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FINAL REPORT

NEARFIELD MONITORING OF SLUDGE PLUMES AT THE 106-MILE DEEPWATER MUNICIPAL SLUDGE SITE: RESULTS OF A SURVEY CONDUCTED AUGUST 31 THROUGH SEPTEMBER 5, 1987

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA), under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, PL 92-532), is monitoring the 106-Mile Deepwater Municipal Sludge Site (106-Mile Site). The objective of the 106-Mile Site monitoring program is to ensure that provisions of EPA's ocean dumping regulations are met through assessment of compliance with permit conditions and assessment of potential impacts on the marine environment. The program is being implemented according to a tiered approach, whereby data collected in each tier are not only used in making site management decisions but also are required as the foundation for the design and extent of monitoring activities in the next (lower) tier. Four tiers are included in the monitoring program: (1) Sludge Characteristics and Disposal Operations; (2) Nearfield Fate and Short-Term Effects; (3) Farfield Fate; and (4) Long-Term Effects.

This report presents the results from nearfield fate studies conducted at the site in September 1987. Currently, dumping at the site is conducted under court order. If permits for disposal of sludges are issued, they will stipulate that water quality criteria (WQC) and limiting permissible concentrations (LPC) may not be exceeded within the site four hours after dumping or outside the site at any time. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring behavior and movement of sludge immediately after disposal is necessary to confirm assumptions regarding dispersion and dilution that were made in issuing permits. Nearfield fate monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short-term. This information will also be used to guide monitoring activities to assess short-term biological effects of sludge disposal.

The 106-Mile Site monitoring plan presents several hypotheses related to nearfield fate of sludge plumes, and these hypotheses were tested during the survey. Results from the survey indicated the following:

Permit Compliance

H_o3: Concentrations of sludge and sludge constituents are below the permitted LPC and WQC outside the site at all times.

Results from the survey indicated that sludge plumes can be transported outside the site before all constituents are diluted to levels below WQC.

H_o4: Concentrations of sludge and sludge constituents are below the permitted LPC and WQC values within the site 4 h after disposal.

Although the conditions at the site during the survey were dispersive, measured concentrations of two sludge constituents, copper and lead, exceeded water quality criteria 4 h after disposal.

H_o5: Pathogen levels do not exceed ambient levels 4 h after disposal.

Concentrations of Clostridium perfringens, a microbial tracer, exceeded ambient levels after 4 h in all sludge plumes monitored during the survey.

Impact Assessment

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

Sludge penetration below 20 m was not observed at any time during the survey. Because a strong current "jet" occurred within the pycnocline throughout the survey, sludge may have been transported quickly from the survey area, precluding observations of settling.

Throughout the region, vertical profiles of natural turbidity exhibited a subsurface maximum situated within the seasonal pycnocline. This suggests that surface-dumped particulate matter may accumulate within the seasonal pycnocline during summer and coexist with natural planktonic species.

H_o7: **The concentration of sludge constituents is not detectable in the site one day after disposal.**

Although sludge plumes were not tracked for longer than 9 h after disposal, calculations of dispersion indicated that all measured sludge constituents would reach ambient levels within 1 day.

H_o8: **The concentration of sludge constituents at the site boundary or in the area adjacent to the site is not detectable one day after disposal.**

Calculations indicated that concentrations of sludge constituents would be diluted to ambient levels within 1 day for all plumes monitored.

H_o9: **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.**

Any depression of oxygen levels in sludge plumes was minor. pH was not monitored during the survey.

Results of the survey have provided the first complete assessment of sludge plume behavior and transport under summer conditions. Many of the measurements will be repeated during the winter, when vertical dispersion is expected to be much greater than in the summer. The measurements will also be repeated in the summer, so that we can develop an understanding of variability of measurements of plume behavior. These results will also be used to plan appropriate measurements of short-term effects of sludge dumping and will guide plans for assessing far-field fate of sludge constituents.

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1.0 INTRODUCTION

Under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, PL 92-532), the U.S. Environmental Protection Agency (EPA) is responsible for regulating disposal of wastes, including sewage sludges, in ocean waters. Under this authority, EPA has published ocean dumping regulations (40 CFR Parts 220-229) that specify procedures for monitoring ocean dumpsites. EPA's responsibility for developing and maintaining monitoring programs for designated ocean disposal sites is described in these regulations.

In carrying out the responsibility for developing monitoring programs, EPA has prepared a monitoring plan for the 106-Mile Deepwater Municipal Sludge Site (106-Mile Site) (EPA , 1992a). The site is located off the coast from New York and New Jersey (Figure 1-1) (EPA , 1987a). Data generated by the program will be used by site managers to make decisions about site redesignation or dedesignation; continuation, termination, or modification of permits; and continuation, termination, or modification of the monitoring program itself.

The objective of the 106-Mile Site monitoring program is to ensure that the regulations are met through assessment of compliance with permit conditions and assessment of potential impacts on the marine environment. The program is being implemented according to a tiered approach, whereby data collected in each tier are not only used in making site management decisions but are also required as the foundation for the design and extent of monitoring activities in the next (lower) tier. Four tiers are included in the monitoring program: (1) Sludge Characteristics and Disposal Operations; (2) Nearfield Fate and Short-Term Effects; (3) Farfield Fate; and (4) Long-Term Effects.

Nearfield fate studies being conducted under Tier 2 of the monitoring program address both the permit compliance and the impact assessment components of monitoring at the site. Currently, dumping at the site is conducted under court order. When permits for disposal of sludges are issued, they will stipulate that water quality criteria (WQC), where they exist, may not be exceeded within the site 4 h after dumping or outside the site at any time. When WQC do not exist, the permits will require that the concentration

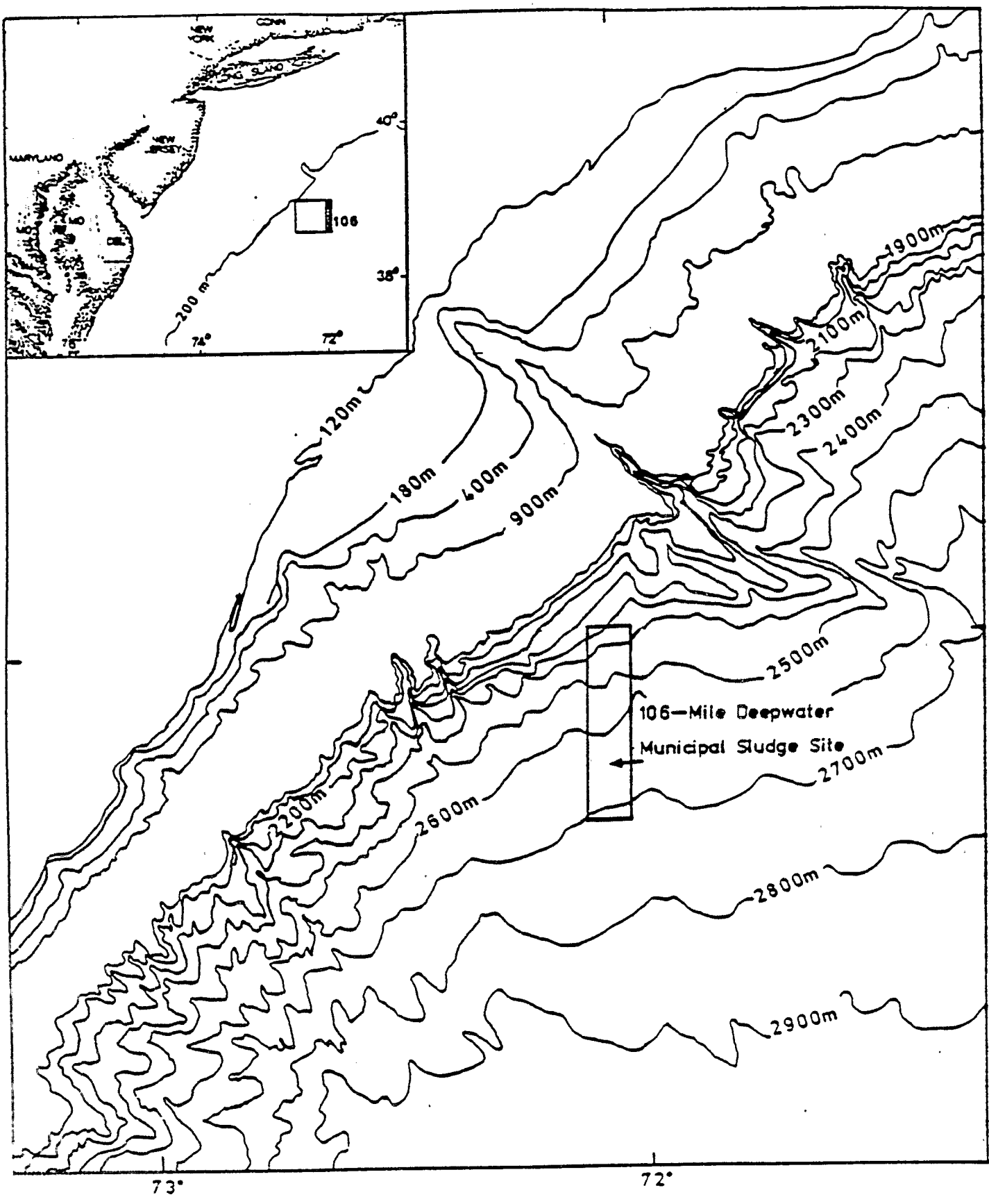


FIGURE 1-1. LOCATION OF THE 106-MILE DEEPWATER MUNICIPAL SLUDGE SITE.

of the sludge not exceed a factor of 0.01 times a concentration known to be acutely toxic after initial mixing, i.e., the limiting permissible concentration (LPC). The combined conformance to LPCs and WQC is thought to be protective of the marine environment.

Nearfield fate monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short term, defined for convenience as 24 h. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring behavior and movement of sludge immediately after disposal is necessary to confirm assumptions regarding dispersion and dilution that will be used in issuing permits. This information will also be used to guide monitoring activities to assess short-term biological effects of sludge disposal.

The 106-Mile Site monitoring plan presents the following hypotheses related to nearfield fate of sludge plumes:

Permit Compliance

H_o3: Concentrations of sludge and sludge constituents outside the site are below the permitted LPC and WQC at all times.

H_o4: Concentrations of sludge and sludge constituents within the site are below the permitted LPC and WQC values 4 h after disposal.

H_o5: Pathogen levels do not exceed ambient levels 4 h after disposal.

Impact Assessment

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.

H_o7: 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 one day after disposal.

H_o8: 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 one day after disposal.

H_o9: 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.

The activities being conducted under Tier 2 have been selected to test these hypotheses. These activities include direct studies of sludge plumes under varied oceanographic and meteorological conditions. Specifically, Tier 2 includes the following activities designed to assess nearfield fate, as described in an implementation plan that supplements the monitoring plan for the site (EPA , 1992b):

Permit Compliance

Measure sludge constituents in the water column to determine fate of sludge constituents, with respect to permit conditions and ambient conditions. Measurements of water quality, chemical and microbiological parameters are being made to determine whether concentrations of sludge constituents meet permit conditions and are at background levels within one day after disposal. These measurements address null hypotheses 3 through 5 and 7 through 9.

Impact Assessment

Conduct sludge plume observations to define the seasonal patterns of sludge dispersion at the 106-Mile Site. Nearfield fate studies include use of a variety of methods to track sludge plumes under summer and winter conditions. These studies are being used to determine when and where samples should be taken, when and where the sludge plume crosses the site boundary, and where to sample to determine whether sludge constituents are detectable one day after disposal. They also provide information on whether sludge particles settle beneath the pycnocline. The studies provide information to guide sampling for sludge constituents in the water column and also address H_o6.

Preliminary observations of plume transport at the site were made during an EPA survey of the site in September 1986 (EPA , 1988). Visual observations and measurements of sludge tracers (total suspended solids and

spores of the microbe Clostridium perfringens) indicated that sludge plumes could be tracked to the boundaries of the 106-Mile Site. These preliminary observations indicated that there is a potential for violating permit conditions and for adverse short-term impacts from disposing sludge at the site.

EPA then developed a strategy for comprehensive assessment of nearfield, short-term fate of sludge constituents (EPA , 1987a). This strategy outlined a plan for assessing various methods of tracking sludge plumes and for measuring compliance with expected permit conditions. It presented the following specific information to be obtained during a plume-tracking exercise at the site:

Permit Compliance

- Determination of whether sludge constituents for which there are WQC are present in concentrations above the WQC within the site boundaries within 4 h after dumping and outside the site boundaries at all times.
- Determination of whether concentrations of the microbe Clostridium perfringens exceed ambient levels within the site 4 h after disposal.

Impact Assessment

- Determination of the dilution of sludge in seawater immediately upon dumping and during the first hour after dumping.
- Determination of the short-term effects of sludge on the dissolved oxygen levels at the site.
- Determination of the rate and direction of movement of the surface and subsurface expression of the plume within the site.
- Determination of the extent of horizontal dispersion of the plume.
- Determination of the extent of vertical dispersion of the dissolved and particulate components of the plume.
- Determination of whether sludge constituents settle below the summer pycnocline.

This information was obtained through repeated sampling of sludge plumes during a survey at the 106-Mile Site in September 1987. Results of that survey are presented in this report. Chapter 2 presents the strategy for making measurements of sludge constituents and tracers of the plume. Chapter 3 describes the sample collection and analysis methods. Chapter 4 describes the oceanographic conditions in the region of the site at the time of the survey and presents the results of the analyses. The conclusions of the study, including an assessment of methods used to track sludge plumes and an assessment of behavior and transport of plumes in terms of the null hypotheses are presented in Chapter 5.

Results of the survey have provided the first complete assessment of sludge plume behavior and transport under summer conditions. Many of the measurements will be repeated during the winter, when vertical dispersion is expected to be much greater than in the summer. The measurements will also be repeated in the summer, so that we can develop an understanding of the variability of measurements of plume behavior. These results will also be used to plan appropriate measurements of short-term effects of sludge dumping and will guide plans for assessing farfield fate of sludge constituents.

2.0 SURVEY OBJECTIVES AND STRATEGY

The objectives of the survey of the 106-Mile Site were to employ a variety of methods to (1) assess the movement, dilution, and settling of sewage sludge as sludge plumes are transported towards and beyond the site boundary, and (2) determine whether water quality requirements that will be included in permits for dumping at the site are being met during ongoing disposal operations. Because this survey was the first field application of proposed technical guidance for plume-tracking activities to be conducted as part of the 106-Mile Site monitoring program, an additional objective was to test equipment and protocols for future plume-tracking activities that may be conducted by EPA or by permittees.

EPA strategy to accomplish these objectives involved conducting the following methods in the survey:

- Identification and tracking of a sludge plume with dye and surface and subsurface drogues.
- Monitoring the movement and dispersion of the marked sludge plume with visual observations from the OSV Peter W. Anderson and a contracted aircraft.
- Acquisition of in situ transmissometry and acoustics data, and shipboard UV/fluorescence data to monitor the movement and dispersion of the plume.
- Collection of samples for chemical and biological tracers and total suspended solids to determine actual concentrations of sludge components and dilution of these components.
- Collection of samples for analysis of those contaminants that have marine water quality criteria (WQC, Table 2-1).
- Acquisition of satellite-derived ocean frontal analyses, conductivity/temperature/depth (CTD) profiles, and measurements of current shear to determine the oceanographic conditions that may have impacted the data generated during the survey.
- Acquisition of real-time navigation data to support plume-tracking activities.

TABLE 2-1. ELEMENTS AND COMPOUNDS FOR WHICH THERE ARE MARINE WATER QUALITY CRITERIA[a]

Inorganic Elements	Arsenic
	Cadmium
	Chromium (hexavalent)
	Copper
	Cyanide
	Lead
	Mercury
	Nickel
	Selenium
	Silver
	Zinc
Organic Compounds	Aldrin/Dieldrin
	Chlordane
	DDT and Metabolites
	Endosulfan
	Endrin
	Heptachlor
	PCBs
	Toxaphene

[a]All samples on this work assignment were analyzed for total chromium instead of hexavalent chromium. Cyanide was not analyzed.

- Observations of endangered species of cetaceans, marine turtles, and seabirds, according to EPA policy to evaluate these animals. This activity did not relate to the objectives of the survey, but is included on all surveys to the 106-Mile Site.

The primary method for tracking sludge plumes was use of transmissometry, which measured turbidity resulting from high levels of total suspended solids in sludge. Both horizontal and vertical transmissometry profiles were used to monitor nearfield fate of disposed sludge in a marked volume (by surface drifters and Rhodamine dye) of sludge plume. Horizontal profiling techniques provided data on the horizontal and vertical dispersion of sludge, and resulted in relatively more data on lateral spreading. Vertical profiling resulted in data on vertical dispersion. Both profiling techniques were supported with the collection of samples for chemical and microbiological tracers. However, relatively more samples were collected during vertical profiling. Surveying operations were also supported with aerial photoreconnaissance provided by Aero-Marine Surveys, Inc. The aerial photoreconnaissance provided information on lateral plume spreading and plume orientation. A summary of horizontal and vertical profiling activities is presented in Table 2-2.

The survey was extremely successful in achieving objectives and performing all survey activities. Several CTD profiles were made during the transit to the site to characterize the water masses at the site and vicinity. At the site before surveying operations began, all equipment and procedures were tested and samples were collected for background water quality. The survey monitored four sludge plumes, identified as DB-1 through DB-4, on September 1 through 4, 1987 (Table 2-3). The sludge plumes were monitored from 3.5 to 9.3 h each, allowing EPA to gather information on short-term and nearfield physical, chemical, and microbiological characteristics of sludge dumped at the site. A fifth sludge plume (DZ-1) was monitored for a short period of time on August 31, 1987. Data from DZ-1 are incomplete and do not contribute significantly to this report.

A complete description of the survey is presented in the initial survey report and in the site condition report for the survey (EPA , 1987d and EPA , 1987e).

TABLE 2-2. MONITORING ACTIVITIES

Activity	Subactivity
Transect CTD Profiles	None
Shakedown Exercises	Use of all oceanographic gear to track dye. Activities include horizontal and vertical profiling with in situ and pumping equipment and collection of water samples for WQC contaminants.
Vertical Profiling	CTD/transmissometer and acoustic vertical profiling; pumping water from surface to 50 m, collection of pumped samples for tracers, WQC contaminants, TSS, and C. perfringens; XCP profiling.
Horizontal Profiling	Towed fish with CTD/transmissometer, transmissometer; pumping water from surface to 50 m (fluorometry measurements), collection of pumped samples for tracers, WQC contaminants, TSS, and C. perfringens; XCP profiling.

TABLE 2-3. BARGES THAT DUMPED MUNICIPAL SEWAGE SLUDGE AT THE 106-MILE SITE DURING THE SURVEY OPERATIONS FROM AUGUST 31 THROUGH SEPTEMBER 4, 1987

Plume[a] Survey	Tug	Barge	Dumping Time (h)	Point of Departure
DZ-1	Buster Bouchard	Sea Trader II	1340 9/1 to 0335 9/2	Graves End Bay, Brooklyn
DB-1	Alice Moran	Spring Creek	1642 9/2 to 1950 9/1	Ward's Island, New York City
DB-2	Ester Moran	Tibbetts Brook	1010 9/2 to 1400 9/2	Wards Island, New York City.
DB-3	Kate	Morris J. Berman	1055 9/3 to 1535 9/3	Port Richmond, New York City
DB-4	Dragon Lady	Leo Frank	2335 9/3 to 0115 9/4	26th Ward, New York City

[a]The notation DB-1, DB-2, etc. may refer to the dumping event or to the sludge plume being monitored during the dumping event, depending on the context.

3.0 SAMPLE COLLECTION AND ANALYSIS METHODS

3.1 PHYSICAL OCEANOGRAPHIC MEASUREMENTS

Physical oceanographic data were acquired during the survey by vertical and horizontal profiling of the water column, vertical profiling of surface currents, and deploying near-surface drifters. Aerial reconnaissance and photography were also employed to document the behavior of the plume.

3.1.1 Water Column Profiling

Vertical and horizontal water column profiling was performed with a Sea-Bird Electronics conductivity-temperature-depth (CTD) system interfaced to an IBM-compatible personal computer. A Sea-Bird Electronics dissolved oxygen sensor and a Sea Tech 25-cm pathlength transmissometer were also interfaced to the CTD underwater unit for concurrent, in situ measurements of oxygen and turbidity (derived from percent light transmission).

The CTD underwater unit transmits digital information to a deck control unit via a Kevlar electromechanical (E/M) profiling cable. The CTD deck control unit passes the raw CTD data to the computer of the shipboard data acquisition system for real-time display and data storage. A Northstar Model 7000 Loran-C receiver was also interfaced to the computer system to obtain and record vessel position information (Loran-C time delays, latitude, and longitude) at 6-second intervals during surveying operations. Figure 3-1 illustrates the hardware configuration of the hydrographic data system developed by Battelle for the operations. Measurement specifications for each of the sensors are presented in Table 3-1.

For all profiling operations, the stainless steel support frame of the CTD underwater unit was attached to the lower side of a 3-foot (wingspan) Endeco V-Fin towed depressor. For horizontal profiling (towing) the E/M cable was attached to the top of the V-Fin such that the CTD was towed horizontally with sensors pointing forward to ensure undisturbed flow past the sensors. For vertical profiling the mechanical termination of the E/M cable was attached to the top end of the CTD support frame, with the V-Fin still attached to the CTD

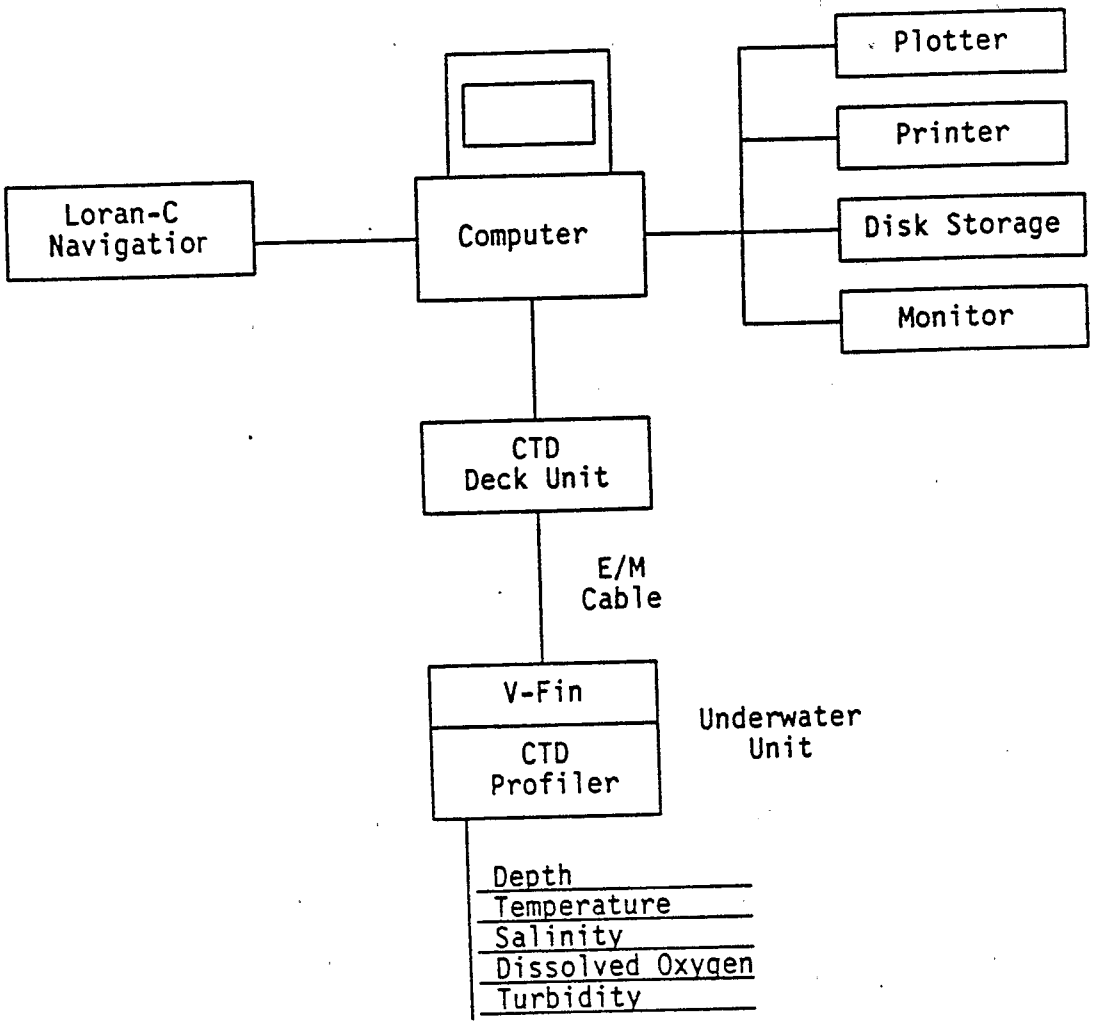


FIGURE 3-1. SCHEMATIC DIAGRAM OF SHIPBOARD DATA ACQUISITION SYSTEM

TABLE 3-1. MEASUREMENT SPECIFICATIONS FOR CTD SENSORS

Parameter	Range	Accuracy	Resolution
Depth	0 to 3000	±60 cm	12 cm
Temperature	-5 to 35°C	±0.004°C	0.0003°C
Salinity	0 to 40 ppt	±0.005 ppt	0.0005 ppt
Oxygen	0 to 15 mL/L	±0.1 mL/L	0.01 mL/L
Light Transmission	0 to 100 %	±0.5 %	0.01 %

Sampling rate: 24 samples per second (averaged to 4 samples per second)

Vertical resolution during profiling: ~40 cm

Horizontal resolution during towing: ~40 cm at 3-knot ship speed

frame. Leaving the V-Fin attached to the CTD allowed faster CTD lowering rates due to the added mass of the V-Fin.

