loading to the Site was hindered by the lack of consistent, frequent, and long-term data on specific sludge parameters that were found to be useful sludge tracers. Therefore, early identification of chemical and physical attributes which can be used as specific and unique tracers to the waste is imperative. These tracers must be measured using methods that provide accurate quantification and must be measured at frequencies sufficient to accurately determine the variability in the waste. This is necessary to better define the endmember concentrations, to better predict fate, and to better provide mass balance estimates. Specific recommendations for characterization studies that would have improved the 106-Mile Site monitoring program include more complete evaluations of the size-specific particle settling rates and fractions within the sludge, characterization of the tracer concentrations within the various particle size classes, earlier identification of unique sludge tracers, and acquisition of more frequent data to address the time varying concentrations of specific tracers in the sludge.

In addition, the 106-Mile Site monitoring program was not designed to address potential secondary effects such as changes in primary production induced by nutrients in the sludge nor the potential beneficial results of such inducements. Specifically, the stable isotope results from the sediment trap program suggested that the sludge disposal may have affected cycling of particulate matter in the receiving waters downstream of the Site. This type of effect can occur in spite of compliance with concentration-based WQC because the ecological responses in the receiving waters are more likely to be flux driven than concentration driven. Thus, future monitoring programs should consider potential cumulative impacts of the constituents of the waste material and significant ecological processes that might influence the transport and fate or effects (both positive and negative) of the material. If such effects are thought to be important, the monitoring program should include specific hypotheses related to the issue and design studies to address these potential secondary effects.

Finally, if sludge disposal at the 106-Mile Site had not stopped, continued monitoring of the fate and effects of the sludge would have been required. The data generated during the 106-Mile Site monitoring program suggested further monitoring activities might include additional source characterization studies, additional modeling efforts incorporating the improved source characterizations, and collection and analysis of sediment from the areas of predicted sludge deposition. The consistency of the model predictions with the sediment trap program results suggested that continued cost-effective monitoring could have been accomplished through a sampling grid incorporating an increasing distance between the stations with increasing distance from the Site. This design would allow locating sampling stations in critical regions while controlling the number of samples required to confirm the model transport and fate. The analytical chemistry component of future monitoring could have focused on a suite of selected tracers that address the range in the expected particulate/seawater partitioning. Continued analysis of stable isotopes in the sludge and receiving environment (sediment) could have effectively addressed changes in the benthic environment and addressed influences of other oceanic processes affecting the region (*e.g.*, resuspension and off-shelf transport of particles).

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