Following the survey, binary data files of the digital CTD data were returned to the laboratory for processing and review. The binary files of raw data are stored on the hard disk of Battelle's IBM-compatible physical oceanographic data processing computer system. Backup copies of the raw CTD data are also stored on 5-1/4 inch floppy disks and archived. Hard copies of printouts and graphic plots of CTD data that were generated in real time during the cruise are also archived with the backup disks of raw data.

The package for processing CTD data from vertical profiles and horizontal tows was used to perform the following functions:

- Conversion of raw (binary) CTD data into engineering units: depth (m), temperature (°C), salinity (ppt), oxygen (mL/L), and light transmission (% light extinction).
- Removal of data points that lie outside reasonable, site-specific ranges for each measurement parameter.
- Retention of data points only when the depth series is monotonically increasing (because good quality CTD data can only be obtained when the sensors are descending through the water column and passing through undisturbed water).

For CTD data files acquired during horizontal profiling operations, the processing procedures were identical to those described above, except that data were not excluded on the basis of depth changes because the sensors are continually towed through undisturbed water.

3.1.2 Current Measurements

Vertical profiles of horizontal currents in the upper 1500 m of the water column were acquired using an expendable current profiling (XCP) data acquisition system and XCP probes manufactured by Sippican Ocean Systems. The XCP data acquisition system consisted of a Hewlett-Packard Model 9816 microcomputer, an XCP controller unit containing a radio receiver, and a radio antenna mounted on the upper deck of the survey vessel. For profiling operations, an XCP probe was launched behind the vessel and data were

transmitted via the radio link to the on-board XCP data acquisition system. During each profile, which lasted roughly 6 minutes, engineering information was stored in computer memory for near real-time analysis. After the profile cycle was complete, a processing program was used to convert the raw data into engineering units of current speed, current direction, and water temperature versus depth. These results were plotted within one-half hour after the launch to provide information on current shear in the upper water column which would affect plume advection and tracking operations. XCP data are stored on floppy disks for easy access from analysis programs.

A comparison of current vectors obtained from an XCP and a 2-h trajectory of a drogue situated at 30 m (plume survey DB-2) indicated that current speeds agreed to within a few centimeters per second and current directions agreed to ± 5 degrees. This comparison suggested that both current measurement techniques worked remarkably well, and that the XCP was a good indicator of absolute currents in the upper water column.

Near-surface drifters, designed to maximize the cross-sectional area of the drogue while minimizing the surface area and windage of the surface markers, were fabricated specifically to track sludge plumes. For each plume tracking operation, one "shallow" drifter was deployed with a drogue tethered 5 m below the surface. These drifters remained with both the surface expression of the sludge plumes and the dye released within the plumes for periods of several hours. A "deep" drifter, having a drogue tethered at a depth of 30 m, was deployed alongside a shallow drifter for one of the plume operations to observe the currents beneath the seasonal pycnocline. Because the sludge plumes were apparently confined to the upper 20 m of the water column, there was no operational need for tracking water beneath the pycnocline, and the use of "deep" drifters was terminated.

Drifters were tracked visually from the survey vessel. During vertical profiling operations, the vessel would periodically stop alongside the drifter to obtain a Loran-C position. During horizontal profiling, drifter positions were obtained when the vessel passed the drifter during repeated transects of the plume. All Loran-C drifter positions and times were recorded by the computer system used to acquire the hydrographic data. For each drifter, a file of positions and times has been archived to facilitate analyses of trajectories and current vectors.

3.1.3 Aerial Photography

Reconnaissance by aerial photography was provided for three of the four plume tracking events. Using twin Hasselblad cameras mounted in the base of a twin-engine survey plane, a total of 169 photographic images were acquired during 9 h of photoreconnaissance at the 106-Mile Site. The majority of these images were taken directly over the survey vessel and dye patch in order that the images could be used to determine the rate of spreading of the sludge plume. To facilitate quantitative analyses, a computerized data file was established for management of the following information for each photograph: time, date, aircraft Loran-C position, aircraft elevation, and aircraft heading.

Of the 169 photographic images obtained, a subset of 55 images were selected for detailed analysis, and a 10 x 10-in color print was made of each image. The selection of images was based upon (1) the requirement that the dye patch and/or survey vessel be within the field of view; (2) the need for distinct surface boundaries of the sludge plume; and (3) the need for a reasonable time series of images throughout the reconnaissance survey.

Quantitative analyses of the photographic prints consisted primarily of measurements of plume width and plume heading. Accurate measurements of plume width were obtained because the elevation of the aircraft was recorded with each image and, therefore, a distance scale could easily be made to convert from millimeters on the photographic print to meters across the plume in full scale. Having the OSV Anderson in the field of view for most of the images provided a useful calibration check on the measurements of plume width because the vessel's length could be measured on the photograph and compared with the vessel's actual length. We estimate that the error in distance measurements from the aerial photographs is on the order of ± 5 m. This error is significantly less than the actual small-scale variability in plume width that is observed as the plumes spread behind the barges.

Thirty minutes after discharge, most of the plumes exhibited a noticeable sinuous behaviour with surface filaments extending downwind, which made it difficult to accurately determine the true width of the plume. Care was taken to measure plume width at the same position (in the vicinity of the dye patch)

in order to minimize interpretation errors, but after about one hour, uncertainties in plume width were on the order ±25 m and useful, quantitative results could no longer be obtained.

Analyses of plume heading were performed using the aircraft heading (the geographic orientation of the photographic image) and the orientation of the plume as measured on the photographic image. The combined error in the determination of plume heading is estimated to be ±5 degrees.

3.2 WATER QUALITY SAMPLE COLLECTION

Seawater samples for analysis of trace metals, organics, total suspended solids (TSS), and C. perfringens were collected from several depths with two pumping systems. One system, designed for collection of surface water samples, consisted of a 10-m Teflon tube connected to either a polypropylene bellows metering pump or a stainless steel pump. Samples for metals, TSS, and C. perfringens analysis were obtained from the polypropylene pump; the stainless steel pump was used to collect water samples for analysis of organic chemicals. A second system for collecting subsurface water samples employed 77 m of Teflon tubing housed on a stainless steel hose winch. The inlet for the tube was connected to the CTD system to deploy it to the desired depth. Subsurface water was pumped through either the bellows pump or, when samples for organics were collected, to a stainless steel centrifugal pump.

Unfiltered samples collected for trace metals analysis were preserved with high purity nitric acid (1 mL/L or 5 mL/L for mercury samples). Samples for TSS were processed on board the survey vessel by filtering seawater samples through 0.4-μm Nuclepore filters. The filters were precleaned and preweighed to within 1 μg. The particulate sample was rinsed three times with 30 mL of deionized water adjusted to pH 8.0 with NH_4OH to remove residual sea salts. Filters were labeled and stored for shipment to the laboratory.

Samples for organic contaminant analysis were collected in 150-L stainless steel tanks and extracted with dichloromethane. The dichloromethane extracts were stored for shipment to the laboratory.

3.3 ENDANGERED SPECIES OBSERVATIONS

Because of concern for the possible impact of ocean dumping activities on endangered or threatened species of marine mammals and turtles, the presence of these species in the area was recorded. Observations were made by a qualified observer on the OSV Anderson. These observations were recorded along predetermined survey paths in 15-min periods, where each period represented a transect.

The data were recorded into two major categories--location/environmental and species/behavior. Information in each category was recorded for each 15-min observation period and both categories were identified by a unique survey and observation number. Location/environmental data included latitude-longitude, start time, elapsed time, vessel speed and course, water depth and temperature, barometric pressure trend, visibility, and wind direction and speed. Species/behavior data included species group (mammal, turtle), species identification, number of animals observed, age, distance and angle to sightings, heading, animal association, debris association, and behavior.

3.4 ANALYTICAL METHODS

Summaries of the data requirements for shipboard and laboratory analytical methods are presented in Table 3-2. Quality control methods used to verify the accuracy and precision of these methods are presented in the Work/Quality Assurance project plan for this work assignment. Results of the laboratory analytical quality control program are discussed in Appendix A and presented in Tables A-1 through A-8 in Appendix A. Analytical methods are presented below.

3.4.1 Trace Metals

Methods for the extraction and analysis of trace metals varied for some elements and are summarized below.

TABLE 3-2. OBJECTIVES FOR ANALYTICAL MEASUREMENTS OF WATER SAMPLES

Parameters	Units	Detection Limits	Percent Accuracy	Percent Precision	Method
Seawater Organics					
PCB congeners, pesticides	µg/L	.001	50	100	Solvent extraction, GC-ECD[a]
Seawater Metals					
Ag, Cd, Zn	µg/L	.015	20	15	Chelation extraction, GFAA[a]
Cr, Pb, Cu	µg/L	.030	20	15	Chelation-extraction, GFAA[a]
Fe	µg/L	.050	20	15	Chelation-extraction, GFAA[a]
Hg	µg/L	.0005	20	15	Gold trap, Hg analyzer[b]
As	µg/L	.02	20	15	Hydride, CVAAS
Se	µg/L	.7	20	15	Hydride, CVAAS
Seawater TSS	mg/L	.01	20	15	Filtration, gravimetric determination[b]

a EPA , 1987b.
b EPA , 1987f.

3.4.1.1 Cadmium, Copper, Iron, Lead, Nickel, and Zinc

Unfiltered seawater samples were extracted at pH 5 with a 1 percent solution of purified ammonium-1-pyrrolidine dithiocarbamate diethylammonium diethyldithiocarbamate (APDC-DDDC) and Freon (Danielsson et al., 1982). Each sample was extracted three times with 5-mL aliquots of Freon; all Freon extracts were combined. The metals were back-extracted into 2 mL of 10 percent nitric acid. The nitric acid solutions were analyzed for cadmium, copper, iron, lead, nickel, and zinc by graphite furnace atomic absorption spectrometry (GFAAS) with Zeeman background correction.

3.4.1.2 Silver

Unfiltered seawater samples were extracted at pH 1.8 using the APDC-DDDC procedure outlined above. Silver was analyzed using GFAAS.

3.4.1.3 Chromium

Total chromium was determined using a modification of the methods described by Cranston and Murray (1977). Chromium was coprecipitated with 0.01 N $Fe(OH)_2$ after an aliquot of seawater was adjusted to pH 8 with NH_4OH. The resulting precipitate was filtered and digested with 6 N nitric acid. After dilution with deionized water to a known volume, the acid digests were analyzed for total chromium by GFAAS.

3.4.1.4 Mercury

Mercury in seawater was determined according to the method of Gill and Fitzgerald (1987). Mercury in a known volume of seawater was reduced with stannous chloride in a closed vessel. The sample was purged with nitrogen and the resulting elemental mercury was concentrated on gold-coated quartz sand. Using heat, the amalgamated mercury was quantitatively desorbed from the gold trap into a stream of helium and analyzed with a Laboratory Data Control UV mercury monitor.

3.4.1.5 Selenium and Arsenic

Selenium and arsenic were determined by hydride generation of aliquots of unfiltered seawater. Selenium and arsenic were reduced with a 3 percent solution of sodium-borohydride. The elements were subsequently purged from the sample into a heated quartz cell and quantified by AAS.

3.4.2 Organic Compounds

High-volume seawater samples (100 L) were extracted with 4 L dichloromethane (DCM) in 150-L stainless steel extraction vessels on board ship. The solvent layer was removed and the aqueous sample was reextracted twice with 2-L aliquots of DCM. Extracts were shipped to the laboratory for analysis. In the laboratory, the extracts from each sample were combined and reduced in volume. Concentrated extracts were fractionated on silica-alumina columns to remove matrix interferences.

Pesticides and polychlorinated biphenyls (PCBs) were analyzed by electron capture detection capillary column gas chromatography (GC-ECD) (EPA , 1987b). Response factors for each compound were determined relative to the internal standard dibromooctafluorobiphenyl. Field and laboratory recoveries were determined through the use of surrogate materials.

3.4.3 Total Suspended Solids (TSS)

In the laboratory, samples were air dried in a Class-100 clean room and the mass of the loaded filter determined. The concentration of TSS was calculated based on the weight of solids collected on the filter divided by the volume of seawater filtered (EPA , 1987c).

3.4.4 Clostridium perfringens

Enumeration of C. perfringens in seawater was performed according to the methods of Bisson and Cabelli (1979). C. perfringens spores were collected by filtering 0.1-, 0.5-, and 1-L aliquots of seawater through 0.4-μm polycar-

bonate filters immediately after collection. The filters were cultured anaerobically on modified C. perfringens (m-CP) medium. Confirmation was obtained by exposing the incubated plates to ammonium hydroxide vapors which turn C. perfringens colonies a magenta color. The bacteria were quantified as number of colonies per 100 mL of filtered seawater.

4.0 RESULTS AND DISCUSSION

Results of the September 1987 survey are presented and discussed in this section. The results are discussed in terms of the background physical oceanographic characteristics of the site at the time of the survey (Sections 4.1 and 4.2). Sludge spreading and mixing are then discussed (Sections 4.3 and 4.4). Impacts of sludge dumping on water quality are presented in Section 4.5. Finally, results of the cetacean and marine turtle survey are presented in Section 4.6.

4.1 OCEANOGRAPHIC CONDITIONS

4.1.1 Water Mass Characteristics

The hydrographic data acquired during the survey represent a high-resolution data set that is ideal for analyses of water mass characteristics and mixing. These data, which include water temperature, salinity, density, dissolved oxygen, and turbidity, were acquired with the high-resolution conductivity/temperature depth (CTD) profiling system described in Section 3. This type of data set can be utilized and presented in a variety of ways to provide information relevant to the objectives of the survey. Examples of such hydrographic analyses are listed below:

- Analyses of the vertical density structure as it relates to mixing of sludge plumes discharged at the 106-Mile Site.
- Analyses of temperature/salinity data for identification of shelf water, slope water, and Gulf Stream warm-core eddies in the vicinity of the site.
- Comparisons between shipboard observations of water mass boundaries and those derived from satellite thermal imagery.
- Analyses of background oxygen and turbidity characteristics at the site for comparison with water properties within sludge plumes.

- Oceanographic characterization of the site to allow comparisons with past and future surveys, and which can ultimately lead to seasonal descriptions of the 106-Mile Site for use in establishing appropriate rates for dumping of sewage sludge.

4.1.1.1 CTD Transect to the 106-Mile Site

During the eastbound transit to the 106-Mile Site on August 31, 1987, a series of seven CTD profiles were made along a line extending from the edge of the continental shelf, through the northern end of the 106-Mile Site, to a position roughly 8 miles northeast of the site (see station positions in Appendix B). The primary objectives of this CTD transect were to locate the position of the shelf water/slope water front (west of the 106-Mile Site), and determine whether a warm-core Gulf Stream eddy was situated near the eastern boundary of the site, as suspected from interpretations of satellite thermal imagery. A detailed discussion of the hydrographic conditions along this transect is given in Appendix B; a summary of the most pertinent results is provided below.

- Hydrographic conditions within the upper 150 m of the water column along the transect were typical for summer conditions, as deduced by comparison with past studies along the U.S. East Coast.
- A thin (~20 m) layer of relatively fresh shelf water extended eastward from the continental shelf such that the shelf water/slope water boundary lies 25 nmi to the west of the 106-Mile Site.
- Despite extensive temperature/salinity variability in the upper water column, vertical profiles of density were very similar at all stations (see Figure 4-1). Beneath a surface mixed layer, a sharp seasonal pycnocline extended from roughly 20 to 40 m along the entire transect that included the northern portion of the 106-Mile Site.
- Throughout the region, vertical profiles of natural turbidity exhibited a subsurface maximum situated within the seasonal pycnocline (see beam attenuation profiles in Figure 4-2).

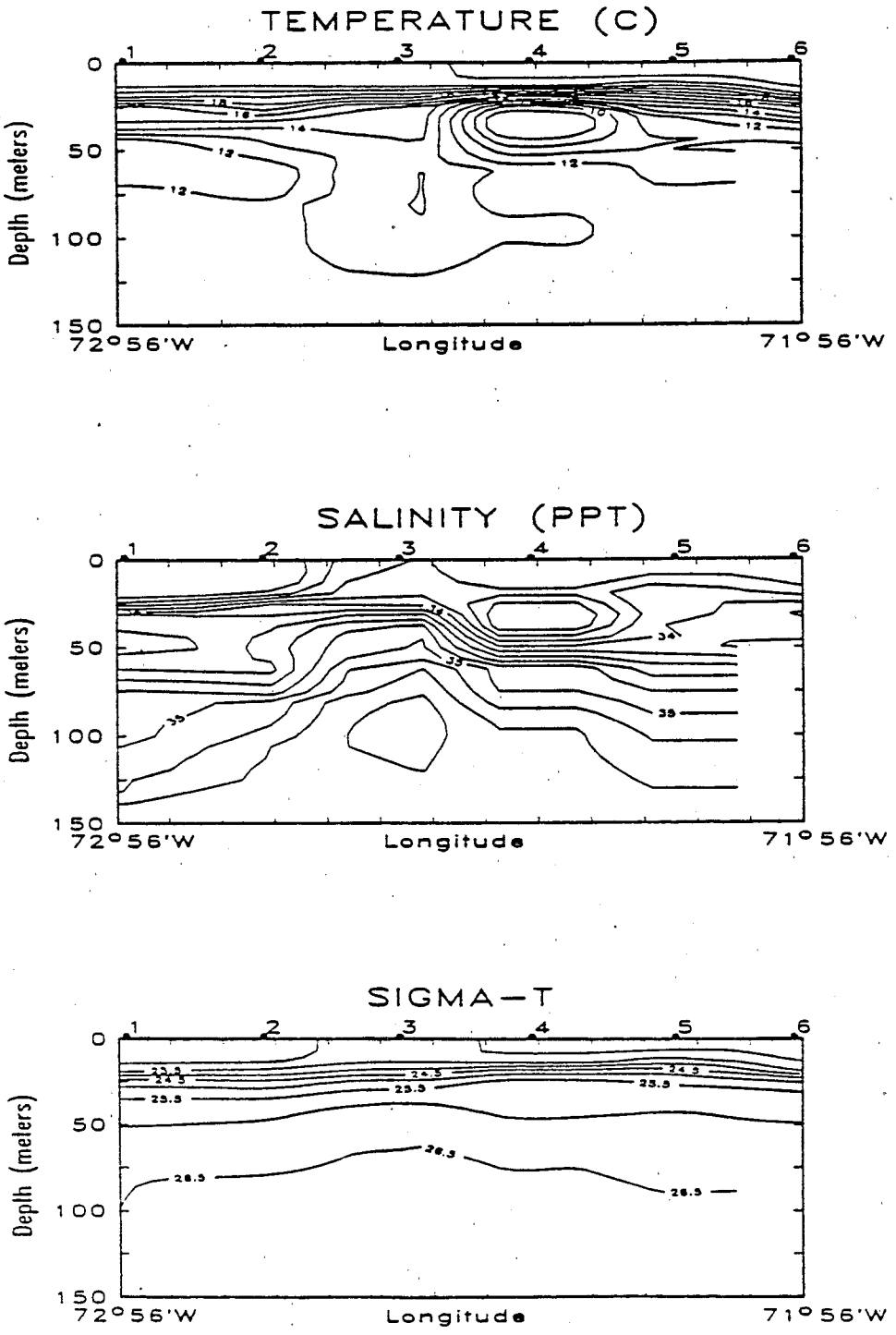


FIGURE 4-1. VERTICAL TRANSECT OF HYDROGRAPHIC PROPERTIES ALONG EASTBOUND CTD TRANSECT (SEE APPENDIX B FOR STATION LOCATIONS); TEMPERATURE (UPPER); SALINITY (MIDDLE); SIGMA-T (LOWER).

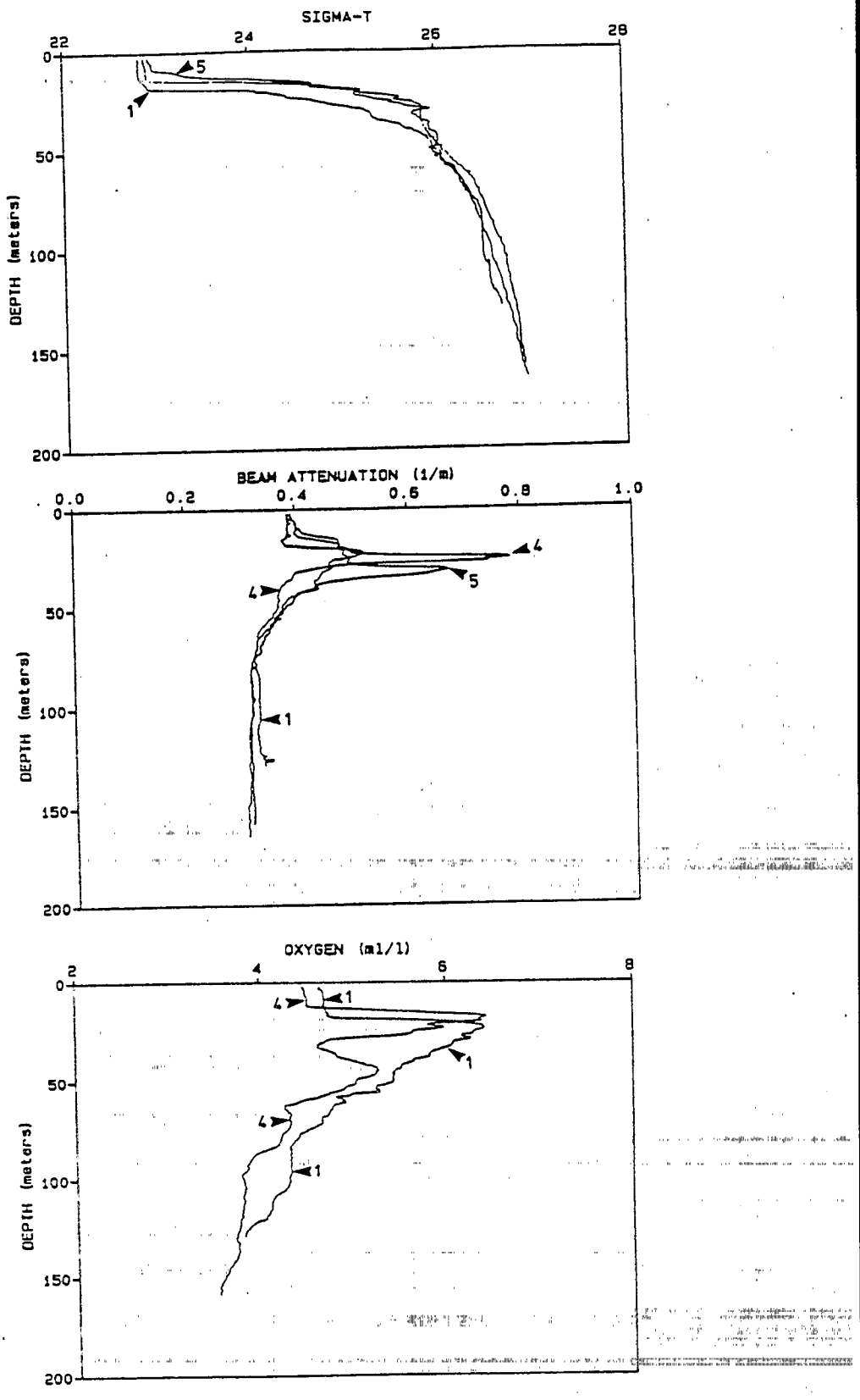


FIGURE 4-2. COMPOSITE OF HYDROGRAPHIC PROFILE RESULTS FROM STATIONS 1, 4 AND 5: SIGMA-T PROFILES (UPPER); BEAM ATTENUATION PROFILES (MIDDLE); OXYGEN (LOWER).

- Dissolved oxygen profiles exhibited maximum values exceeding 6 mL/L within the seasonal pycnocline (see Figure 4-2); percent saturation values within this maximum reached 110%. These high natural oxygen levels are associated with high biological productivity and relatively high natural turbidity within the pycnocline.

4.1.1.2 Satellite Thermal Imagery

As discussed in the site condition report (EPA , 1987e), the Ocean Frontal Analyses of the U.S. East Coast, prepared by the Marine Climatological Investigation of the National Marine Fisheries Service in Narragansett, Rhode Island, frontal analyses are marginally useful for locating ocean thermal features during summer months. These weekly, low-resolution analyses provide a composite view of the Gulf Stream position, the location of the shelf water/slope water front, and the positions of warm-core and cold-core eddies formed by Gulf Stream meanders, but during summer, surface warming greatly reduces the thermal contrast between these water masses.

During a 3-week period prior to the survey, a warm-core eddy named "87-E" approached the 106-Mile Site from the northeast, but satellite tracking of this feature became increasingly difficult because of (1) the weak surface thermal expression of the eddy, and (2) extensive cloud cover which greatly reduced the number of useful satellite images. Figure 4-3 presents a simplified version of the ocean frontal analysis for August 31, 1987, the first day of the survey. This analysis suggests that eddy "87-E" was situated only 50 km to the east of the site, such that currents at the site would be directed toward the northeast. Hydrographic and current data presented elsewhere in this report illustrate that water properties and near-surface dynamics at the site were being affected by the outer edges of eddy "87-E" during the 5-day survey.

4.1.1.3 Hydrographic Conditions at the Site

Although the majority of the CTD profiles during the survey were made within sludge plumes, analyses of data from stations outside of the plumes

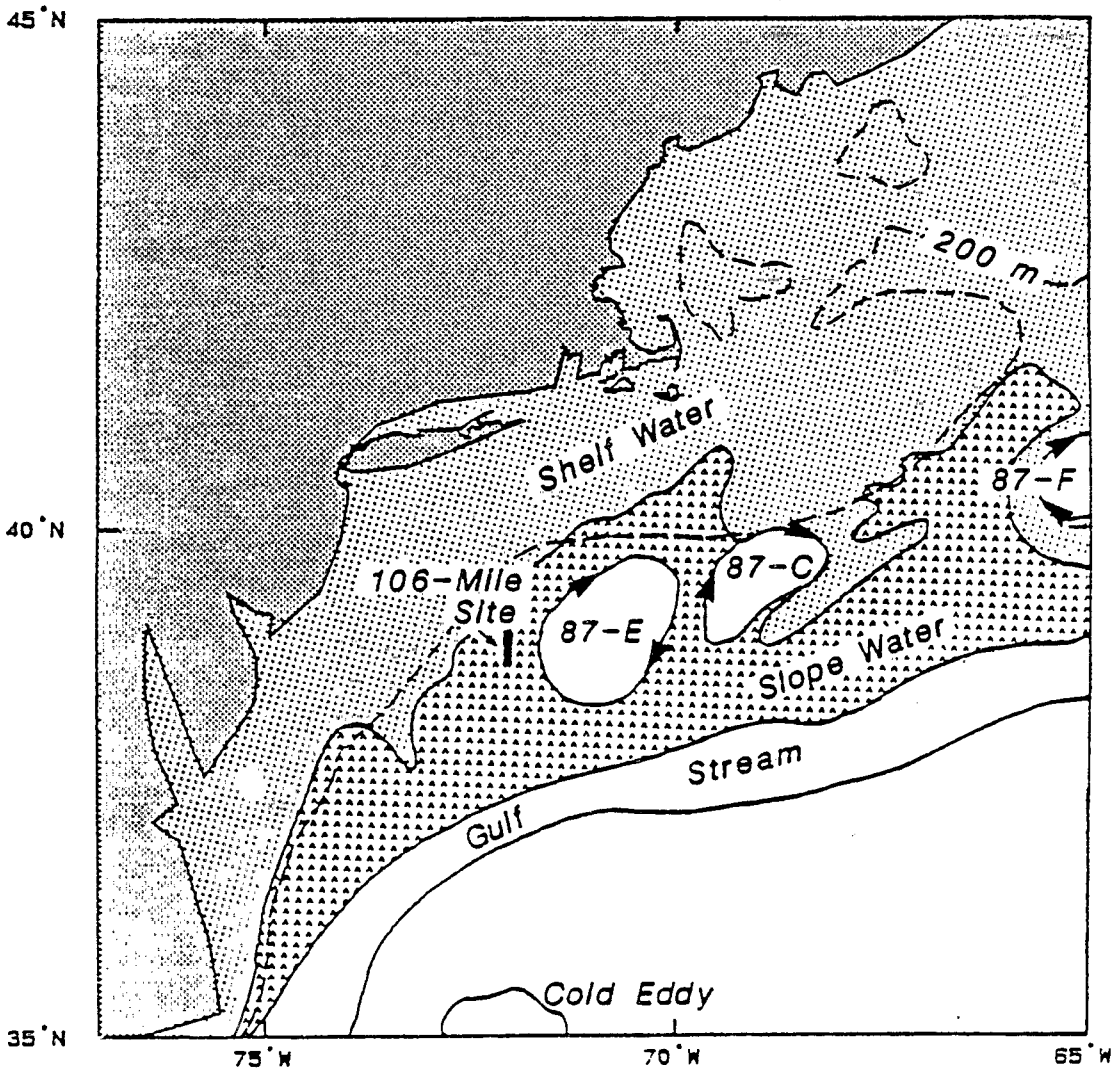


FIGURE 4-3. SCHEMATIC REPRESENTATION OF WATER MASS BOUNDARIES ALONG THE U.S. EAST COAST ON SEPTEMBER 1, 1987, AS DERIVED FROM SATELLITE THERMAL IMAGERY. WARM-CORE EDDIES ARE LABELED "87-E", "87-C", AND "87-F".

illustrate the background hydrographic conditions of the receiving water at the site:

- Large (>1 ppt) salinity variations were observed between profiles in the upper 50 m of the water column due to the influx of relatively saline water of Gulf Stream origin from the periphery of warm-core eddy "87-E."
- Between 50 and 150 m (the maximum depth of the CTD profiles), water properties were representative of slope water conditions.
- The seasonal pycnocline was situated between roughly 14 and 40 m, despite large variations in near-surface temperature/salinity properties.
- Dissolved oxygen concentrations were consistently high (>6 mL/L, and ~110% saturation) within the seasonal pycnocline.

4.1.2 Near-Surface Currents

Near-surface current observations during the survey were obtained from (1) expendable current profilers (XCPs), and (2) tracking of surface markers that were attached to subsurface drogues. The XCPs were the primary current measurement tool, as they provided accurate, high-resolution profiles of current shear from the surface to depths of 1500 m. Because the XCPs worked well, only one or two drifters were deployed during each plume tracking survey. The drifters were primarily used (in conjunction with dye) to mark the specific portion of the sludge plume that would be the focus of the individual survey.

The current profile data have been analyzed with the objective of resolving the local current regime at the time of the survey. As will be shown below, the field measurements were adequate for resolving

- The profile of current speed and direction over the upper 1500 m of the water column;
- The vertical structure of an intense current "jet" situated within the seasonal pycnocline;
- The rate at which sludge plumes were advected out of the site.

4.1.2.1 XCP Current Profile Results

All six of the expendable current profiler (XCP) probes that were launched during the survey provided good-quality, high-resolution current data from the surface to depths of approximately 1500 m. Due to an inherent design limitation, XCPs generally do not provide good quality data within the upper 5 to 7 m of the water column. Therefore, the results presented below are based upon current profiles that begin at a depth of 7 m. Note also that the high-resolution data have been vertically averaged to provide current observations at 3-m intervals throughout the profile range.

Figure 4-4 presents vertical profiles of current speed, current direction, and water temperature that were acquired during XCP profile 6, which was launched at the northern boundary of the site on the final day of the survey, September 4, 1987. This profile is representative of the current conditions observed at the site throughout the survey. Figure 4-4 illustrates that current speeds were weak (<10 cm/s) and relatively constant below 600 m (the base of the main thermocline), but speeds above that level generally increased toward the surface. The highest current speeds (~0.9 kn) were observed above 50 m, apparently within the strong seasonal thermocline that ranged from roughly 12 to 22°C. Current directions were eastward above 300 m, and northeastward below that level.

To illustrate the variability in upper ocean currents during the survey, Figure 4-5 presents a composite of current profile data obtained from the four XCPs (3 through 6) launched during the four plume tracking events (DB-1 through DB-4). This composite of current vectors presents data from six depth levels to allow detailed comparison between individual profiles. Each current vector illustrates the direction of flow using the standard compass convention, with north pointing upward. The length of each vector is proportional to current speed with a scale given at the bottom of the figure. Note, that the current vectors at 5 m are derived from drifter trajectories because the XCPs do not provide good quality data at the surface.

From the composite of current vectors presented in Figure 4-5, the following characteristics of the local current regime emerge:

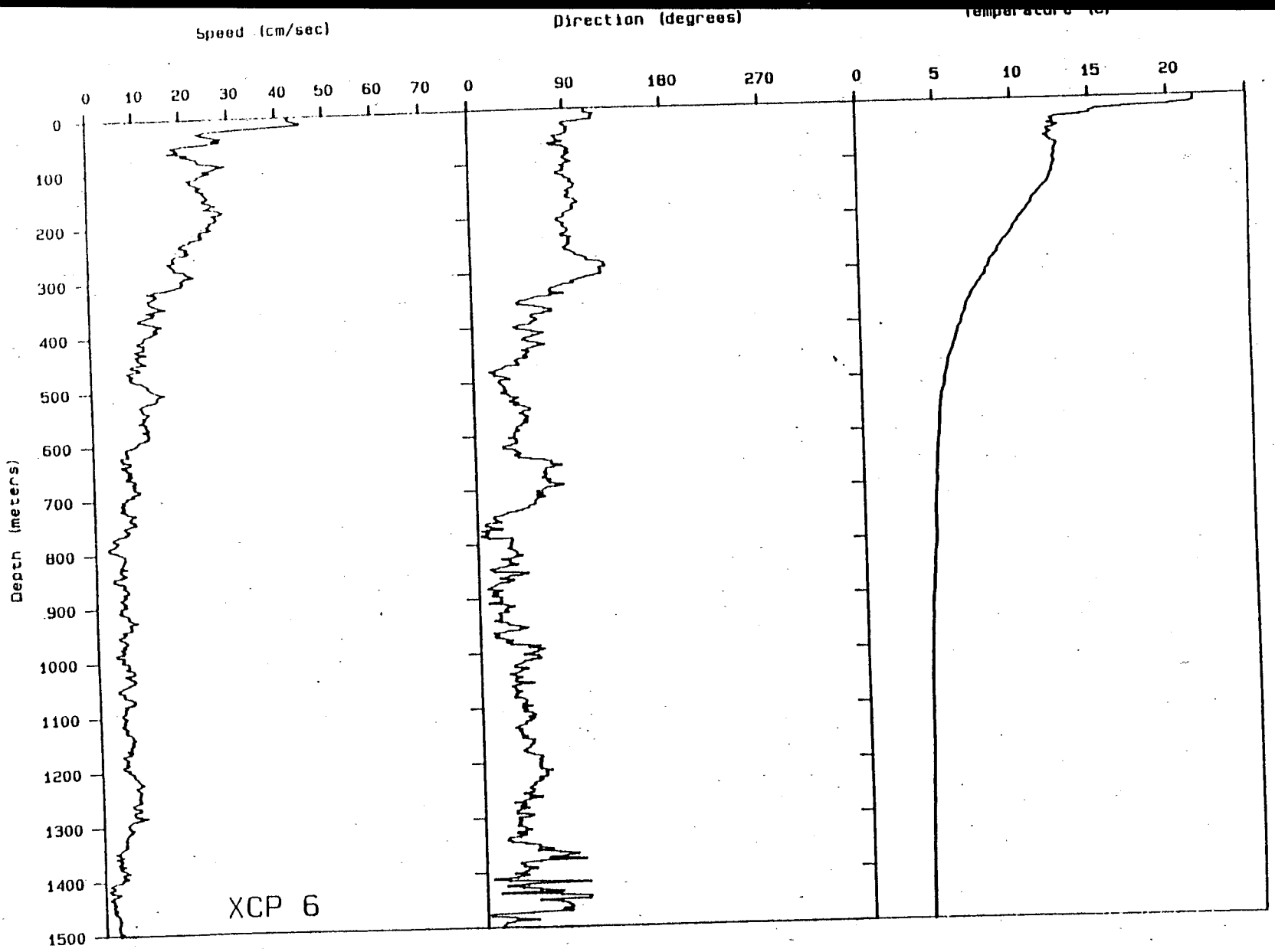


FIGURE 4-4. VERTICAL PROFILES OF CURRENT SPEED, CURRENT DIRECTION, AND WATER TEMPERATURE FROM XCP NO. 6 ON SEPTEMBER 4, 1987.

OBSERVED CURRENT VECTORS

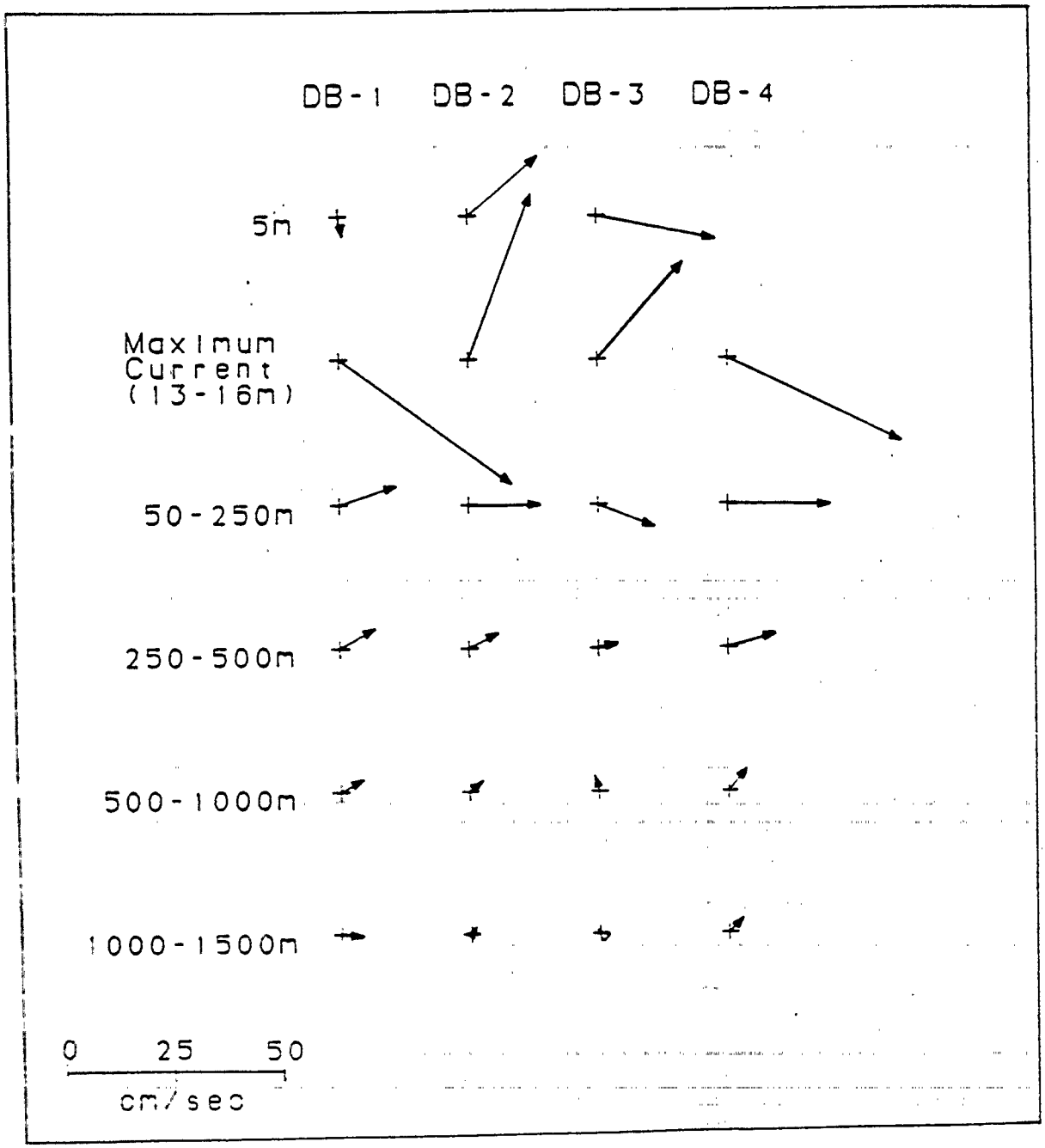


FIGURE 4-5. COMPOSITE OF CURRENT VECTORS AT SIX DEPTH INTERVALS FOR EACH OF FOUR PLUME SURVEYS (DB-1 THROUGH DB-4). NORTHWARD CURRENTS ARE REPRESENTED BY AN ARROW POINTING UPWARD.

- For all profiles, the maximum current speed was observed at 13 to 16 m; current directions within this "jet" were highly variable, but the easterly component was pronounced.
- Currents at 5 m were much less intense than currents within the "jet" located only 10 m deeper.
- Currents between 50 and 250 m were very constant and directed toward the east.
- Currents at lower levels were weak and more variable in direction, but most had an eastward component.

The most striking feature evident from the current profile data is the intense current "jet" situated at roughly 15 m. These intense currents were apparently situated within the seasonal pycnocline, but further inspection is required to demonstrate this vertical correspondence. Figure 4-6 presents current and temperature profile data from the upper 100 m of the four XCPs presented in Figure 4-5. All four profiles demonstrate maximum current speeds within a depth range from 15 to 20 m, which coincides with the near-surface thermocline (and pycnocline). This "jet" was most intense during the first two days of the survey, possibly because of the sharp (8° to 20°C) thermocline that was observed at that time; warmer (12°C) water displaced the temperature minimum during the final two days of the survey, causing a weaker seasonal thermocline. It is unknown whether the "jet" was associated with the perimeter of the warm-core eddy situated to the east of the site or if the "jet" is a persistent feature that will be present during other seasons, or during the summer every year. Implications of the pycnocline current "jet" with regard to mixing and transport of sludge dumped at the 106-Mile Site are discussed later in this report.

4.1.2.2 Near-Surface Drifter Results

Real-time current profile data from the XCPs provided valuable real-time information during the plume-tracking operations, but deployment of near-surface drifters proved helpful (1) as visual markers within the specific portion of the sludge plume being tracked, and (2) for determination of currents 5 m below the surface, where XCPs cannot provide good quality data.

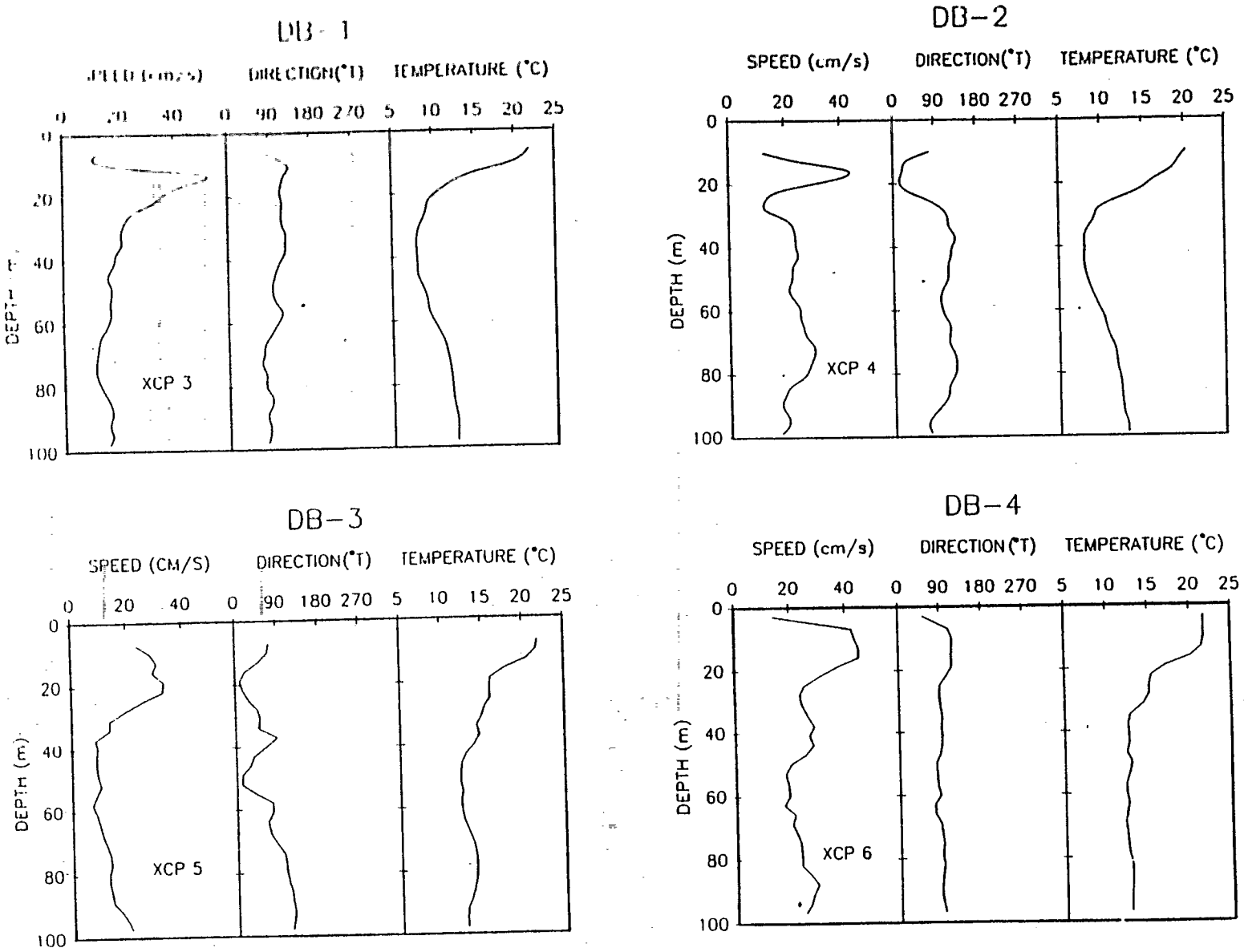


FIGURE 4-6. COMPOSITE OF CURRENT AND WATER TEMPERATURE PROFILES OBTAINED FROM XCPs LAUNCHED DURING THE FOUR PLUME SURVEYS (XCP NO. 3 FOR DB-1, XCP NO. 4 FOR DB-2, ETC.)

Thus, the drifters provided the best ground-truth measurements of currents at the sea surface, and because the sludge plumes remained within the upper 20 m of the water column, the drifters provided valuable information on the advection of the plumes.

Figure 4-7 presents a summary of drifter results from plumes DB-1, DB-2 and DB-3. The launch and recovery positions of a single 5-m drogue are shown for each plume event; a 30-m drogue was also deployed during DB-1 for comparison with the 5-m drogue. Analysis of the drifter trajectories reveals that

- Near-surface (5-m) currents varied greatly over the 3-day period.
- Currents at 30 m were much stronger than 5-m currents during plume event DB-1.
- Near-surface currents for plumes DB-2 and DB-3 were directed toward the east at speeds of ~0.6 kn.
- The drifter results generally agreed with near-surface current data from the XCPs.

4.2 BACKGROUND WATER QUALITY

Water collected at reference sites was analyzed for water quality criteria (WQC) contaminants (Table 2-1), iron, total suspended solids, and C. perfringens to determine background water quality at the time of the survey. Reference sites were located northeast of the 106-Mile Site and within the site near the northern boundary. Near-surface current data indicated that these background stations would not be affected by sludge dumping at the site during the sampling periods. Reference samples collected within the site were collected prior to or immediately following each plume-tracking event. A summary of background water quality analyses is presented in Table 4-1. The complete data record for these analyses is presented in Tables C-1 through C-6, in Appendix C.

The concentrations of most trace metals were uniformly low in all background samples. Concentration of elements for which there are marine water quality criteria (Table 2-1) were more than a thousand times lower than the

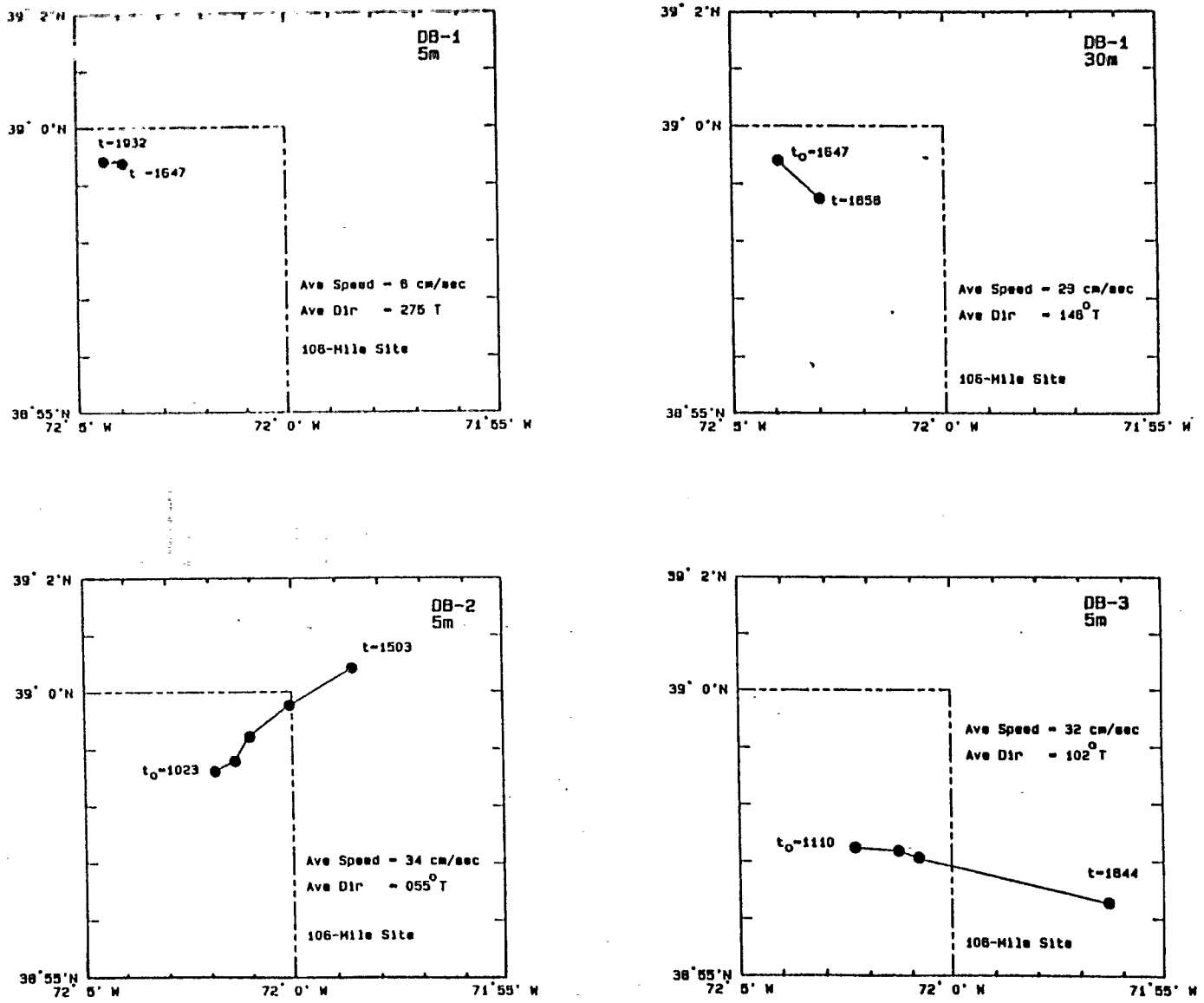


FIGURE 4-7. SUMMARY OF NEAR-SURFACE DRIFTER TRAJECTORIES FROM PLUME SURVEYS DB-1 (TWO DRIFTER LEVELS), DB-2 AND DB-3. TIMES ARE GIVEN FOR THE START AND END POSITIONS OF EACH TRAJECTORY.

TABLE 4-1. BACKGROUND WATER QUALITY MEASUREMENTS IN SEAWATER AT THE 106-MILE SITE, SEPTEMBER 1-4, 1987

Parameter	Concentration[a] Range	EPA Marine Water Quality Criteria	
		Chronic	Acute
Metals	(µg/L)		
Arsenic, total	0.93-1.29	2,319[b]	
Cadmium	0.013-0.028	9.3	43
Chromium, total	0.11-0.15	50[b]	1,100[b]
Copper	0.17-0.23	2.9	2.9
Lead	0.033-0.12	5.6	140
Mercury	0.004-0.013	0.025	2.1
Nickel	0.23-0.27	8.3	75
Selenium	<.03	54	410
Silver	0.002-0.020	-	2.3
Zinc	0.02-0.20	86	95
Organic Compounds	(ng/L)		
Aldrin	ND	-	1,300
Chlordane	ND	4	90
Dieldrin	ND	1.9	710
p,p'-DDT	ND	1	130
p,p'-DDE	ND	-	-
α-Endosulfan	ND	8.7	34
Endrin	ND	2.3	37
Heptachlor	ND	3.6	53
Total PCB	ND- 0.066	3.0	10,000
Toxaphene	ND	0.2	210
α-BHC	ND- 9.4	-	-
γ-BHC	ND- 2.5	-	-
Total Suspended Solids	(mg/L)		
	0.16 to 0.93[c]	-	-
C. perfringens	(#/100 mL)		
	0[d]	-	-

ND = Not Detected.

[a] Two background samples collected prior to event DB-2 are not included in the range. Metals and C. perfringens levels in these two samples were elevated. Sampling equipment was thought to be contaminated with sludge from DB-1.

[b] Values for arsenic V and chromium VI are reported.

[c] Highest values were in the particle maximum located in the pycnocline.

[d] Detectable concentrations were found in two sets of background samples, but are throught to be from carryover in sampling equipment.

criteria. Metals levels in background water were lower than previously reported at the 106-Mile Site (EPA , 1987c, EPA , 1988). The lower reported concentrations are the result of improved collection and analysis techniques required for determination of ambient open-ocean levels of these elements.

Ambient concentrations of organic contaminants were also uniformly low. All WQC pesticides were below detection limits. Analysis for PCB revealed no distinct elution pattern by gas chromatography. However, a single PCB isomer was found and quantified in some samples. Two pesticides (alpha BHC and gamma BHC) that are not on the EPA water quality criteria list were identified in almost all background water samples. Those compounds were also found previously in site waters (EPA , 1987c, EPA , 1988).

TSS concentrations in surface waters at the 106-Mile Site were relatively constant, ranging between 0.18 and 0.56 mg/L during the survey. Concentrations in the pycnocline (starting at 15-m and ending at 20-m depth) were consistently elevated relative to those at 6-m depth. The TSS data are consistent with in situ transmissometry, which showed a particle maximum in the pycnocline. Several background samples collected after plume tracking was initiated contained measurable levels of C. perfringens. However, no C. perfringens colonies were found in the control station sampled prior to plume tracking. Low C. perfringens counts may have resulted from contamination of sampling equipment during plume tracking events.

4.3 BARGE RECORDS

An essential component in the analyses of sludge plume behavior is the information contained in the Ocean Dumping Notification Forms submitted to EPA following each dumping event. From the information given on these forms, it is possible to determine the volume of sludge dumped, the length of the plume, the speed of the barge, and the average rate of dumping (volume divided by elapsed time). This information is extremely important for analyses of sludge plume behavior because the initial size of the plume, the concentration of sludge within the plume, and the rate of initial mixing are all highly dependent upon the dumping characteristics of the barge.

Table 4-2 presents a summary of dumping information for the barges which used the site from August 31 through September 4, 1987. In addition to the four plume events (DB-1 through DB-4) addressed in this report, dumping characteristics are also given for a fifth sludge plume (DZ-1) which was dumped on the afternoon prior to survey DB-1. Information for plume DZ-1 has been included for comparison because the sludge volume and plume length of DZ-1 were so much greater than the other four plumes surveyed.

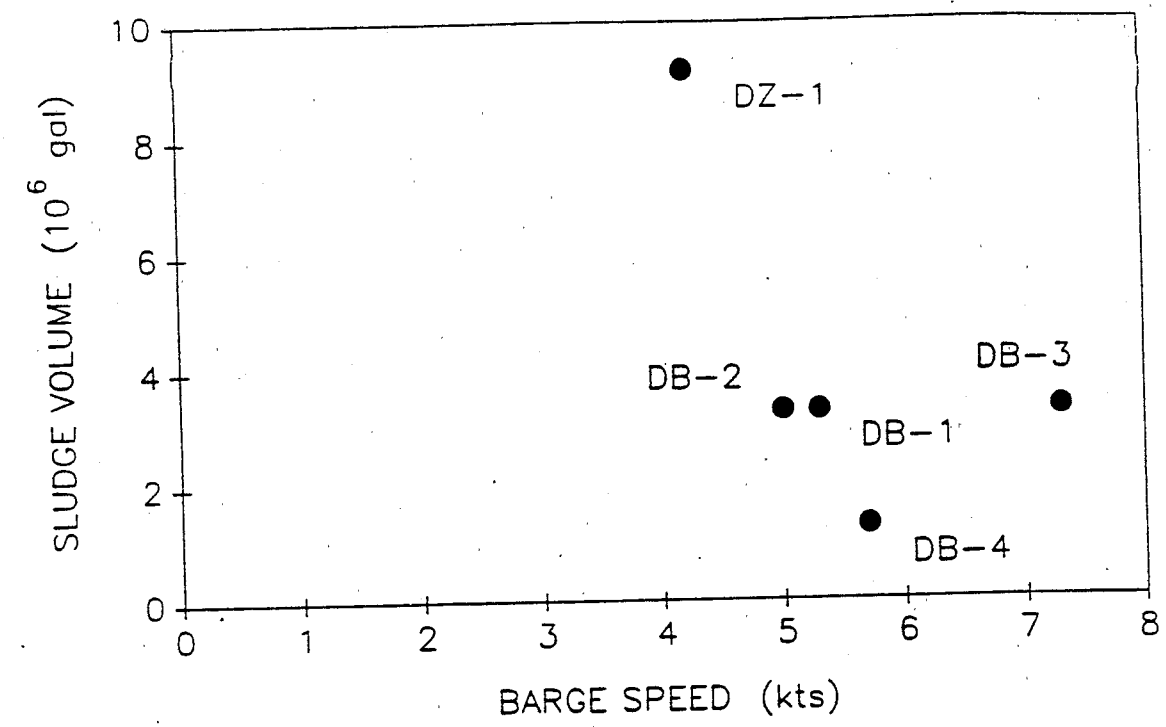
Figure 4-8 graphically presents information from Table 4-2 to illustrate significant differences between the individual dumping events. The upper panel in Figure 4-8 presents a plot of sludge volume dumped versus barge speed for the five dumping events. This figure illustrates a number of differences between the various dumping events: dumping event DZ-1 had much greater sludge volume than the other four events (DB-1 through DB-4), whereas barge speed was the lowest of all five barges; sludge volumes of events DB-1, DB-2 and DB-3 were nearly identical, but barge speed for DB-3 was significantly greater than for all other barges.

Of more importance in the analysis of plume behavior are (1) the actual sludge dumping rate, and (2) the initial concentration of sludge within the plume. The average rate of sludge dumping can be calculated from each barge record by dividing the total volume of sludge dumped by the time spent during dumping. The initial concentration of sludge within the plume is related to the amount of sludge that is dumped along the entire track (plume) length. The volume of sludge per meter of track length can be obtained by simply dividing the volume of sludge by the total length of the plume.

The lower panel of Figure 4-8 presents a plot of these two calculated quantities, dumping rate (gallons/min) and sludge volume per unit of track length (gallons/meter), for each of the five dumping events. Dumping event DB-1 was the only one of the five events in which sludge dumping rates exceeded 15,500 gal/min. In terms of sludge dumped per unit of track length, event DB-1 also had the highest values. In contrast, event DB-3 had the lowest value of sludge per unit of track length, and presumably, this plume would initially have the lowest sludge concentrations (and highest dilutions) of all plumes surveyed. As will be shown in following sections, sludge volume per unit track length is an important parameter affecting of plume dilution.

TABLE 4-2. SUMMARY OF DUMPING INFORMATION FOR BARGES DUMPING SEWAGE SLUDGE AT THE 106-MILE SITE FROM AUGUST 31 THROUGH SEPTEMBER 4, 1987

Survey	DZ-1	DB-1	DB-2	DB-3	DB-4
Date	8/31	9/1	9/2	9/3	9/4
Tug	Buster Bouchard	Alice Moran	Ester Moran	Kate	Dragon Lady
Barge	Sea Trader	Spring Creek	Tibbetts Brook	Morris Berman	Leo Frank
Sludge Volume (gal)	9,200,000	3,291,428	3,328,831	3,342,893	1,309,090
Barge Speed (kn)	4.2	5.3	5.0	7.3	5.7
Dumping Time (h)	13.9	3.1	3.8	4.7	1.7
Plume Length (nmi)	58.3	16.5	19.2	34.0	9.5
Average Dumping Rate					
(gal/min)	11,018	17,506	14,473	11,939	13,091
(gal/meters)	85	108	94	53	74
(m^3/m)	0.32	0.41	0.36	0.20	0.28



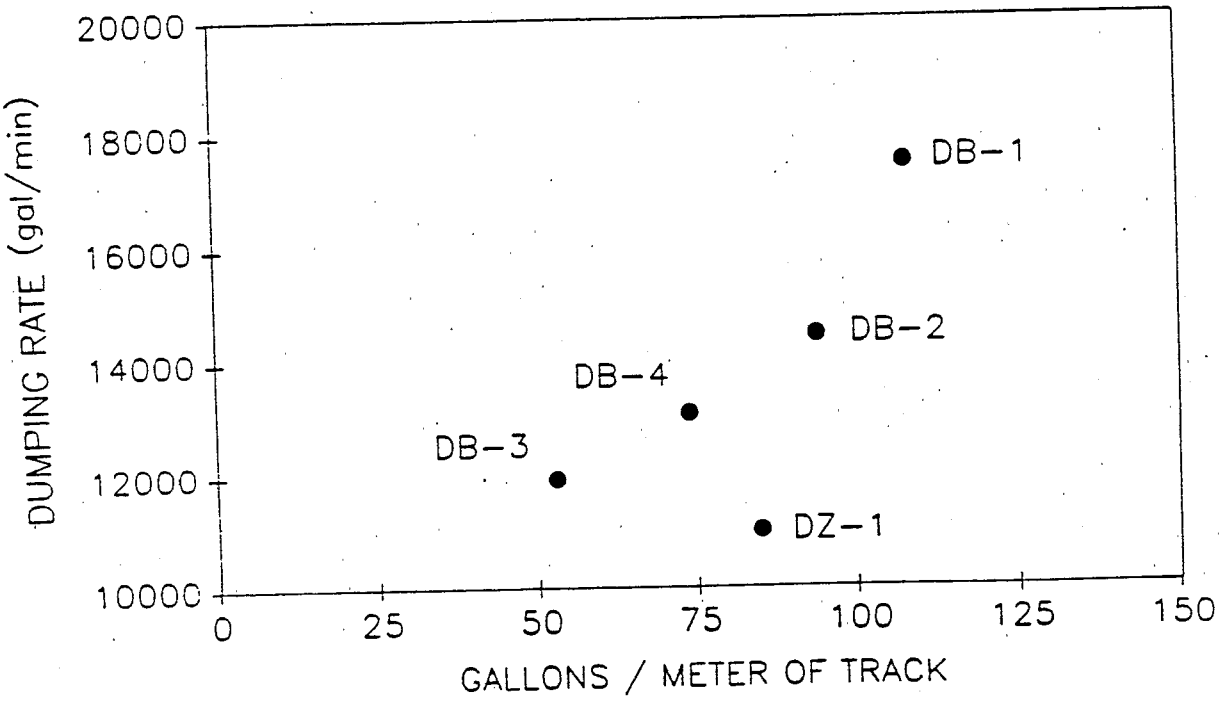


FIGURE 4-8. BARGE DUMPING CHARACTERISTICS FOR THE FOUR PRINCIPAL PLUME SURVEYS (DB-1 THROUGH DB-4), AS WELL AS A BARGE (DZ-1) THAT DUMPED ON THE DAY PRIOR TO SURVEY DB-1.

4.4 SLUDGE PLUME BEHAVIOR

4.4.1 Lateral and Vertical Spreading

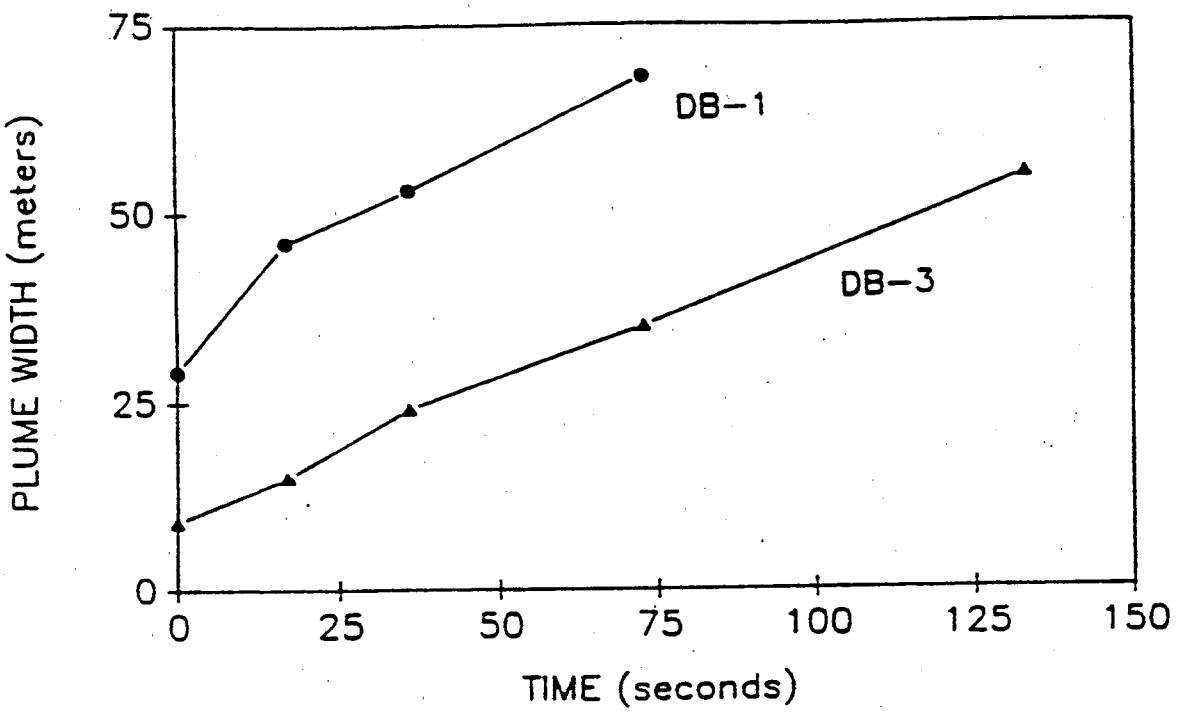
To determine the short-term mixing and dispersion characteristics of sludge plumes that were dumped at the 106-Mile Site, it is first necessary to quantify their spatial scales and the rates at which they vary. The following sections present analyses of sludge plume width and thickness, as determined from aerial photography and shipboard profiling with the CTD/transmissometer system.

4.4.1.1 Lateral Spreading

Plume width data were obtained from four separate plumes, and repeated observations within each plume allow analysis of the rate at which plumes spread laterally. Plume width data were obtained from horizontal profiling for two plumes (DB-2 and DB-4) and from aerial photography for three plumes (DB-1, DB-2, and DB-3).

Figure 4-9 presents a summary of results obtained from aerial photographs of three plumes. The upper panel presents estimates of plume width versus time during the first 2 min following sludge dumping from the barge. The results from plumes DB-1 and DB-3 were each obtained from a single photograph of the sludge plume immediately behind the barge. The data were derived by (1) using the known speed of the barge to convert from distance-behind-the-barge to time-since-dumping, and (2) measuring the plume width (corrected for aircraft elevation) at various distances behind the barge. This figure illustrates that plume DB-1 was initially much wider than plume DB-3 (29 m versus 11 m, respectively), but their rates of spreading were very similar over the 2-min duration of the analysis.

The average rate of spreading during the first 2 min of plumes DB-1 and DB-3 was 43 cm/s. This period of rapid plume spreading and intense mixing is attributed to wake dispersion, where the initial mixing is driven by (1) turbulent dispersion within the wake of the barge (proportional to the speed of the barge), (2) the velocity at which the sludge is being dumped or pumped from the barge, and (3) density differences between the sludge and the



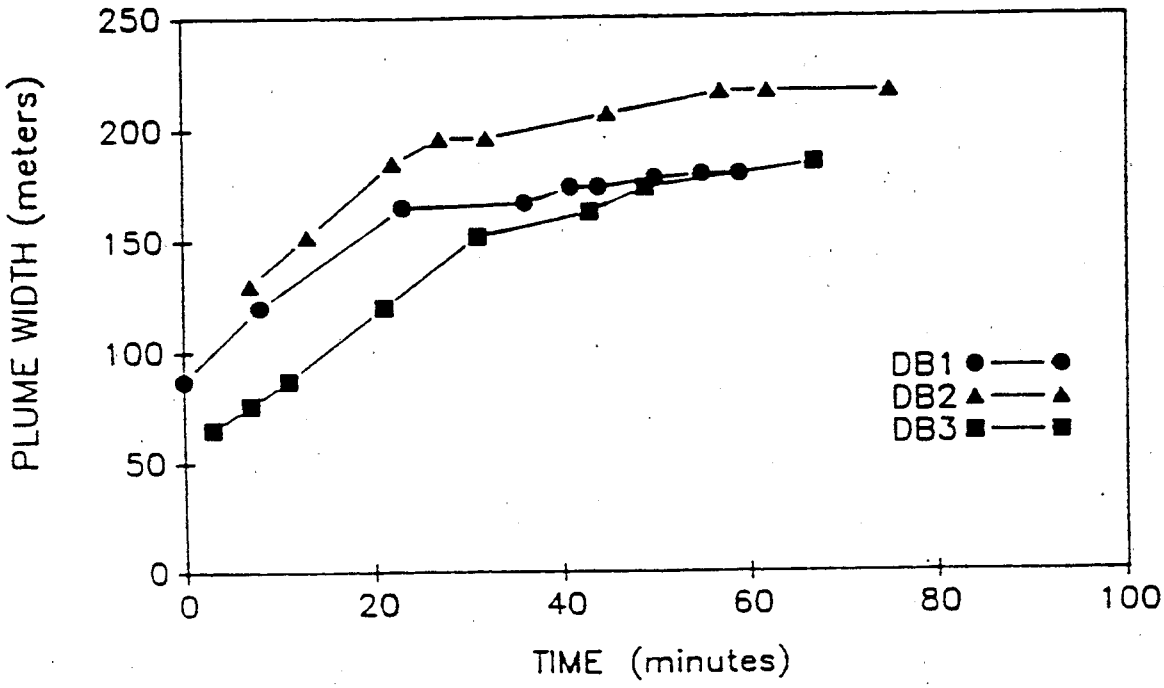


FIGURE 4-9. RESULTS FROM ANALYSES OF AERIAL PHOTOGRAPHY FOR PLUME SURVEYS DB-1 THROUGH DB-3: PLUME WIDTH VERSUS TIME AFTER DUMPING.

receiving water. Csanady (1981) and other investigators have estimated plume spreading rates during this period of initial mixing, but the observations presented here represent direct measurements from which accurate mixing calculations can be based.

The lower panel of Figure 4-9 presents additional measurements of plume width over a 1-h period following each event. These results were derived from repeated aerial photographs of the plume at the location of the dye patch. This ensured that variations in plume width were associated with the rate of plume spreading, rather than variations in width at different positions along the plume. On this and subsequent figures, T=0 h represents the time at which the survey vessel initially stopped behind the barge to deploy the drogues and dye, and begin profiling measurements. This T=0 h for surveys DB-1 through DB-3 was generally 2 to 3 min after that specific portion of sludge had been discharged from the barge.

The lower panel of Figure 4-9 illustrates that the three plumes had roughly the same widths, and their rates of spreading were remarkably similar. Plume DB-2 was the widest of the three plumes; plume DB-3 was initially the narrowest but its width was equivalent to that of DB-1 within 1 h of dumping. The fact that plume DB-3 was the narrowest of the three plumes is consistent with the computed volume of sludge discharged per unit of plume length (lower row in Table 4-2): 0.20 m^3/m for plume DB-3 compared to roughly 0.4 m^3/m for plumes DB-1 and DB-2.

Horizontal profiling of turbidity proved to be an accurate method for determining plume width because the natural turbidity of the near-surface receiving water was low and remarkably constant within the dumpsite. Measurements of plume width were obtained by (1) identifying the beginning and end of the turbid plume water from the horizontal profile data, (2) calculating the distance along the vessel track, and (3) making a cosine correction for the angle between the vessel track and the orientation of the plume axis.

Plume width estimates from horizontal profiling within plume DB-4 are presented in Figure 4-10. The upper panel of Figure 4-10 illustrates that, during the first hour after dumping, plume widths at 5 m increased quite sharply to values of roughly 350 m. Measurements during the next 1/2 h revealed that plume widths at 5 m stopped increasing, and widths began to vary

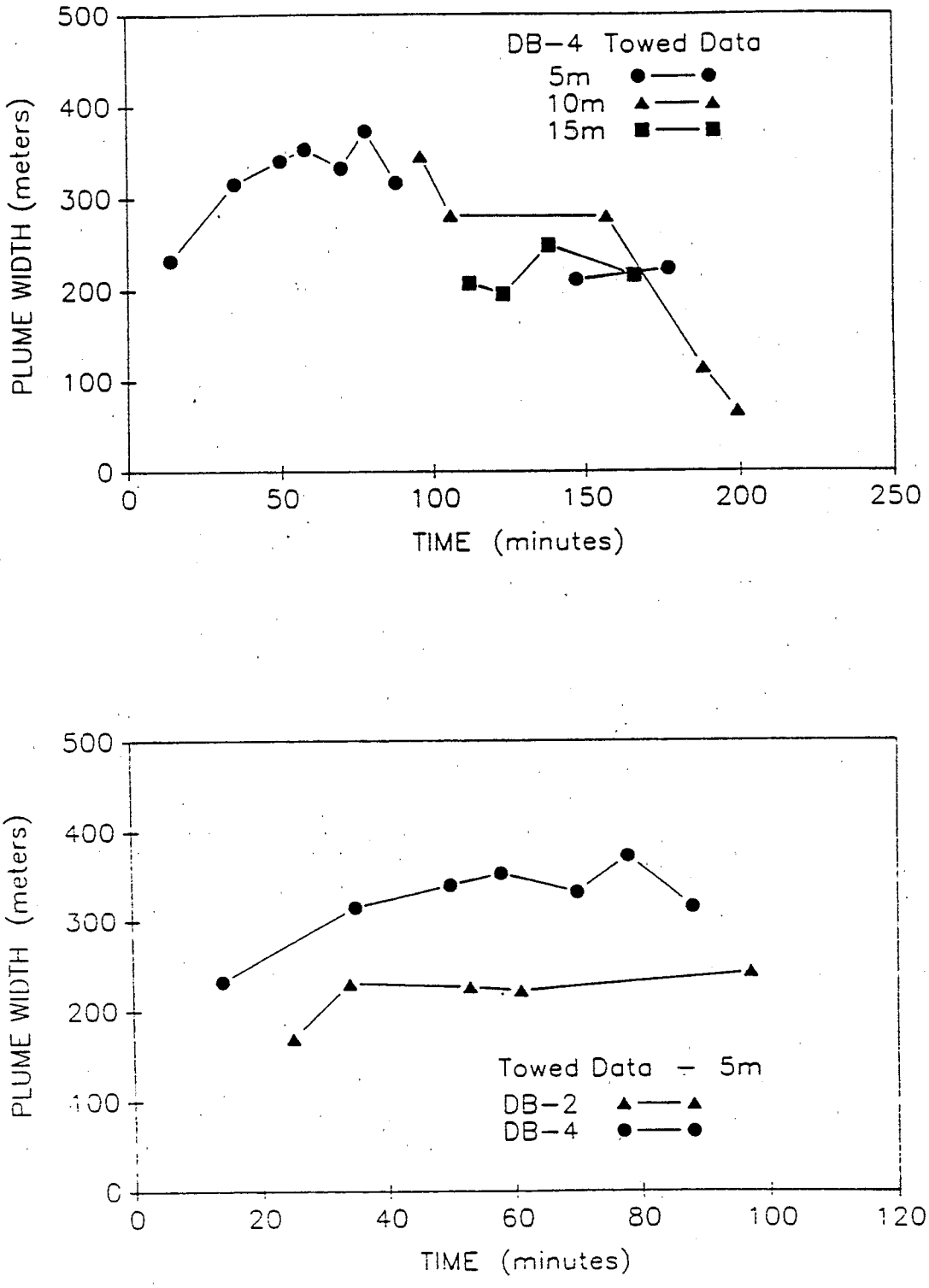


FIGURE 4-10. ANALYSIS OF PLUME WIDTH FOR PLUMES DB-2 AND DB-4: RESULTS OF TOWED DATA FOR DB-4 (UPPER); COMPARISON OF TOWED DATA FROM PLUMES DB-2 AND DB-4 (LOWER).

significantly from tow to tow. Subsequent tows (between 1.5 and 2.0 h) at greater depths indicated that plume widths at 10 m were roughly equivalent to those at 5 m, and plume width at 15 m was less than at shallower depths. As time progressed, plume widths became equal at all three levels (~220 m), but this width was significantly less than the maximum observed width of the plume (at T=1 h). Beyond 3 h, parcels of the plume could be tracked, but meaningful measurements of plume width could no longer be obtained.

Because sludge concentrations certainly had not increased within the plume, the reduction in plume width (and volume) indicates that sludge had escaped from the specific volume (plume transect) that was being surveyed. The vertical current shear, imposed by the strong currents within the seasonal pycnocline, was apparently the mechanism for this dispersion.

The lower panel of Figure 4-10 presents a comparison of plume widths for plume surveys DB-2 and DB-4, as derived from horizontal profile results from a depth of 5 m. This figure illustrates that plume DB-4 was roughly 50 percent wider than plume DB-2 which was the broadest of plumes DB-1 through DB-3. Within 1 h, minutes after discharge, plume DB-4 had reached widths in excess of 300 m.

The results of the various aerial and horizontal profiling analyses of plume width are summarized below.

- The rates of lateral spreading were generally similar for the four plumes studied, although their initial widths differed by a factor of five or more.
- Analyses of plume width revealed four stages of lateral spreading:

  1) From 0 to ~5 min, turbulent mixing due to wake momentum resulted in rapid spreading with rates of approximately 40 cm/s. Turbidity within the plume was high, yet boluses of clear receiving water were observed within the plume.

  2) From 5 to ~30 min, gradual mixing due to buoyancy and oceanic mixing processes resulted in spreading rates of ~5 cm/s. Turbidity was relatively homogeneous across the axis of the plume.

  3) From ~30 min to 2-4 h, lateral spreading of the surface plume was slow (~1 cm/s), but the base of the plume was elongated due to vertical shear in the seasonal pycnocline. Thus, the cross-sectional area of the plume increased rapidly although

the width of the surface plume remained nearly constant. Turbidity values decrease greatly during this phase.

4) A few hours after dumping (actual time dependent upon mixing conditions), the quasi-linear plume broke into parcels of various sizes and concentrations.

- The effective lateral spreading rate during the first hour following a dump was approximately 5 cm/s; beyond 1 h, spreading rates were less than 1 cm/s.
- Both the width and turbidity concentration within plume DB-4 were much greater than the characteristics of the other three plumes surveyed, which suggests that the dumping rate for plume DB-4 was significantly greater than that of the other plumes.

4.4.1.2 Vertical Spreading

Vertical profile measurements were effective for determining the depth to which sludge plumes penetrated during the summer survey. Results from plumes DB-1 and DB-3 were used for analyses of the physical processes that govern the vertical spreading of sludge plumes.

Figure 4-11 presents a composite of six vertical profiles of turbidity (beam attenuation) obtained for plume DB-3. These profiles represent a time series of vertical profiles that extends from the beginning of the survey (T=0 h) to the last profile within the plume (T=8.5 h). At T=0 h within the axis of the plume, high turbidity values (>5 m^{-1}) extended downward from the sea surface to a depth of approximately 9 m, below which turbidity dropped sharply, reaching background values at a depth of about 13 m. At 0.2 h after dumping, mixed-layer turbidity values had decreased slightly (to <5 m^{-1}) but relatively high values were seen to penetrate to depths of about 14 m. After 0.9 h, the plume had penetrated to 16 m and mixed-layer turbidity values continued to decrease.

These results indicate that, within the first hour, plume DB-3 penetrated to a depth of roughly 15 m, which corresponded with the top of the seasonal pycnocline. Turbidity concentrations were relatively constant throughout the mixed layer, even though concentrations were observed to decrease significantly during the first hour.

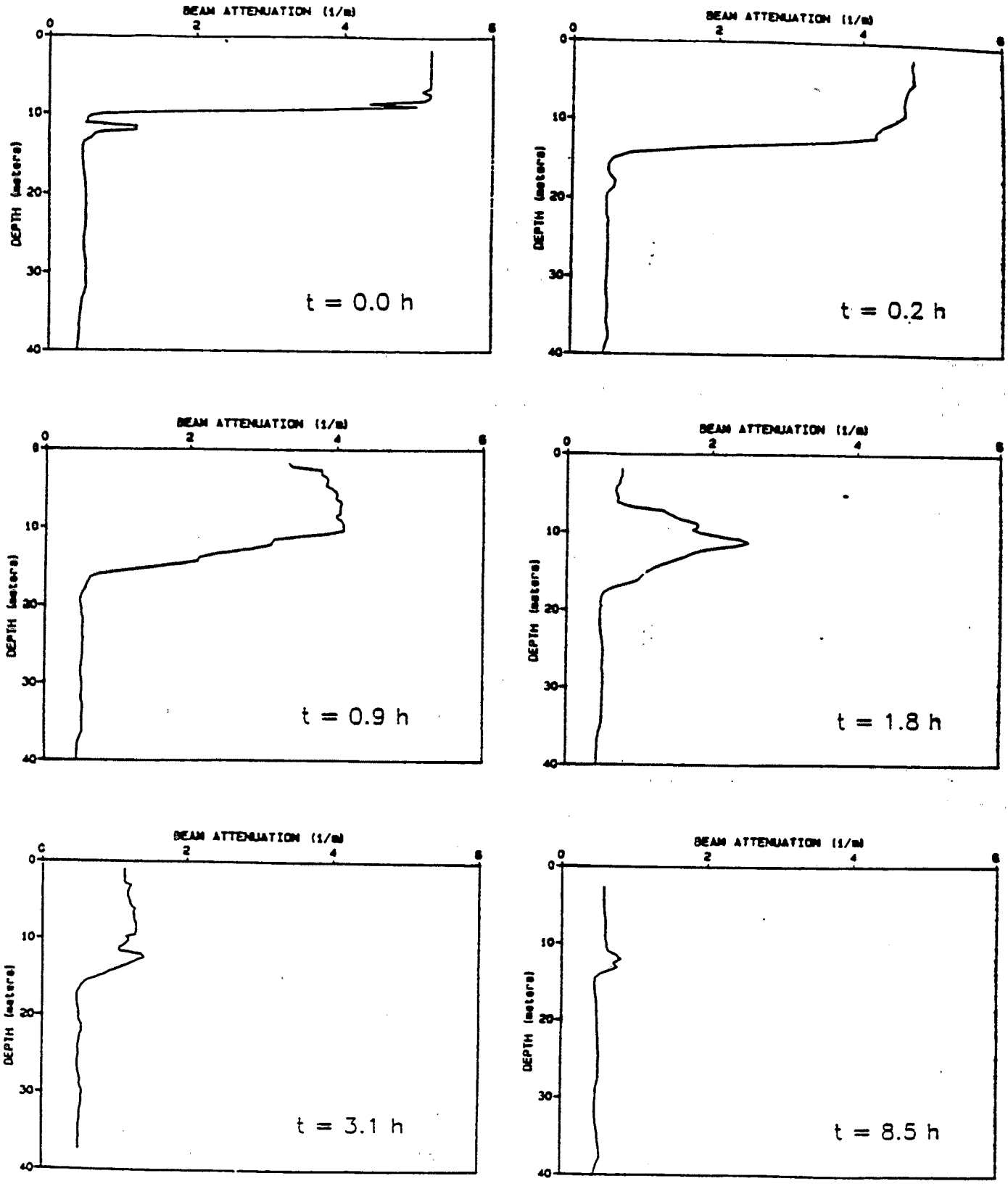


FIGURE 4-11. COMPOSITE OF VERTICAL TURBIDITY (BEAM ATTENUATION) PROFILES MADE WITHIN PLUME DB-3; TIMES AFTER DUMPING FROM THE BARGE ARE INDICATED.

Beyond 1 h, a number of vertical profiles of plume DB-3 revealed that an appreciable quantity of sludge was being transported laterally away from the main, surface portion of the sludge plume. Vertical turbidity profiles within this displaced portion of the plume revealed large subsurface maxima in turbidity (1.8 h in Figure 4-11). The profile taken at T=1.8 h illustrates a concentrated layer of sludge centered near a depth of 11 m, with maximum sludge penetration to 18 m; surface turbidity values above this layer of sludge were only slightly above background.

An additional six vertical profiles were obtained during the remaining 7 h of event DB-3. Some of these profiles were made within the surface expression of the plume, but after a few hours, the surface expression of the plume was no longer evident, and horizontal profiling was used to locate concentrated portions of sludge water, in which vertical profiles were made. The lower-right panel of Figure 4-11 presents a turbidity profile that was made 8.5 h after sludge dumping from the barge. This profile reveals a subsurface turbidity maximum near 12 m, above which lies a mixed layer of very dilute plume water.

Vertical profile results from survey DB-1 were similar to those presented for survey DB-3. A limited number of tows at a depth of 15 m in sludge plumes DB-2 and DB-4 suggest that these plumes had similar vertical characteristics to DB-1 and DB-3.

In summary, the vertical profile results from the individual plume events indicate that

- The vertical distribution of suspended solids (as turbidity) in the four plumes surveyed were very similar.
- Initial mixing (within 5 min after dumping) resulted in sludge penetration to roughly 10 m.
- Vertical mixing over the first 2 h resulted in sludge penetration to roughly 18 m, which corresponded with the top of the seasonal pycnocline.
- After 8 h for plume DB-3, the highest concentrations of sludge were located at a depth of 12 m, which suggests that dilution processes above (due to winds and waves) and below this level (due to the strong current shear within the "jet") were stronger than at the 12 m depth.

- There was no indication that sludge settled to depths greater than 20 m, with penetration beneath the seasonal pycnocline.

4.4.2 Sludge Dilution and Transport

Calculations of sludge dilution are necessary to determine that LPCs are being met at the site 4 h after sludge disposal, and to estimate concentration of WQC contaminants when those contaminants cannot be measured directly in sludge plumes. Plume volume, transmissometry, TSS, and chemical tracer data were used in the calculation of sludge dilution for plumes monitored during the survey. Dilution calculations presented in subsections 4.4.2.1 (plume volume) and 4.4.2.2 (transmissometry analysis) provide estimates of dilution for the entire plume. In contrast, dilution estimates based upon analyses of TSS data (subsection 4.4.2.3) and chemical tracer data (subsection 4.4.2.4) from discrete water parcels yield significantly lower dilutions, as shown below.

4.4.2.1 Dilution Based On Plume Volume

The ratio of plume volume to the volume of sludge dumped into the plume provides the most basic method for calculating the dilution of sludge. The volume of the plume per meter of track length was calculated from the observed width and thickness of the plume, multiplied by a 1-m length. The volume of sludge dumped per meter of plume length was estimated from the total volume of sludge dumped, and the overall length of the plume (Table 4-2). This rate may vary greatly along a single plume, but for the purpose of this analysis, the average dumping rate is treated as a constant, average value.

This simple volume dilution analysis has inherent limitations because it does not require conservation of mass, but it does reveal a number of basic results which are summarized below:

- Dilution 3 min after discharge from the barge was approximately 2500:1 for all plumes. Dilutions ranged from 6,000:1 to 12,000:1 0.5 h after discharge.
- Dilution progressed at a constant rate for roughly 1.0 h, but rates of dilution varied by a factor of 3 for the plumes surveyed.

- For plumes DB-1, 2, and 3, the dilution (plume volume) and the rate of change of dilution (increase in plume volume) both varied inversely with the effective dumping rate; dilutions were highest when less sludge was dumped along a unit track length.

- Because plume DB-4 had the largest plume volume and highest turbidity concentrations, we can deduce that the dumping rate at the beginning of the plume (the location of the survey event) was significantly greater than the average dumping rate (0.28 m^3/m) over the entire plume length.

- Dilution estimates based upon plume volume calculations were not useful >1.0 h after discharge because the current jet within the seasonal pycnocline appeared to advect sludge constituents away from the bottom of the plume.

4.4.2.2 Dilution Based On Transmissometry Data

Turbidity (transmissometry) data were also used to calculate dilution. Horizontal transmissometry profile data from DB-4 were calibrated to corresponding TSS data and were used to estimate a time-series of mass loading in the plume throughout the monitoring event. Mass loading information was then compared to initial mass loading calculated from barge discharge records and average sludge particulate concentrations (Santoro and Fikslin, 1987) to derive sludge dilution.

The relationship between TSS and transmissometry data was calculated for each dumping event to verify that light transmission monitoring techniques accurately reflected particle concentrations in sludge plumes. To develop the relationship, individual TSS sample concentrations from each of the plumes were plotted against the beam attenuation obtained for that sample. Figure 4-12 shows the relationship between these two parameters for each plume. Although there is much scatter in the data, the slopes for each relationship are similar. All plumes display a relationship that is consistent with the expected response of the transmissometer to suspended matter. Within the statistical limits of this relationship, it appears that the sludge from these four disposal events gives similar beam attenuation, suggesting that the transmissometer output can be used to directly estimate sludge concentrations with sewage sludge plumes. However, most of the data reflect sampling of low turbidity water, and hence, statistically derived slopes of the relationship

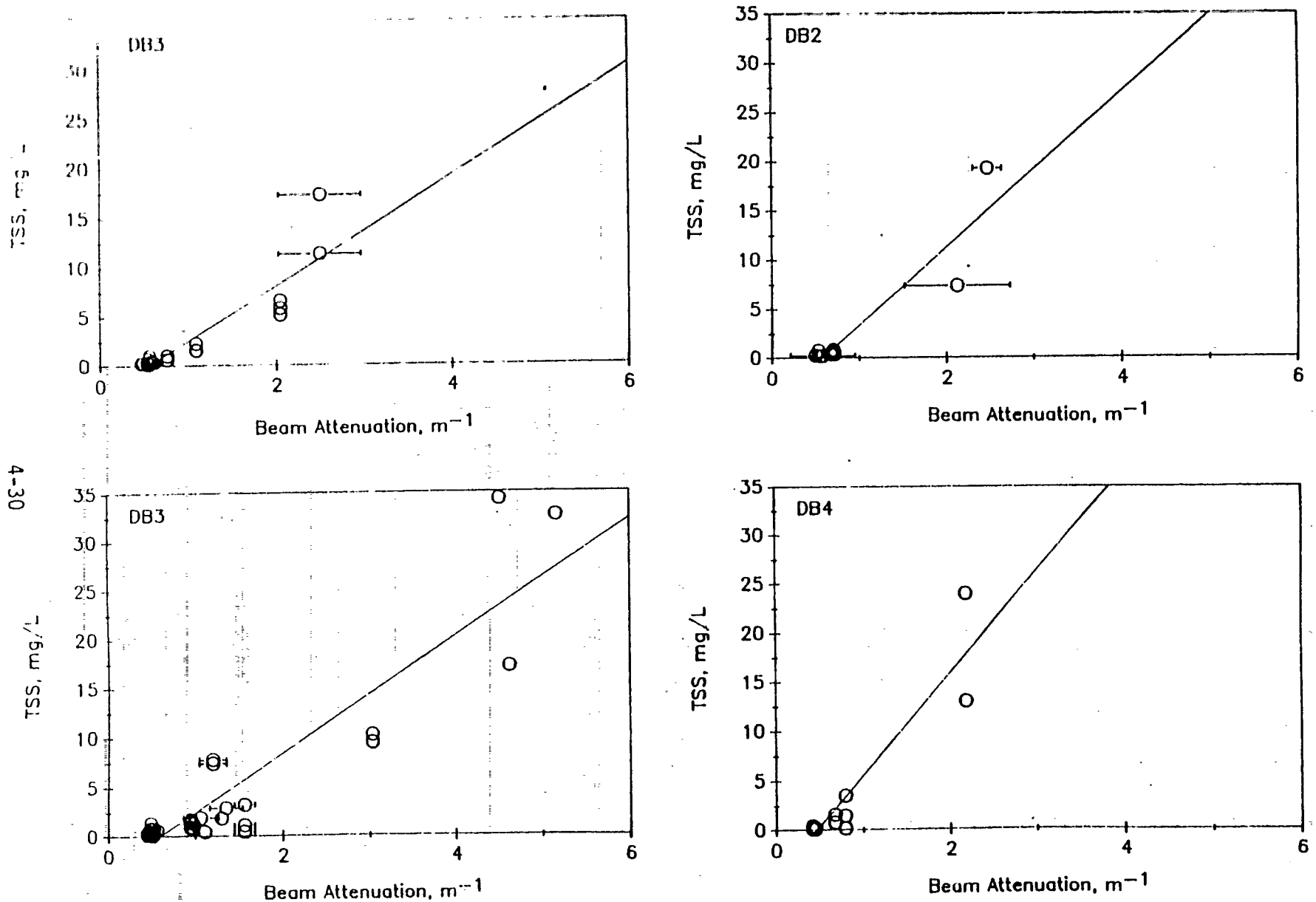


FIGURE 4-12. RELATIONSHIP BETWEEN TOTAL SUSPENDED SOLIDS AND LIGHT TRANSMISSION (BEAM ATTENUATION) MONITORED DURING DUMPING EVENTS DB-1 AND DB-4.

between total suspended solids and turbidity may have considerable error. A best estimate of the relationship of TSS to beam attenuation is used to calculate mass balance based on transmissometry data.

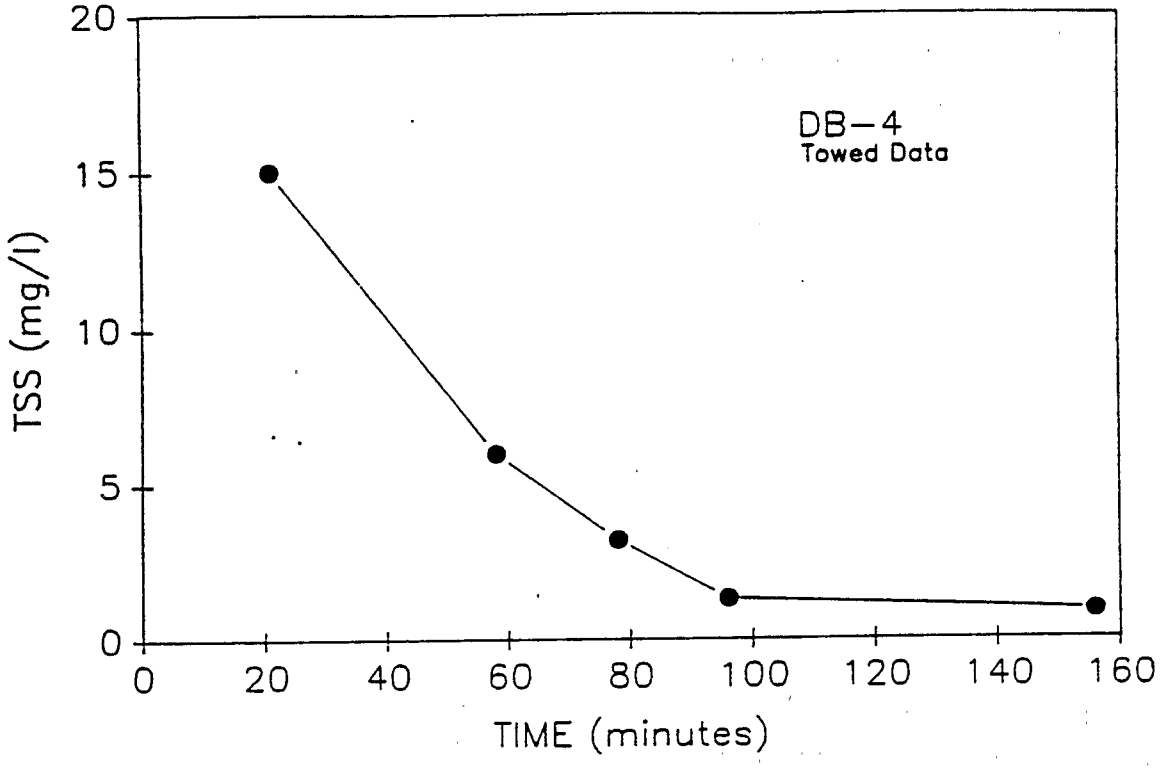
Figure 4-13 presents a time series of the average particulate concentration and the particulate mass loading within a complete transect of plume DB-4, based on transmissometry data. This figure illustrates that total suspended solids are being lost during the time between the repeated crossings of the plume. The rate of sludge loss from the plume appears to start gradually, but after about 1 h, the loss is quite rapid.

Roughly 20 min after discharge, the total mass of suspended solids with a 1-m wide transect of the plume was approximately 42 kg (estimated TSS concentration of 15 mg/L and a plume cross-sectional area of roughly 2800 m^2). This load was reduced to 7 kg about 1.5 h later, which corresponds with an 83 percent loss of solids over this time period.

The explanation for this rapid loss of sludge is that the strong currents within the seasonal pycnocline were an effective mechanism for lateral transport of sludge away from the axis of the plume. During plume event DB-4, currents above 10 m were relatively weak (<15 cm/s), but between 10 and 15 m, currents were in excess of 40 cm/s within the current "jet." In addition to this strong vertical shear in current speed, the direction of the "jet" (~125°) was significantly different from the direction of the near-surface flow (~60°). The combined effect of this speed and directional shear apparently had a major effect upon the transport of sludge within plume DB-4. The results indicate that the bottom of the plume was rapidly and continually being advected away from the main body of the plume, but this layer was so thin (<5 m) that it was not evident during the horizontal profiling operations.

To determine the effect that this current "jet" had on the lateral dispersion and dilution of the plume, the calculated TSS load information can be used to obtain an independent calculation of plume dilution versus time. Using the particulate load (41,760 g) calculated for the transect of plume (DB-4) at 20 min after dumping, we obtain the following results.

- If the effective dumping rate at the position of the plume transect was equal to the average rate over the entire plume (0.28 m^3/min, see Table 4-2), then the initial TSS concentration of the sludge within the barge would have been (~149,000 mg/L). Because



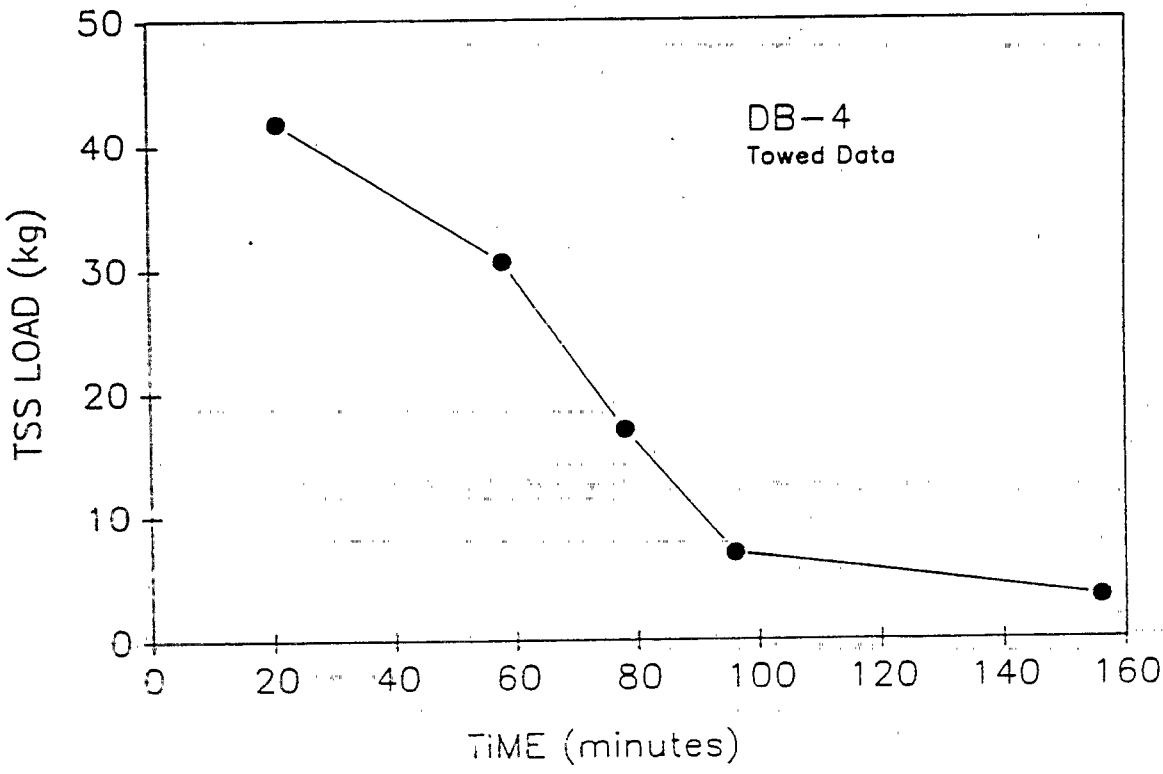


FIGURE 4-13. TSS CONCENTRATION AND TSS LOAD CALCULATED FROM TRANSMISSOMETRY WITHIN A 1-m WIDE TRANSECT OF THE PLUME.

this TSS concentration is excessively high, we suspect that the instantaneous dumping rate was much higher than the average value.

- If the initial TSS concentration of the sludge from plume DB-4 (from the New York 26th Ward facility) was ~25,000 mg/L as reported by Santoro and Fikslin (1987), the particulate load estimate can be used to calculate an effective dumping rate of 1.67 m^3/m. This rate is roughly 6 times the average dumping rate (0.28 m^3/m) for the entire plume length. Using an average TSS concentration of 15 mg/L within the plume at 20 min, the average plume dilution would be ~2,000:1, a low value for the entire plume.

- In the absence of direct measurements of (1) the TSS concentration within the barge and (2) the actual dumping rate from the barge, accurate plume-averaged dilution rates cannot be determined. The results do, however, suggest that (1) the effective dumping rate of plume DB-4 was roughly twice the average rate for the plume, and (2) the initial TSS concentration of the sludge may have been on the order of 90,000 mg/L, or 2 to 3 times the published estimates.

- Given the large uncertainties in the above method, rough estimates of the plume-averaged dilution for plume DB-4 are:

~6,000:1	20 min after dumping
~15,000:1	1 h after dumping
~80,000:1	2 h after dumping
~100,000:1	3 h after dumping

4.4.2.3 Dilution Based on TSS Data

Dilution was also estimated by dividing typical sludge TSS concentrations (Santoro and Fikslin, 1987) by the measured increase in TSS concentration over background levels. Although actual TSS data from sludge in the barges would be more appropriate for the calculation, the difficulty in obtaining these samples for the survey precluded this approach. However, the use of published data does provide mixing estimates to compare with estimates determined by other methods.

TSS concentrations in sludge plumes at T=0 h ranged from 17 to 32 mg/L, corresponding to initial sludge dilutions ranging from 1,030:1 to 810:1 (Table 4-3). Thus, dilutions based on TSS data from discrete samples are lower than dilutions based upon the entire plume. Flocculation of organic matter and metal species, occurring when freshwater mixes with saltwater (Stumm and

TABLE 4-3. TOTAL SUSPENDED SOLIDS IN SLUDGE PLUMES AND ESTIMATES OF INITIAL DILUTION AT THE 106-MILE SITE

Plume	Total Suspended Solids, Concentration (mg/L)			Increase Over Background[c]	Dilution at T=0
	Sludge[a]	Plume Maximum at T=0 h	Background[b]		
DB-1	18,100	17.4	0.18	96	1,050:1
DB-2	18,100	19.2	0.23	83	1,010:1
DB-3	26,400	32.6	0.18	180	810:1
DB-4	24,200	24.8	0.34	73	1,030:1

[a]Data from Santoro and Fikslin, 1987.
[b]Mean of DB-1, DB-3, and DB-4 6.0 m background TSS results.
[c]TSS concentration for plume divided by background concentration.

DB-1 = Sludge from Wards Island sewage treatment plant, New York City, NY.
DB-2 = Sludge from Wards Island sewage treatment plant, New York City, NY.
DB-3 = Sludge from Port Richmond sewage treatment plant, New York City, NY.
DB-4 = Sludge from 26th Ward sewage treatment plant, New York City, NY.

Morgan, 1981) and a process similar to that occurring naturally in estuaries, may increase the apparent particulate concentrations relative to actual dilution. If the process is occurring, initial mixing calculations based on TSS may underestimate the extent of initial mixing. However, variations in sludge dumping rates or discrepancies between actual sludge TSS content and that reported in Santoro and Fikslin (1987) may also account for the difference in mixing calculated by TSS concentrations.

The change in TSS concentration in the plume following dumping is presented in Figure 4-14 for plumes DB-1 and DB-3. The TSS data suggest that after 0.5 h, the decrease in TSS with time was linear for plume DB-1. Based on the rate of decrease (linear regression fit; r= 0.9, n= 14), plume DB-1 would reach ambient TSS concentrations in approximately 3 h. However, at the end of both monitoring events, measured TSS levels remained elevated over ambient levels. TSS concentrations determined at the end of each dumping event were used to calculate final dilution of the sludge (Table 4-4). Dilution estimated ranged from 11,000:1 to 25,000:1.

The TSS data displayed high variability among sample replicates collected as the ship drifted through sludge plumes. Because of the consistency of light transmission data over the same time period, the TSS variability probably reflects the difficulty in collecting discrete samples in and at the edge of a sludge plume rather than TSS heterogeneity in a given parcel of the plume. The data demonstrate the difficulty in obtaining adequate replication using conventional sampling techniques. Because of the variable nature of TSS data, the above calculations were based on individual samples rather than average values of several replicates.

4.4.2.4 Dilution Based on Chemical Tracer Data

Chemical signatures of sludge to trace the sludge as it was dispersed at the site were also used to measure dilution. Copper, iron, lead, and zinc were selected as chemical tracers based on their relatively high concentrations in sludge dumped at the site (O'Connor et al., 1985) and their ease of analysis. Chemical tracer data are used to support and confirm nearfield fate analyses based on other measurement techniques. Additional analyses were performed on

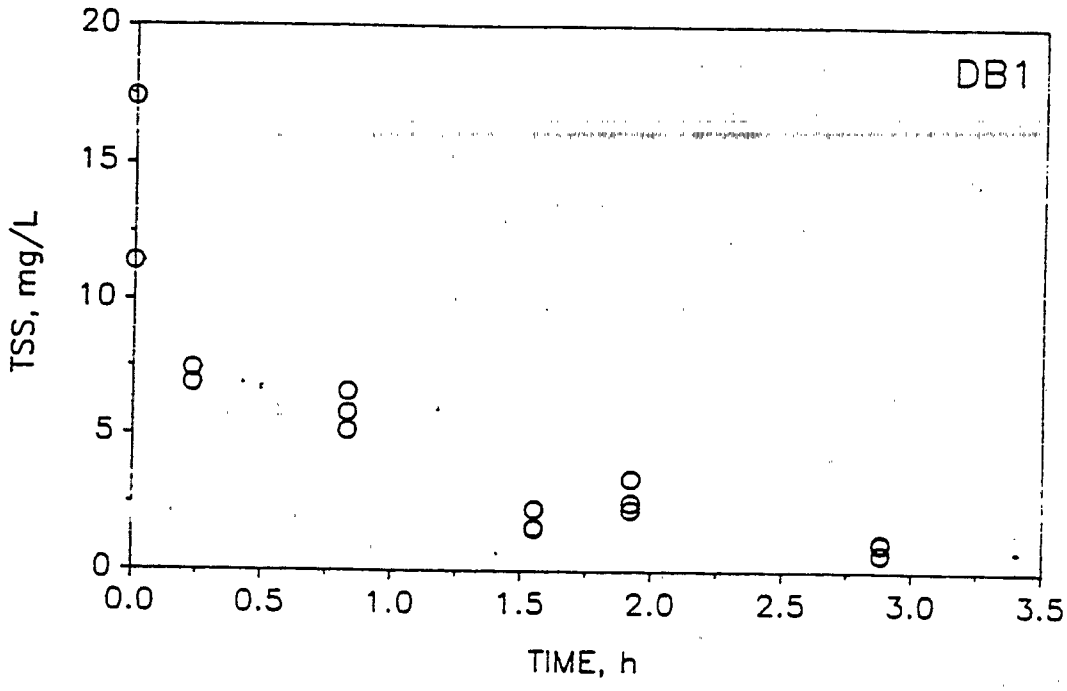


FIGURE 4-14A. TOTAL SUSPENDED SOLIDS CONCENTRATIONS MONITORED DURING DUMPING EVENT DB-1 (SLUDGE FROM WARDS ISLAND SEWAGE TREATMENT PLANT, NEW YORK, NY).

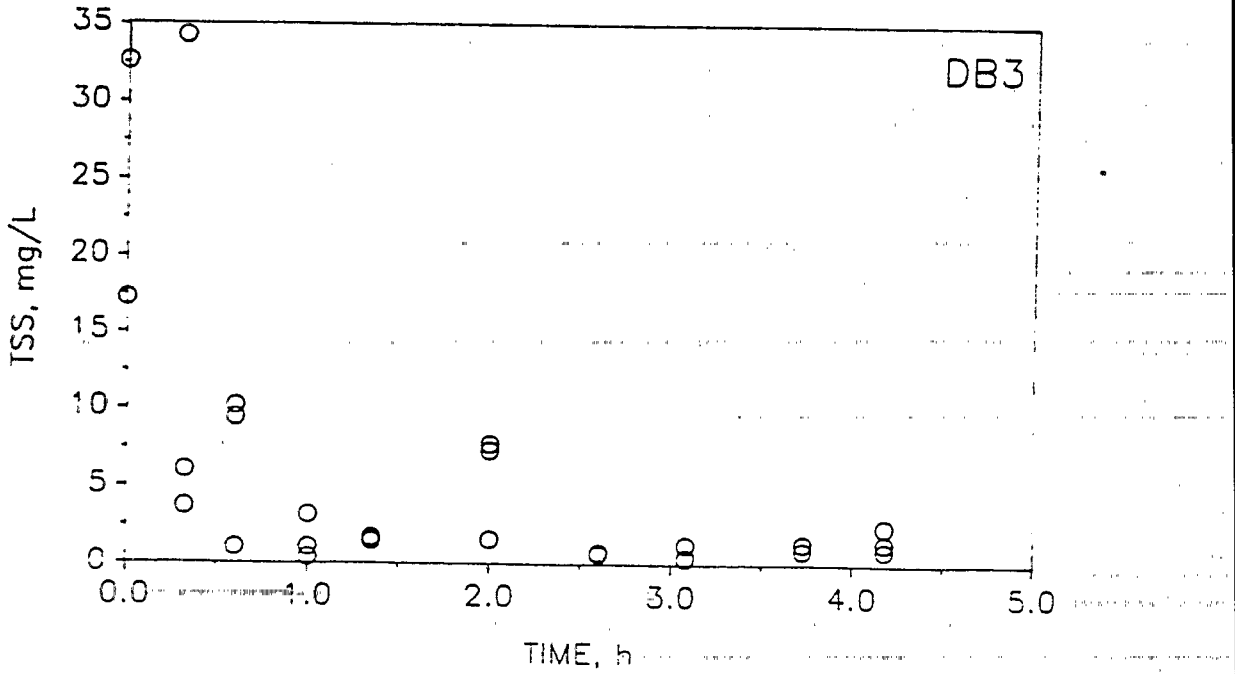


FIGURE 4-14B. TOTAL SUSPENDED SOLIDS CONCENTRATIONS MONITORED DURING DUMPING EVENT DB-3 (SLUDGE FROM PORT RICHMOND SEWAGE TREATMENT PLAN, NEW YORK, NY).

TABLE 4-4. TOTAL SUSPENDED SOLIDS IN SLUDGE PLUMES AT THE 106-MILE SITE MONITORED AFTER DUMPING

Plume	Time After Dilution (h)	Depth (m)	TSS Concentration (mg/L)	Increase Over Background[a]	Dilution of Sludge[b]
DB-1	2.88	6	1.06	4.9	2.1×10^4
DB-2	4.3	6	0.95	3.1	2.5×10^4
DB-3	4.18	6	2.5	12.9	1.1×10^4
DB-3	4.35	10.4	1.9	9.2	1.5×10^4
DB-4	4.72	6	3.5	10.3	2.4×10^4
DB-4	4.72	10.4	1.6	3.6	1.9×10^4

[a]Calculated by dividing final sludge plume TSS concentrations by ambient TSS values.
[b]Calculated by dividing source levels (Santoro and Fikslin, 1987) by final sludge plume TSS concentrations.

chemical tracers to determine which, if any, element is more suitable for tracing the sludge.

Dilutions at T=0 h for two dumping events were calculated by comparing concentrations of chemical tracers in sludge plumes with average concentrations of those tracers in the sludges being dumped (Santoro and Fikslin, 1987). As with similar calculations based on TSS data, actual tracer data from sludge in the barges dumping at the site would be more appropriate for mixing calculations, but the difficulty in obtaining sludge samples for the summer survey precluded this approach. However, the use of published data does provide mixing estimates to compare with estimates determined by other methods. As with TSS, the variability in chemical tracer data made it difficult to calculate mass balances. Dilution calculations are presented below.

Concentrations of the metal tracers, copper, lead, and zinc, in sludge plumes DB-2 and DB-3, and estimates of dilution are presented in Table 4-5. The calculated initial dilution varied both between plumes and for each tracer within a plume. Initial dilutions calculated for DB-2 ranged between 2,600:1 and 6,300:1. Initial dilution calculated for DB-3 was lower, ranging between 400:1 and 1,100:1 dilution depending on the element used in the calculation. Dilutions calculated from samples collected at T=4.3 h range from 25,000:1 to 52,000:1 for plume DB-2, and from 1,900:1 to 6,300:1 for plume DB-3.

Metal concentrations in the receiving water within the sludge plumes DB-2 and DB-3 increased between 90:1 and 2,340:1 above background at T=0 h. The amount of increase varied with the sludge being monitored and with each metal for a given sludge. No one tracer gave consistently high relative increases between the two events being monitored, reflecting the variability in metal concentrations of the source material. However, of the three metals analyzed at T=0 h, copper showed the lowest relative increase over ambient concentrations for both dumping events.

Metal concentrations within the plumes monitored behaved similarly after initial dilution and decreased exponentially with time as illustrated in Figure 4-15. The mean exponential decay rate derived from the rate of decay for each element for plume DB-3 was relatively constant ($0.51 \pm 0.02\ h^{-1}$). Thus, under the conditions found at the 106-Mile Site during this one event, the concentration of tracers in the sludge plume decreased by a factor of 2 (halved) every hour following disposal.

TABLE 4-5. ESTIMATES OF DILUTION AT T=0 h AND T=4.3 h BASED ON METAL TRACER CONCENTRATIONS

Event	Source Concentrations[a]	T=0 h Sludge Plume Concentrations	T=0 h Initial Sludge Dilution	T=4.3 h Sludge Plume Concentrations	T=4.3 h Initial Sludge Dilution
			Copper, µg/L		
DB-2	52,700	14.7	3,600:1	2.1	25,000:1
DB-3	50,900	50.0	1,000:1	11.2	4,500:1
			Lead, µg/L		
DB-2	20,700	3.3	6,300:1	0.4	52,000:1
DB-3	19,300	51.5	400:1	10.4	1,900:1
			Zinc, µg/L		
DB-2	35,100	13.4	2,600:1	1.3	27,000:1
DB-3	48,400	48.4	1,000:1	7.7	6,300:1

[a]Santoro and Fikslin, 1987.

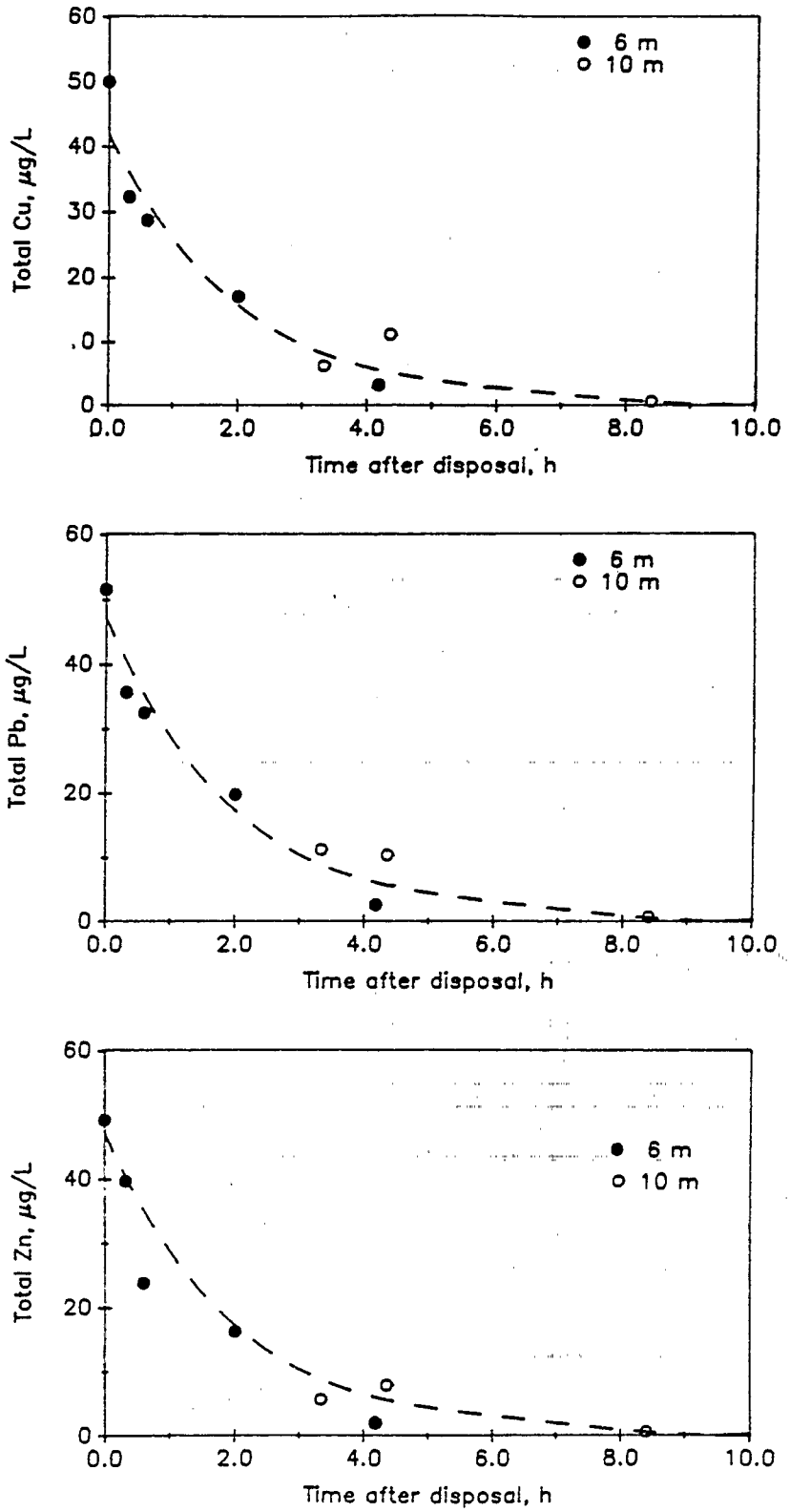


FIGURE 4-15. COPPER, LEAD, AND ZINC CONCENTRATIONS MONITORED DURING DUMPING EVENT DB-3 (SEPTEMBER 3, 1987). DASHED (--) LINE DEPICTS MEAN EXPONENTIAL FIT.

To determine which, if any, element was significantly more useful as a chemical tracer of sewage sludge, metal concentrations from individual samples were plotted against one another to determine how well the results for one metal predicted the behavior of the other tracer metals. Metals were plotted against iron, the metal with the highest concentration in plumes DB-2 and DB-3 at T=0 h. A strong correlation between iron and the other three metals analyzed was found for each plume event (Figure 4-16). These results show striking consistency in metal behavior within each plume and tentatively suggest that analysis of one metal can be used to predict the nearfield fate of the other metals in sludge plumes over similar time frames, provided metal ratios are established for each plume.

Figure 4-16 also illustrates that metal ratios may be used to develop sludge "signatures" that can be used to trace and identify individual sludge plumes throughout the nearfield, short-term monitoring. The characteristic ratios have significant potential for identification of individual sludge plumes when multiple barges are dumping at the site. The signature concept also has potential for long-term fate studies (i.e., monitoring the change in sediment trap metal ratios against oceanic "control" values) and potential for monitoring the operation of individual treatment plants in relation to the effectiveness of point-source control measures.

4.4.2.5 Plume Transport

Knowledge of the time required for sludge plumes to leave the 106-Mile Site is of critical concern because water quality criteria must not be exceeded at any time outside of the site. In addition to the use of current profile data for prediction of rates of sludge plume advection, continual contact with the plumes during the four sampling events (DB-1 through DB-4) yields a direct measurement of the time that each of the plumes crossed the site boundaries. Figure 4-17 illustrates the movement of sludge plumes DB-1 and DB-2 during the individual plume-tracking events; Figure 4-18 illustrates the movement of plumes DB-3 and DB-4. The information shown for each plume includes (1) the positions of initial (T=0 h) and final contact with the plume, (2) elapsed time (in hours) since dumping from the barge, and (3) the initial orientation of the plume at the initial position of the tracking event.

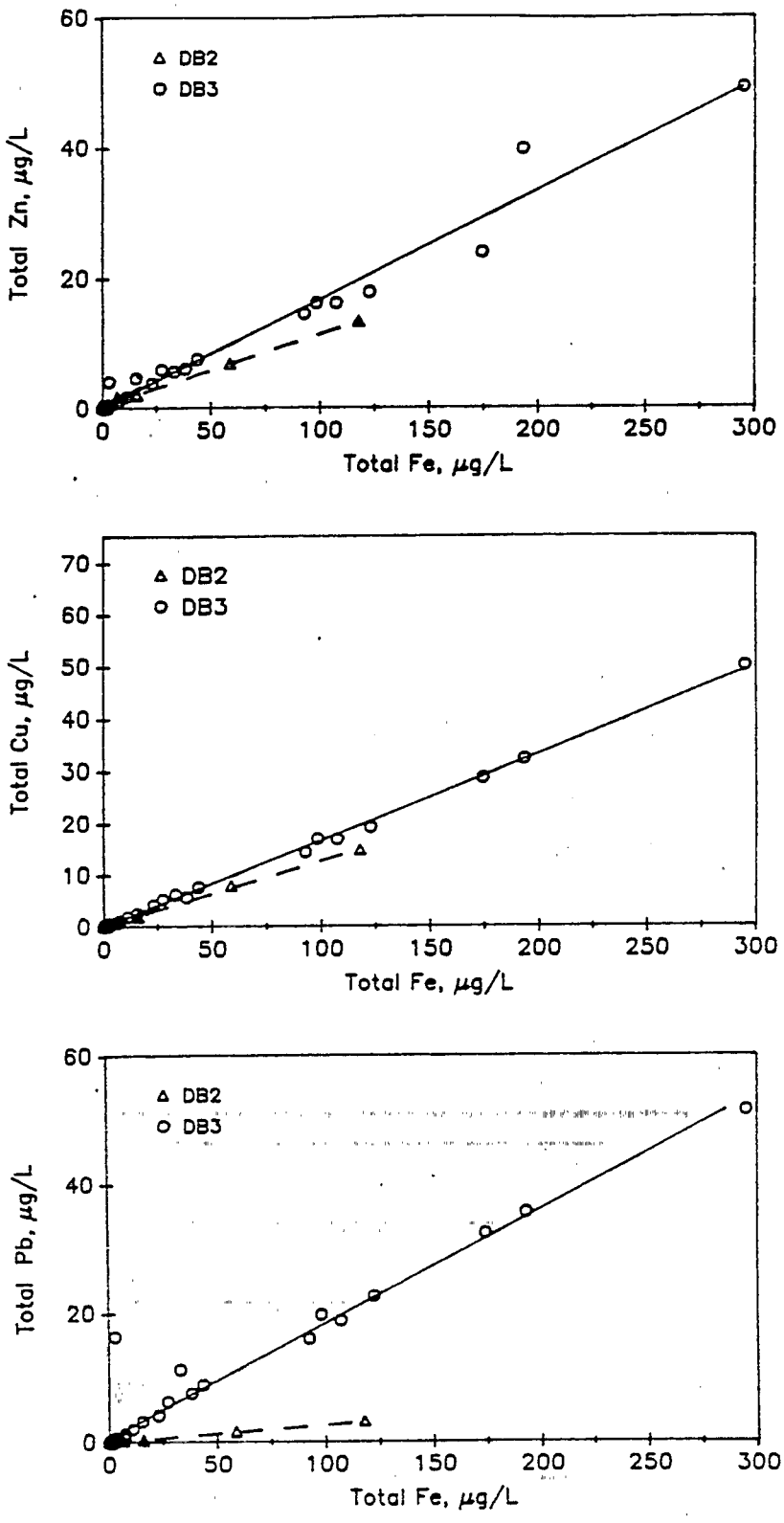
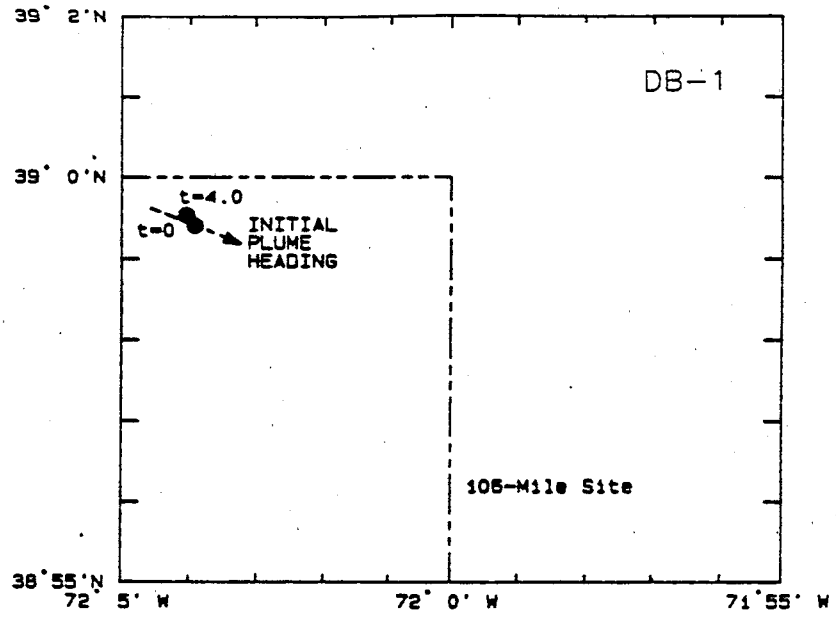


FIGURE 4-16. DIAGNOSTIC TRACER RATIOS FOR SLUDGE PLUMES DB-2 (SLUDGE FROM WARDS ISLAND SEWAGE TREATMENT PLANT, NEW YORK CITY, NY) AND DB-3 (SLUDGE FROM PORT RICHMOND SEWAGE TREATMENT PLANT, NEW YORK CITY, NY).



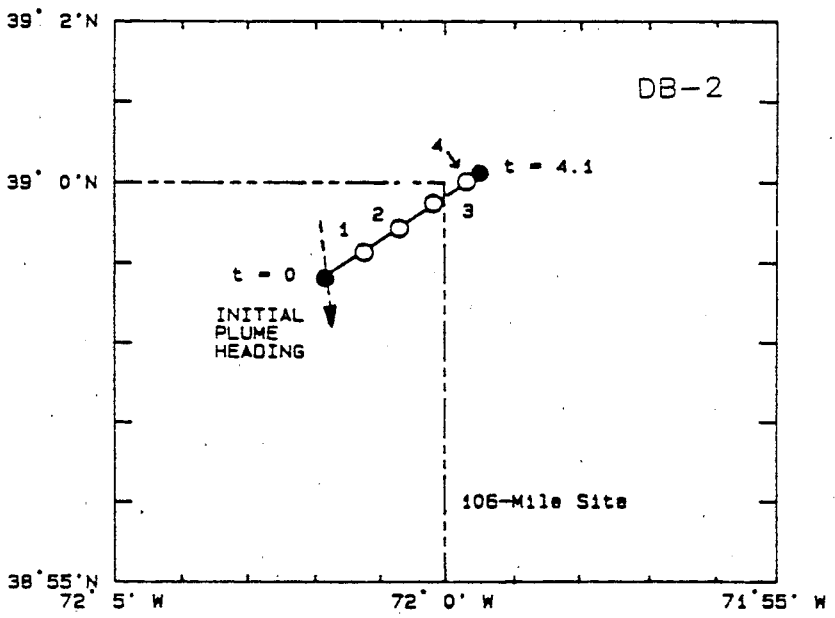
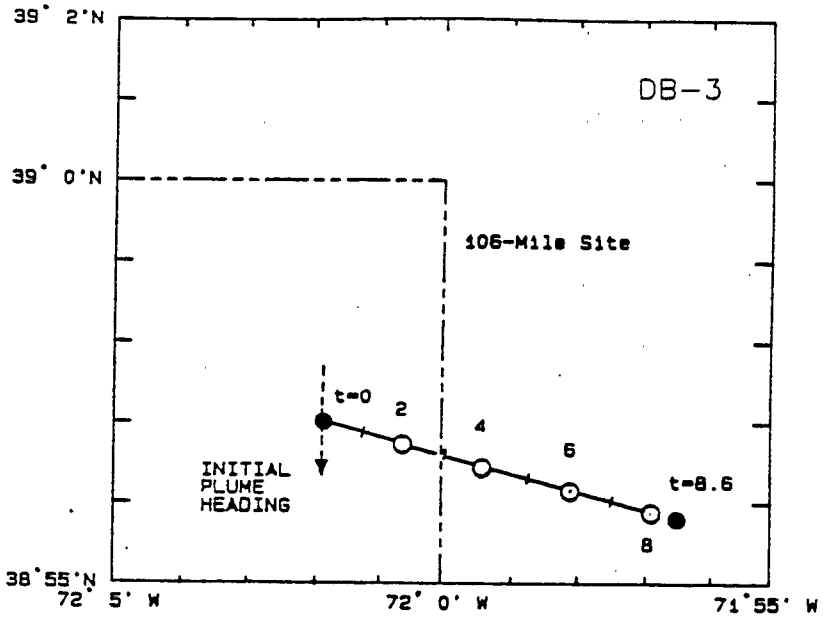


FIGURE 4-17. SUMMARY OF PLUME ADVECTION FOR PLUMES DB-1 AND DB-2. HOURLY POSITIONS OF THE PLUME ARE INDICATED, AS WELL AS THE INITIAL HEADING OF THE PLUME.



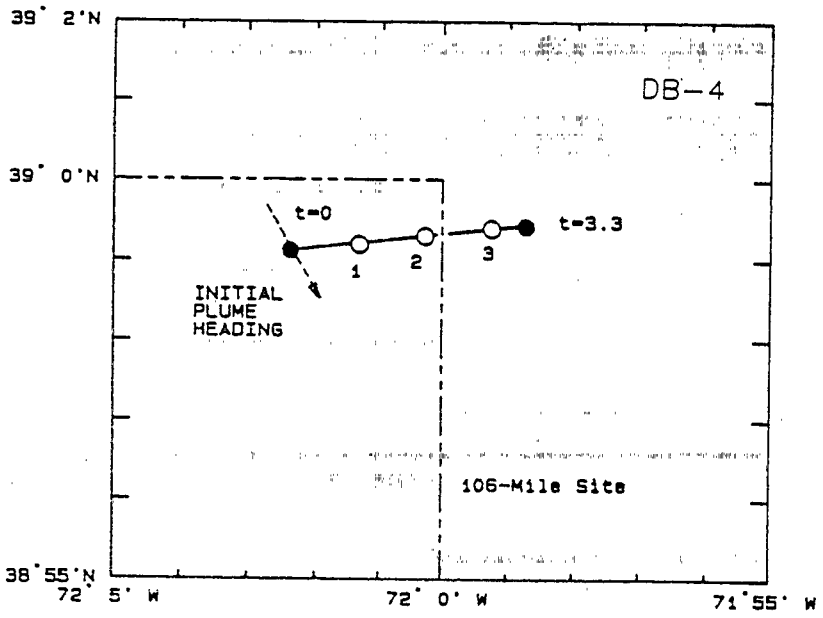


FIGURE 4-18. SUMMARY OF PLUME ADVECTION FOR PLUMES DB-3 AND DB-4. HOURLY POSITIONS OF THE PLUME ARE INDICATED, AS WELL AS THE INITIAL HEADING OF THE PLUME.

The results of plume advection can be summarized as follows:

- Plume DB-1 remained within the site for at least 4 h after it was dumped at the northern boundary of the site.
- The remaining three plumes crossed the eastern boundary of the site within 2 to 3 h after they were dumped near the center of the site (near 72°02'W).
- Plume advection toward the east was in direct opposition to the expected mean (westward) flow direction of slope water at the site. Eastward advection was probably related to the anticyclonic flow around the warm-core eddy situated to the east (or southeast) of the site.
- Had real-time current data been used to direct dumping operations toward the western boundary of the site, all plumes would have remained within the site boundaries for at least 4 hours after dumping.

The current regime that was encountered during the survey may have been atypical for the 106-Mile Site, but during these events, strong near-surface currents can move sludge plumes out of the site in a few hours. The observed currents may have represented a worst-case for plume advection because the currents were directed across the narrow, east-west dimension of the 106-Mile Site. However, during the passage of a warm-core Gulf Stream eddy, near-surface currents can reach speeds 3 to 4 times greater than those observed during the survey, and plume residence times within the site may be reduced to an hour or less.

4.5 WATER QUALITY MEASUREMENTS

A primary concern of the 106-Mile Site monitoring program is to verify (1) that the adverse impacts of sludge dumping on water quality at the site, as measured by increased metal and organic contaminant concentrations, and increased pathogen counts, are not in excess of those permitted by the ocean dumping regulations and permit requirements; and (2) that sludge dumping has no significant effect on dissolved oxygen levels or pH at the site. The survey addressed water quality issues through the analysis of water samples collected in sludge plumes for WQC contaminants. Although samples for the analysis of contaminants for which there are EPA water quality criteria were collected in

all four sludge plumes monitored, only two sets of samples, those from DB-2 and DB-3, were analyzed. Additional monitoring was conducted to verify that the disposal of sludge does not cause a significant depletion of dissolved oxygen content of the water and to monitor the levels of the microbiological tracer, C. perfringens; pH was not monitored. A summary of water quality findings is presented below. A complete set of water quality data is presented in Appendix D.

4.5.1 Comparison to Water Quality Criteria

Results of the analysis of samples collected within plumes DB-2 and DB-3 indicate that all organic contaminants and all but two metal contaminants (copper and lead) were below water quality criteria approximately 4 h after disposal. Copper levels exceeded WQC in both plumes studied, but lead concentrations exceeded WQC only in DB-2. Mercury concentrations in both sludge plumes were within a factor of 2 of WQC at 4 h, whereas nickel concentrations were within a factor of 2 of WQC after 4 h in plume DB-3 (Table 4-6). Concentrations of other metal WQC contaminants and all organic WQC contaminants were well below WQC levels in both sludge plumes.

Sludge plume DB-3 was advected outside the site within 4 h, and although water samples were not collected at the site boundary, concentrations of contaminants in the plume could be calculated based on chemical tracer. Using the mean tracer dilution rate for sludge plume DB-3 (Section 4.4.4) and reported contaminant concentrations in sewage sludge (from the Port Richmond sewage treatment plant), (Santoro and Fikslin, 1987), copper met marine WQC 5.2 h after disposal, whereas lead, mercury, and nickel met WQC 4.1 h, 3.25 h, and 0.9 h after disposal, respectively. Because sludge plume DB-3 was advected outside of site boundaries at 2.5 h, calculated concentrations of copper, lead, and mercury exceeded WQC outside the site. Other metal and organic contaminants were calculated to be below marine WQC when the plume was transported beyond site boundaries.

Because Santoro and Fikslin (1987) presents contaminant information for all 19 sewage treatment plants using the 106-Mile Site, the data can be used to predict contaminant levels in site waters assuming sludges from other plants were dumped under the same conditions, resulting in the same initial and

TABLE 4-6. COMPARISON OF METAL MEASUREMENTS IN SLUDGE PLUMES DB-2 AND DB-3 APPROXIMATELY 4 h AFTER DISPOSAL AT THE 106-MILE SITE TO EPA MARINE WATER QUALITY CRITERIA (CONCENTRATIONS EXCEEDING EPA WATER QUALITY CRITERIA ARE UNDERLINED.)

Sample Depth (m)	Time After T=0 h	Concentration[a] Ag	As	Cd	Cr	Cu	Fe	Ni	Pb	Se	Zn	Hg
		(μg/L)										(ng/L)
DB-2												
6.0	4.3	0.006	0.93[b]	0.034	0.474	2.134	13.31	0.346	0.438	<0.03[b]	1.29	12.35
DB-3												
6.0	4.18	0.075	0.99	0.131	2.061	3.225	13.277	0.610	2.549	<0.03	2.000	10.23
10.4	4.35	0.243	1.04	0.400	6.445	11.210	44.640	1.424	10.358	<0.03	7.960	14.72
Water Quality Criteria		2.3	36	9.3	50	2.9	NA	8.3	5.6	54	86	25

[a]Mean of duplicate analysis except where indicated.
[b]Single analysis.

continuing dispersion as determined for event DB-3. The average concentration of eight metals in sludge from each treatment plant was used to determine the T=0 h concentration (assuming initial dilution of 1000), and the mean exponential rate of tracer decay in the plume (0.51 $\bar{x}$ 0.02 h^{-1}, Section 4.4.2.4) was used to calculate the expected concentration of each metal in the plume 4 h after disposal. These estimates were compared to EPA WQC. For the 19 sewage treatment plants reported in Santoro and Fikslin (1987), 18 would not meet the marine water quality criteria for copper under the conditions prevailing during dumping event DB-3. The results of this exercise are presented in Table 4-7.

Because the calculated rate of tracer decay with time in plume DB-3 is based on few data points, and because the published data may not reflect changes in contaminant levels in current sludges, the results in Table 4-7 must be considered an estimate. TSS data show a more rapid rate of dispersion during dumping event DB-3, and using TSS dispersion rates, fewer sludges would exceed WQC. Because different oceanographic conditions may be more or less dispersive, caution must be used in drawing conclusions from dispersion rates calculated from dumping event DB-3. However, Table 4-7 does illustrate that of the contaminants for which there are marine water quality criteria, only arsenic and cadmium are not of concern vis-a-vis the 106-Mile Site monitoring program. Calculations show that other elements, to varying degrees, exceed or approach marine WQC 4 h after disposal of one or more typical sludges at the 106-Mile Site.

4.5.2 Dissolved Oxygen

Dissolved oxygen concentrations were monitored continuously during vertical and horizontal profiling operations using an in situ oxygen probe interfaced to the CTD/transmissometer profiling system. Analyses of oxygen data from within the various plumes revealed extremely small reductions (0.3 mL/L) of oxygen during the first hour after sludge discharge, but the magnitude of these variations was well below the expected accuracy of the sensor (±0.1 mL/L). These oxygen reductions could only be attributed to the sludge plumes when the data were analyzed along horizontal transects through the plumes.

TABLE 4-7. NUMBER OF SLUDGE PLUMES NOT MEETING EPA WATER QUALITY CRITERIA 4 h AFTER SLUDGE DISPOSAL AT THE 106-MILE SITE. NON-COMPLIANCE BASED ON MEAN CONTAMINANT CONCENTRATIONS IN SLUDGES FROM 19 SEWAGE TREATMENT PLANTS IN THE NEW YORK METROPOLITAN AREA (Santoro and Fikslin, 1987), AND MEAN DISPERSION RATES (FROM METAL TRACER DATA, SLUDGE PLUME DB-3)

	Number of Sludge Plumes	
Element	Above WQC	Within 3x WQC
Arsenic	0	0
Cadmium	0	0
Chromium	0	2
Copper	18	19
Mercury	5	13
Nickel	0	1
Lead	4	8
Zinc	0	1

Figure 4-19 presents a stackplot of horizontal profile measurements versus distance along a transect through plume DB-4. The top of this figure illustrates the high turbidity (beam attenuation) within the plume. Visual inspection of the salinity, sigma-t, and oxygen profile results reveals reduced values for each parameter at the same location as the high turbidity values. These results demonstrate that sludge plumes are less saline and have lower oxygen values than receiving water. The observed temperature variability is presumed to be associated with natural variability, as the sludge apparently had temperatures equivalent to the receiving water. Thus, salinity is the controlling factor in plume density, and therefore, the plumes were less dense than the receiving waters near the sea surface. This information also supports the observation that sludge plumes did not sink beyond the seasonal pycnocline.

4.5.3 Clostridium perfringens

A microbiological tracer of sewage sludge, C. perfringens, was found at elevated levels in sludge plumes throughout each plume tracking event (Table 4-8). For one sludge plume (DB-1), C. perfringens levels throughout the survey remained too numerous to count, indicating that C. perfringens may be the most sensitive sludge tracer used on the survey. The data also indicate that C. perfringens concentrations in sludges may vary dramatically, suggesting that levels of pathogens in sludges may also vary. C. perfringens is a spore-forming anaerobe thought to be associated with forms of food poisoning (Higgins and Burns, 1975). Because it exists as a cyst, this species is thought to be more viable than other bacteria and is useful as a sewage tracer (Cabelli and Pederson, 1982). C. perfringens levels in sludge plumes at the site may not reflect levels of other more harmful pathogens. C. perfringens was not found in any out-of-site control samples analyzed. Complete C. perfringens data are presented in Tables C-5 through C-8 in Appendix D.

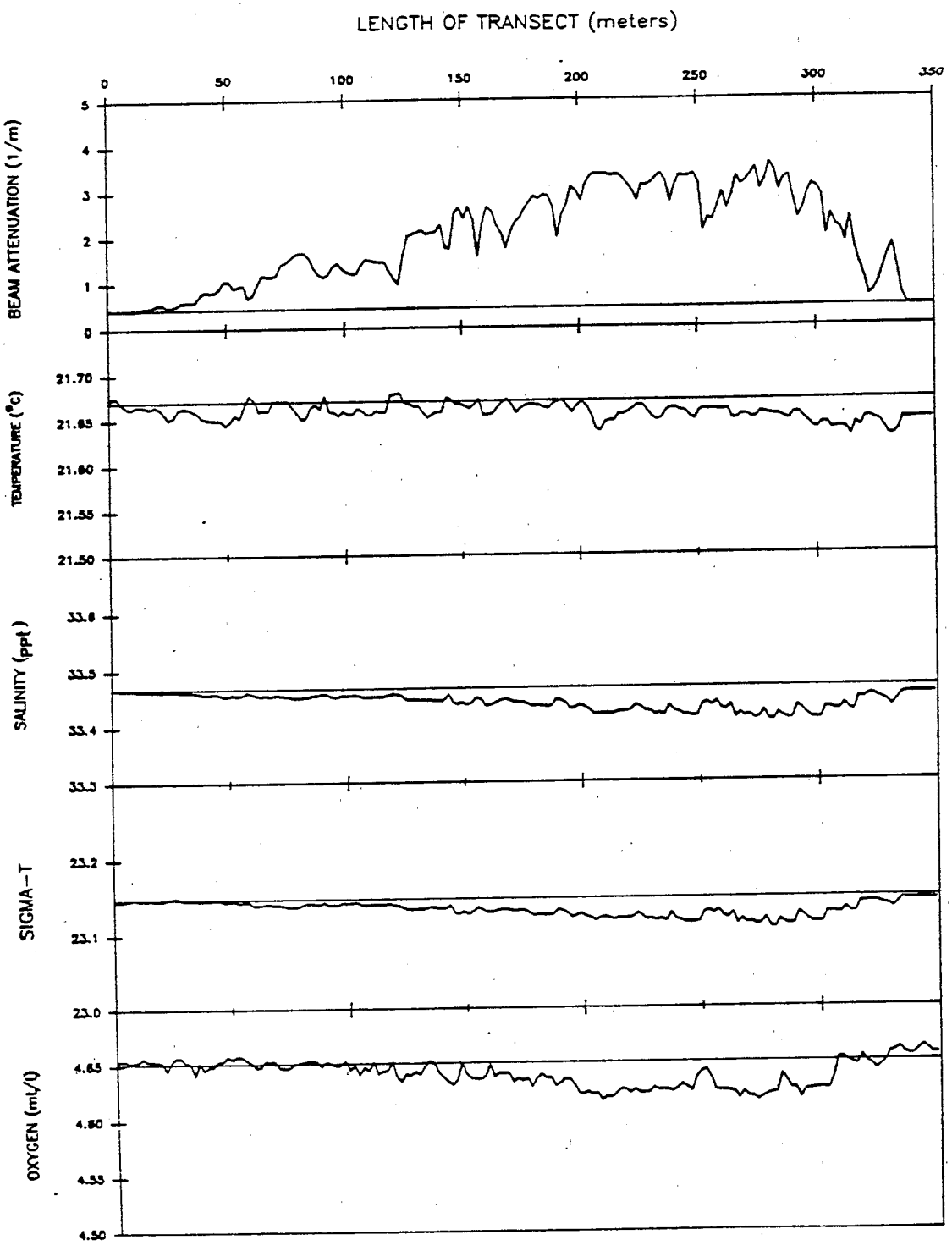


FIGURE 4-19. VARIATIONS IN WATER PROPERTIES ALONG A TRANSECT OF PLUME DB-4 THAT WAS MADE 55 MINUTES AFTER DISCHARGE FROM THE BARGE. REDUCTIONS IN SALINITY, SIGMA-T, AND OXYGEN CORRESPOND WITH HIGH TURBIDITIES (BEAM ATTENUATION) WITHIN THE PLUME.

TABLE 4-8. CONCENTRATIONS OF C. perfringens IN THE SLUDGE PLUMES AT T=0 AND BETWEEN 4 AND 7 h AFTER DISPOSAL. (RESULTS ARE BASED ON THE MAXIMUM OBSERVED IN THE SET OF REPLICATE SAMPLES FOR THE SAMPLE PERIOD.)

Plume	T=0	T=4	T=7
DB-1	TNTC[a]	TNTC[b]	--
DB-2	>207[c]	292[d]	300[e]
DB-3	257	150[f]	--
DB-4	TNTC	20[g]	--

TNTC = Colonies too numerous to count.
[a]Number of colonies estimated as >1500/100 mL.
[b]Number of colonies estimated as >820/100 mL.
[c]Concentration for one replicate; colonies in two of the three replicates were TNTC.
[d]Collected at T=4.3 h.
[e]Collected at 10 meters, T=7.25 h.
[f]Collected at 6m, at T=4.18 h.
[g]Collected at 6m, T=4.72 h.

4.6 OBSERVATIONS OF CETACEANS AND MARINE TURTLES

Five species of cetaceans, including two species of whales and three species of dolphins, were observed in slope and shelf-edge waters. There were no marine turtles observed during the survey. A complete discussion of results is included in the site condition report (EPA , 1987f).

5.0 CONCLUSIONS

5.1 DISCUSSION OF NULL HYPOTHESES

Monitoring the nearfield fate of sludge plumes is one component of Tier 2 monitoring activities presented in the 106-Mile Site monitoring plan (EPA , 1987a). Nearfield fate monitoring addresses both permit compliance and impact assessment. It addresses permit compliance because the permits for disposal of sludges at the 106-Mile Site will stipulate that Water Quality Criteria (WQC), where they exist, may not be exceeded within the site 4 h after dumping and outside the site at any time. When WQC do not exist, the permits will require that the waste concentration not exceed a factor of 0.01 of a concentration known to be acutely toxic after initial mixing, i.e., the limiting permissible concentration (LPC). The combined conformance to LPCs and WQC is thought to be protective of the marine environment.

Nearfield fate (and short-term effects) monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short-term, defined for convenience as 24 h. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring the behavior and movement of sludge immediately after disposal is necessary to confirm assumptions made about dispersion and dilution when issuing permits.

The 106-Mile Site monitoring plan (EPA , 1992a) uses site and waste characteristics to predict possible impacts of sludge disposal and formulate testable null hypotheses that these predictions suggest. Results of the summer survey are discussed in terms of hypotheses addressing issues associated with Tier 2 of the monitoring plan. The hypotheses H_o3 through H_o9 are divided into two categories: permit compliance and impact assessment.

Permit Compliance: Nearfield Fate

H_o3: Concentrations of sludge and sludge constituents outside the site are below the permitted LPC and WQC at all times.

The summer survey demonstrated that sludge dumped in the site can be transported outside site boundaries before all

constituents are diluted below LPC and WQC. This was demonstrated for the sludge constituents copper and lead, and are predicted for mercury and nickel. Organic sludge constituents were significantly below WQC.

H_o4: Concentrations of sludge and sludge constituents within the site are below the permitted LPC and WQC 4 h after disposal.

Although oceanographic conditions at the site during the summer survey were considered dispersive, concentrations of the sludge constituents copper and lead exceeded WQC 4 h after disposal. WQC for mercury would also be exceeded in sludge plumes from some sewage treatment plants using the site.

H_o5: Pathogen levels do not exceed ambient levels 4 h after disposal.

The microbial tracer, C. perfringens, exceeded ambient levels in all sludge plume water collected 4 h or more after disposal. C. perfringens is not a pathogen, but a conservative microbial tracer of sewage; therefore, C. perfringens data are not conclusive proof that pathogen levels are being exceeded 4 h after disposal. The data suggest that a suitable replacement for C. perfringens be developed for future nearfield fate surveys.

Impact Assessment: 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.

Sludge penetration below 20 m was not observed on the survey, even 8 h after sludge discharge. Because of the strong "jet" in the pycnocline during the time of the survey, sludge could have been carried away in the pycnocline and potential settling not observed.

Throughout the region, vertical profiles of natural turbidity exhibited a subsurface maximum situated within the seasonal pycnocline. This suggests that surface-dumped particulate matter may accumulate within the seasonal pycnocline during summer and coexist with natural planktonic species.

H_o7: 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.

Concentrations of the sludge constituents copper and lead exceeded WQC 4 h after disposal. WQC for mercury would also be exceeded in sludge plumes from some sewage treatment plants using the site. Although sludge could not be tracked for more than 9 h after disposal, calculations of sludge dispersion indicate that all measured sludge constituents would reach ambient concentrations within 1 day after disposal.

H_o8: 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.

The summer survey demonstrated that sludge dumped in the site can be transported outside site boundaries before all constituents are diluted below LPC and WQC. This was demonstrated for the sludge constituents copper and lead and predicted for mercury and nickel. Organic sludge constituents were significantly below WQC. Calculations of dispersion indicate that all measured constituents would reach ambient concentrations within 1 day after disposal.

H_o9: 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.

The observed depression in dissolved oxygen levels in sludge plumes is minor and at the limit of instrument resolution. The observed depression of dissolved oxygen is that predicted by simple mixing models, and not the result of depletion caused by chemical oxygen demand (COD) or biological oxygen demand (BOD). During the summer survey, pH was not monitored in sludge plumes.

5.2 EVALUATION OF MEASUREMENT TECHNIQUES

Because the September 1987 survey was the first field application of proposed technical guidance for plume-tracking activities to be conducted as part of the 106-Mile Site monitoring program, an objective of the survey was to evaluate methods that may be used in the future by EPA or by permittees. The following methods (originally presented in Section 2.0) are evaluated in terms of the success of the September 1987 survey:

- **Identification and tracking of a sludge plume with dye and surface and subsurface drogues.**

  Both dye and drogues worked well for identifying a portion of a sludge plume for surveying. Dye mixed in from the OSV Anderson resulted in only a surface expression, and thus could not be used to monitor dispersion. Dye introduced from the barge would be more useful as a sludge tracer.

- **Monitoring the movement and dispersion of the marked sludge plume with visual observations from the OSV Anderson and a contracted aircraft.**

  All visual observations were successful in monitoring the movement and dispersion of the plume. Aerial photo-reconnaissance proved to be a useful tool for determining lateral dispersion and orientation of the plume.

- **Acquisition of in situ transmissometry and acoustics data, and shipboard UV/fluorescence data to monitor the movement and dispersion of the plume.**

  Transmissometry was the most sensitive and reliable real-time tracking method and provided the most data for nearfield fate analyses. Horizontal transmissometry profiling (transmissometer on a V-fin depressor) allowed continuous profiling while the ship was under power and making reciprocal passes through the sludge plume. Acoustics pr filing (27 and 300 kHz) of two sludge plumes (EPA , 1987f) provided good quality data. However, the data were not quantitative, and because the acoustics profiler and the transmissometer could not be used at the same time on the OSV Anderson, acoustic profiling was not continued on the survey. If appropriate transducers can be hull-mounted, acoustic profiling may provide useful supplemental information to transmissometry. However, because of the power of transmissometry for plume tracking, acoustic profiling is not recommended as a primary survey method.

  For the September 1987 survey, seawater was pumped through a conventional UV fluorometer. Air bubbles in the seawater lines continually interfered with fluorescence measurements and the method was abandoned before its utility for plume tracking was fully investigated. A flurometer would be extremely useful if dye could be introduced in a plume from a moving barge (see above).

- Collection of samples for chemical and biological tracers and total suspended solids to determine actual concentrations of sludge components and dilution of these components.

  The chemical tracers and TSS proved to be valuable measurements for determination of nearfield fate of disposed sludge. Without these measurements, transmissometry data could not be related to actual contaminant levels at the site.

- Acquistion of satellite-derived ocean frontal analyses, CTD profiles, and measurements of current shear to determine the oceanographic conditions that may have impacted the data generated during the survey.

  In addition to providing critical information for post-survey data analysis, the above oceanographic measurements also provided data that was extremely useful at sea for predicting sludge plume behavior. CTD profiles and current shear measurements proved necessary for interpretation of plume-tracking data.

- Acquisition of real-time navigation data to support plume-tracking activities.

  Real-time navigation provided critical information necessary for positioning the ship during plume tracking. By showing the position of the ship in relation to the plume, real-time navigation was an indispensible aid to the plume-tracking survey.

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APPENDIX A

A.1 DATA QUALITY REQUIREMENTS AND OBJECTIVES

The data requirements for chemical analysis are summarized in Table 3-2. Accuracy of the chemical analyses were determined by analysis of procedural blanks and certified reference materials, when available. Samples were also spiked with known amounts of the analyte of interest and the recovery of the spike monitored to determine extraction efficiencies. For organic compounds, both field and laboratory extraction efficiencies were monitored through addition of surrogate compounds. Precision of analysis were determined by analysis of duplicate samples.

The accuracy of Clostridium perfringens and total suspended solids (TSS) results could not be determined from independent standards because certified reference standards are not available. Analysis of spiked samples for these parameters is not feasible.

A.2 QUALITY CONTROL RESULTS

A.2.1 Total Suspended Solids

Analysis of duplicate TSS samples showed precision of less than 10 percent relative percent difference (RPD). The precision was consistent throughout the wide range in TSS concentrations; e.g., TSS mean = 24, RPD = 6.0; TSS mean = 0.79, RPD = 3.8. Six blank filters processed in the field resulted in mean TSS concentrations of 0.3 ± 0.9 mg/L, reflecting the difficulty in obtaining accurate TSS determinations of low turbidity water. The procedural blank values are thought to result from changes in humidity affecting both tare and final filter weights. TSS results were not corrected for blanks. The precision was within the objectives for the analysis of TSS. However, because of the absence of reference material, accuracy could not be determined.

A.2.2 Metals

The method detection limits determined during the analysis of the samples for trace metal concentrations are listed in Table A-1. All detection

limits are sufficient to determine the concentration of the metals analyzed at background oceanic levels. The detection limits obtained are within the objectives listed for this project, except for arsenic and mercury. The detection limits achieved for these two elements were, however, sufficient to provide detectable concentrations of these elements for all samples analyzed. Results of procedural blanks (Table A-2) indicate most metals were analyzed without significant contaminant contribution to the sample. A consistent contribution from the analytical procedure was found for iron, mercury, and zinc. Sample results were corrected for these blanks. Results of duplicate analyses indicate excellent precision (<10 percent as the RPD) was obtained in the laboratory (Table A-3). Silver (67% as the RPD) and cadmium (24% as the RPD) had relatively poor precision due to the extremely low concentrations found in the samples. Chromium results were also more variable (RPD = 24).

Recovery of matrix spikes (Table A-4) was excellent, generally ranging between 80 and 120 percent of the known addition. Lower recoveries of silver (51%) were observed, and iron and lead recoveries were variable, with significant overrecovery observed in several samples. Metal recoveries from certified seawater samples (Table A-5) were higher than observed for matrix spikes. Silver is not certified in standard seawater, therefore no estimate of accuracy is available from this quality control check.

A.2.2 ORGANIC COMPOUNDS

Method detection limits for the pesticides and polychlorinated biphenyl (PCB) analysis are shown in Table A-6. Detection limit objectives were met for these compounds. Recoveries of organic compounds were determined at two steps of the extraction procedure, during field extractions and within the laboratory. Field recoveries were determined by the addition of a known amount of decachlorobiphenyl to each sample. The recoveries determined for this compound were low and variable (Table A-7), ranging between 6 and 58 percent. Sample results are not corrected for this extraction efficiency. In the laboratory, a suite of compounds were spiked into a sample and the recovery efficiency determined (Table A-8). Recoveries were excellent, with the exception of α-endosulfan and β-endosulfan. The results indicate that the cleanup step (silica-alumina column chromatography) necessary to achieve the

required detection limits allowed successful recovery of all analytes except for the two with low recoveries.

TABLE A-2. RESULTS OF PROCEDURAL BLANKS ANALYZED WITH TRACE METAL SAMPLES, NANOGRAPHS OF METAL CONTRIBUTED TO SAMPLES

Sample Type	Analytical[a] Batch	Metal										
		Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Tracer	1	-	-	-	-	<1.08	24.6	-	-	<0.64	-	8.8
	1	-	-	-	-	<1.08	33.2	-	-	<0.64	-	9.2
	1	-	-	-	-	<1.08	29.6	-	-	<0.64	-	14.8
	2	-	-	-	-	<1.00	31.4	-	-	<0.66	-	9.2
	2	-	-	-	-	<1.00	24.4	-	-	<0.66	-	8.6
	2	-	-	-	-	<1.06	25.0	-	-	1.82	-	10.4
	3	-	-	-	-	1.08	35.2	-	-	<1.36	-	11.6
	3	-	-	-	-	<1.08	14.4	-	-	1.46	-	13.8
	3	-	-	-	-	<1.08	32.0	-	-	<1.36	-	12.4
Water Quality	1	4.6	-	0.8	<1.3	<1.2	14	0.23[b]	<5	<1.8	-	13.2
	1	7.7	-	0.7	-	<1.2	17	0.21[b]	<5	<1.8	-	12.7
	1	5.4	-	3.5	-	<1.2	15.8	0.39[b]	<5	<1.8	-	13.7
		-	-	-	-	-	-	0.41[b]	-	-	-	-

[a]Batch number refers to the analytical blanks run with each batch of samples.
[b]Mean of 5 procedural blanks run with each analytical batch.

TABLE A-1. METHOD DETECTION LIMITS FOR ANALYSIS OF SAMPLES FOR TRACE METAL CONCENTRATIONS DURING PLUME-TRACKING EXERCISES SEPTEMBER 1987

Analyte	Detection Limit (μg/L)
Arsenic	0.68
Cadmium	0.0009
Chromium	0.009
Copper	0.006
Iron	0.06
Lead	0.009
Mercury	0.002
Nickel	0.03
Selenium	0.03
Silver	0.002
Zinc	0.003

TABLE A-3. RESULTS OF ANALYSIS OF DUPLICATE SAMPLES REPORTED AS RELATIVE PERCENT DIFFERENCE (RPD)

Sample Type	Analytical Batch	Metal										
		Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Tracer	1[a]	-	-	-	-	8	5	-	-	4	-	1
	2[b]	-	-	-	-	2	7	-	-	11	-	2
	3[c]	-	-	-	-	6	2	-	-	4	-	12
Water Quality	1[d]	67	6[e]	24	26	5	7	-	4	5	-	3

[a]Plume DB-2, 10.7 m, 7.25 h after disposal.
[b]Plume DB-3, 6.0 m, 2.0 h after disposal.
[c]Plume DB-3, 20.2 m, 4.23 h after disposal.
[d]Plume DB-3, 24.0 m, Background sample.
[e]Plume DB-2, 6 m, 4.3 h after disposal.

TABLE A-4. PERCENT RECOVERIES OF METALS FROM SAMPLES SPIKED WITH KNOWN AMOUNTS OF METAL

Sample Type	Analytical Batch	Metal										
		Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Tracer	1[a]	-	-	-	-	88	84	-	-	98	-	106
	2[b]	-	-	-	-	137	77	-	-	170	-	89
	3[b]	-	-	-	-	90	181	-	-	95	-	70
Water Quality	1[b]	51	NA	113	86	96	115	NA	108	134	124[c]	88

NA = Not available.
[a]Spike to NASS 2 certified reference material.
[b]Spike to CASS 1 certified reference material.
[c]Mean of duplicate analyses.

TABLE A-5. PERCENT RECOVERY OF METALS FROM CERTIFIED STANDARD REFERENCE MATERIAL ANALYZED WITH EACH BATCH

Sample Type	Analytical Batch	SRM	Metal										
			Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Tracer	1	NASS-2	-	-	-	-	98	66	-	-	94	-	74
	1	NASS-2	-	-	-	-	99	71	-	-	92	-	69
	2	CASS-1	-	-	-	-	96	109	-	-	93	-	102
	2	CASS-1	-	-	-	-	102	101	-	-	102	-	108
	3	CASS-1	-	-	-	-	104	126	-	-	122	-	115
	3	CASS-1	-	-	-	-	105	132	-	-	101	-	116
Water Quality	1	CASS-1	NA	88	90	111	126	91	NA	124	101	NA	114

NA = Not available.

TABLE A-6. METHOD DETECTION LIMITS FOR ANALYSIS OF ORGANIC COMPOUNDS FROM 100-L SAMPLES DURING THE PLUME-TRACKING EXERCISES, SEPTEMBER 1987

Analyte	Detection Limit (ng/L)
Cl_2(8)[a]	0.004
Cl_3(18)	0.001
Cl_3(28)	0.003
Heptachlor	0.001
Cl_4(52)	0.001
Aldrin	0.001
Cl_4(44)	0.002
Cl_4(66)	0.003
o,p'-DDE	0.001
Cl_5(101)	0.002
Chlordane	0.002
Dieldrin	0.001
p,p'-DDE	0.002
Cl_4(74)	0.013
o,p'-DDD	0.008
Cl_5(118)	0.002
p,p'-DDD	0.004
o,p'-DDT	0.003
Cl_6(153)	0.002
Cl_5(105)	0.007
p,p'-DDT	0.001
Cl_6(138)	0.003
Cl_5(126)	0.010
Cl_7(187)	0.005
Cl_6(128)	0.007
Cl_7(180)	0.000
Cl_7(170)	0.001
Cl_8(195)	0.001
Cl_9(206)	0.000
α-Endosulfan	Not determined
Endosulfan sulfate	Not determined

[a] Cl_2, Cl_3, Cl_4, etc. refer to PCB level of chlorination. The number in parentheses refers to the isomer number, IUPAC nomenclature.

TABLE A-7. RECOVERY OF DECACHLOROBIPHENYL SPIKED INTO 100-L SAMPLES OF SEAWATER PRIOR TO EXTRACTION IN THE FIELD

Plume or Event	Depth (m)	Rep. No.	Start Time	Time After T=0 (h)	Percent Recovery
S8	6.0	1	2051	BKG	Not available
S8	6.0	2	2057	BKG	Not available
DB-2	6.0	1	0722	BKG	37.6
DB-2	6.0	2	0730	BKG	30.6
DB-2	6.0	3	0738	BKG	33.2
DB-2	24.5	1	2133	BKG	36.0
DB-2	24.5	2	2212	BKG	15.3
DB-2	24.5	3	2236	BKG	25.6
DB-2	6.0	1	1456	4.5	57.9
DB-2	6.0	2	1505	4.6	11.8
DB-2	6.0	3	1510	4.7	11.3
DB-2	10.1	1	1822	7.9	6.4
DB-2	10.5	2	1833	8.1	7.6
DB-2	10.3	3	1847	8.3	22.4
DB-3	6.0	1	0900	BKG	28.7
DB-3	6.0	2	0911	BKG	30.5
DB-3	6.0	3	0918	BKG	30.8
DB-3	6.0	1	1535	4.4	23.5
DB-3	6.0	2	1543	4.5	27.0
DB-3	6.0	3	1551	4.7	15.2
DB-3	7.0	1	1613	5.0	33.7[a]
DB-3	5-7	2	1644	5.6	23.3

[a]Mean of two replicate analyses.
BKG denotes background samples.

TABLE A-8. RESULTS OF BLANK SPIKE ANALYSIS, ORGANIC COMPOUNDS

Compound	Percent Recovery
Pesticides	
Heptachlor	110
Aldrin	111
Heptachlor epoxide	-
α-Endosulfan	8.6
Dieldrin	-
4,4'-DDE	120
Endrin	114
β-Endosulfan	9.6
4,4'-DDD	-
Endrin aldehyde	-
Endosulfan sulfate	-
4,4'-DDT	-
Methoxychlor	-
PCBs	
Cl_2(8)	91.8
Cl_3(18)	96.4
Cl_3(28)	117
Cl_4(52)	96.7
Cl_4(44)	105
Cl_4(66)	102
Cl_5(101)	92.7
Cl_5(118)	144
Cl_6(153)	110
Cl_5(105)	162
Cl_6(138)	145
Cl_7(187)	105
Cl_6(128)	101
Cl_7(180)	102
Cl_7(170)	101
Cl_8(195)	96.2
Cl_9(206)	89.3

APPENDIX B

CTD TRANSECT TO THE 106-MILE SITE

WATER MASSES DURING PLUME-TRACKING SURVEYS

CTD Transect to the 106-Mile Site

During the eastbound transit to the 106-Mile Site on August 31, 1987, a series of seven CTD profiles was made along a line extending from the edge of the continental shelf, through the northern end of the 106-Mile Site, to a position roughly 8 miles northeast of the site (Figure B-1). The primary objective of this transect was to locate the position of the shelf water/slope water front (east of the 106-Mile Site), as well as to determine whether a warm-core Gulf Stream eddy was situated near the eastern boundary of the site, as suspected from interpretations of satellite thermal imagery.

To illustrate variations in water properties along the eastbound CTD transect, Figure B-2 presents vertical profiles of temperature (top panel) and salinity (middle panel) versus depth for Stations 1, 4, and 5 along the transect. Stations 1 and 5 are located at the edge of the continental shelf and within the 106-Mile Site, respectively; Station 4 is shown for comparison because it exhibited anomalous water mass properties.

The upper panel of Figure B-2 illustrates that the surface mixed layer at the offshore stations was more than 1°C warmer than surface waters at Station 1, and that the mixed layer deepened toward shore. Profiles of all stations revealed a sharp, seasonal thermocline beneath the shallow, surface mixed layer. Although temperatures were relatively constant (between 11 and 14°C) over the depth range between 50 and 150 m, large variations were observed between 25 and 50 m. The most extreme temperature variation was at Station 4, where an isothermal layer of 8°C-water was observed between 30 and 40 m.

The middle panel of Figure B-2 illustrates that salinities at Station 4 were also relatively low within this isothermal layer (between 30 and 40 m). This specific water type (8°C, 33.2 ppt) is normally associated with a well-known east coast hydrographic feature named the "cold pool." This water mass obtains its properties during late winter when the mixed layer at the edge of the continental shelf is relatively cool and fresh. As the surface waters warm during spring and summer, the lower portion of this water mass (the prior winter's mixed layer) becomes isolated from the surface, and its properties remain unchanged for many months.

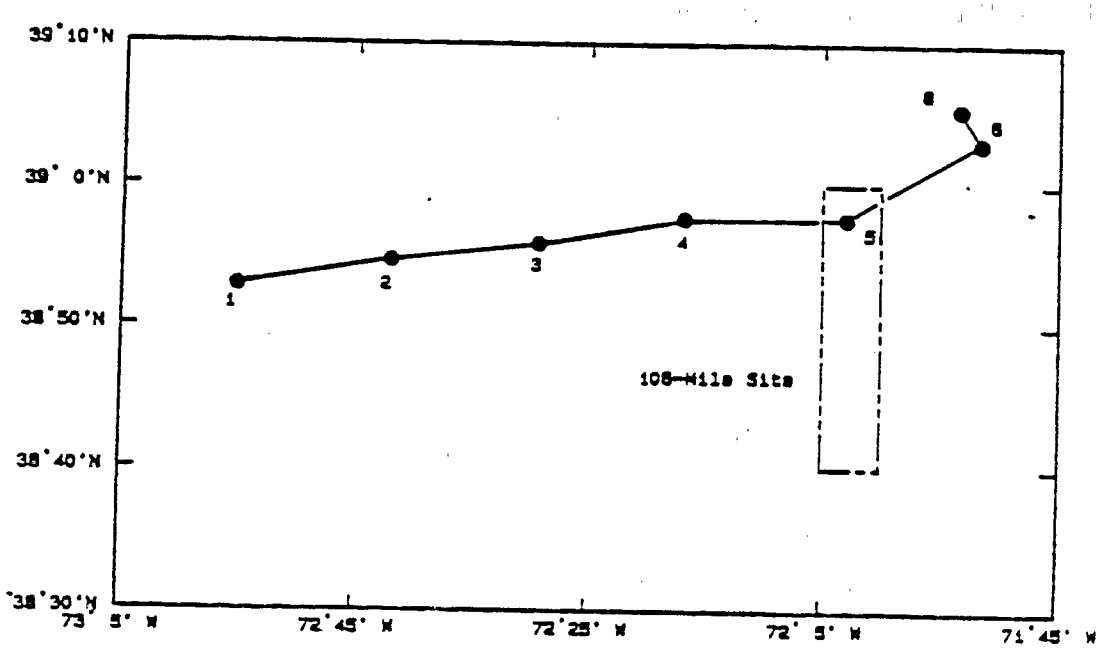

FIGURE B-1. LOCATIONS OF CTD PROFILE STATIONS OCCUPIED ALONG THE EASTBOUND TRANSECT TO THE 106-MILE SITE ON AUGUST 31, 1987.

The cold, fresh layer of "cold pool" water observed at Station 4 appears to be a small, isolated water parcel because water properties at the surrounding stations were distinctly different. This isolated parcel of water may have been attached to a larger parcel extending north or south of the transect. This theory, however, could not be confirmed by the existing station data.

The lower panel of Figure B-2 presents a composite of temperature/salinity (T/S) diagrams from Stations 1, 4, and 5. The highest temperature of each profile represents the surface properties at each station. This figure illustrates that the near-surface waters (>15°C) at Station 1 were significantly fresher than offshore surface waters or, in other words, near-surface waters at Station 1 were representative of shelf water whereas slope water was observed at the offshore stations. Note, however, that the layer of shelf water at Station 1 penetrated to only 25 m and that relatively saline slope water was found below this depth. Shelf water was observed within the upper 18 m of the water column at Station 2 but none was found farther offshore. From this analysis, it appears that the offshore (surface) boundary of the shelf water was situated approximately 25 nm west of the 106-Mile Site on August 31, 1987.

The T/S diagrams presented in Figure B-2 also illustrate the extremely cold, fresh characteristics of the "cold pool" water (8°C, 33.2 ppt) at Station 4. Beneath this anomalous layer, slope water characteristics are observed at all three transect stations (1, 4, and 5).

Figure B-3 presents vertical profiles of density (sigma-t), light transmission (beam attenuation), and dissolved oxygen for the three stations presented in Figure B-2. Despite the large variability in T/S structure at the three stations, vertical profiles of sigma-t (top panel) are relatively similar showing strong vertical density gradients of the seasonal pycnocline extending from the base of the shallow, surface mixed layer to depths of roughly 40 m. Below this depth, weak vertical gradients are similar at all stations.

The middle panel of Figure B-3 presents vertical gradients of transmissometry data, presented in terms of the beam attenuation coefficient, for Stations 1, 4, and 5. Beam attenuation is linearly proportional to total suspended solids or turbidity. The Sea Tech transmissometer interfaced to

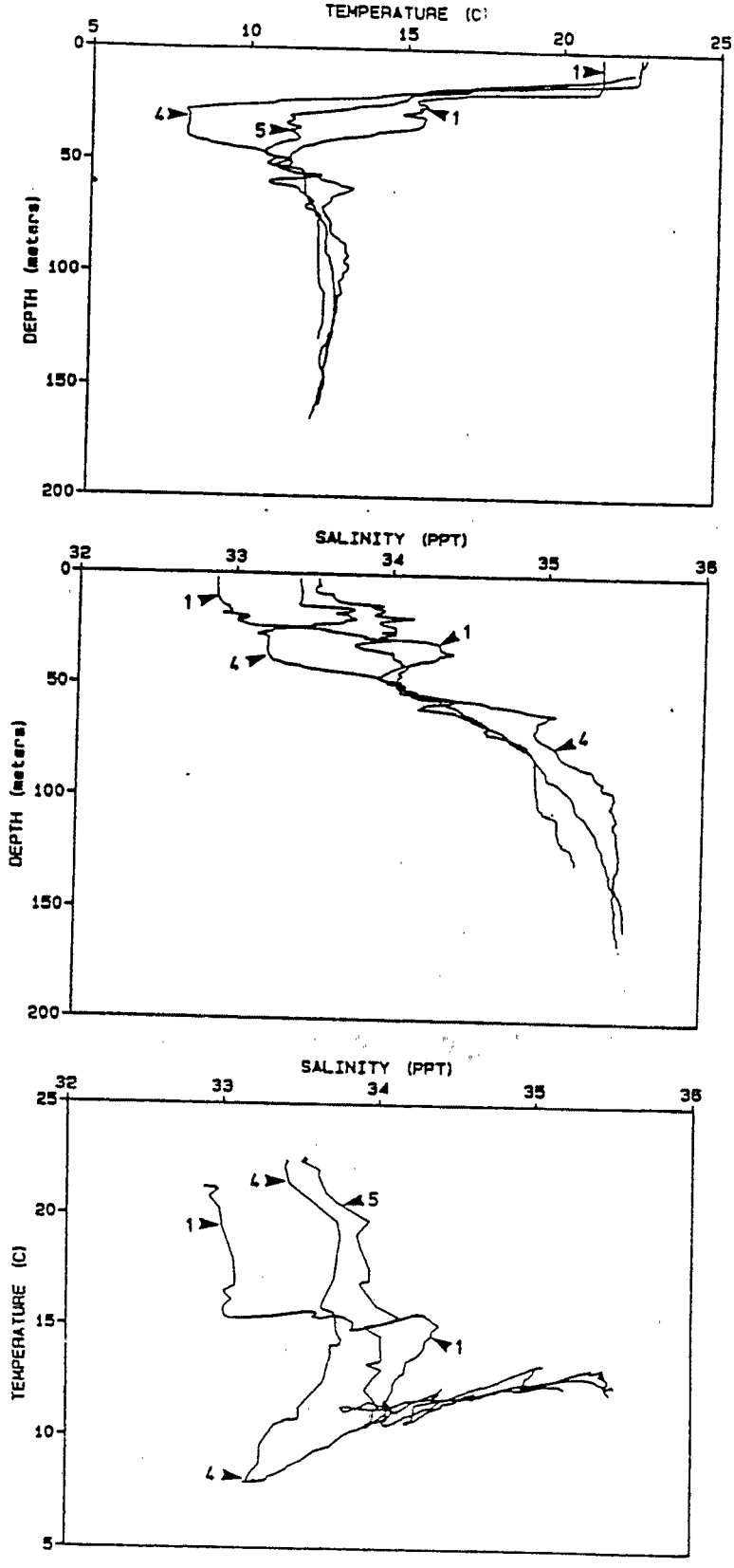

FIGURE B-2. COMPOSITE OF HYDROGRAPHIC PROFILE RESULTS FROM STATIONS 1, 4 AND 5 (SEE FIGURE 4.1 FOR LOCATIONS): TEMPERATURE PROFILES (UPPER); SALINITY PROFILES (MIDDLE); TEMPERATURE/SALINITY CORRELATIONS (LOWER).

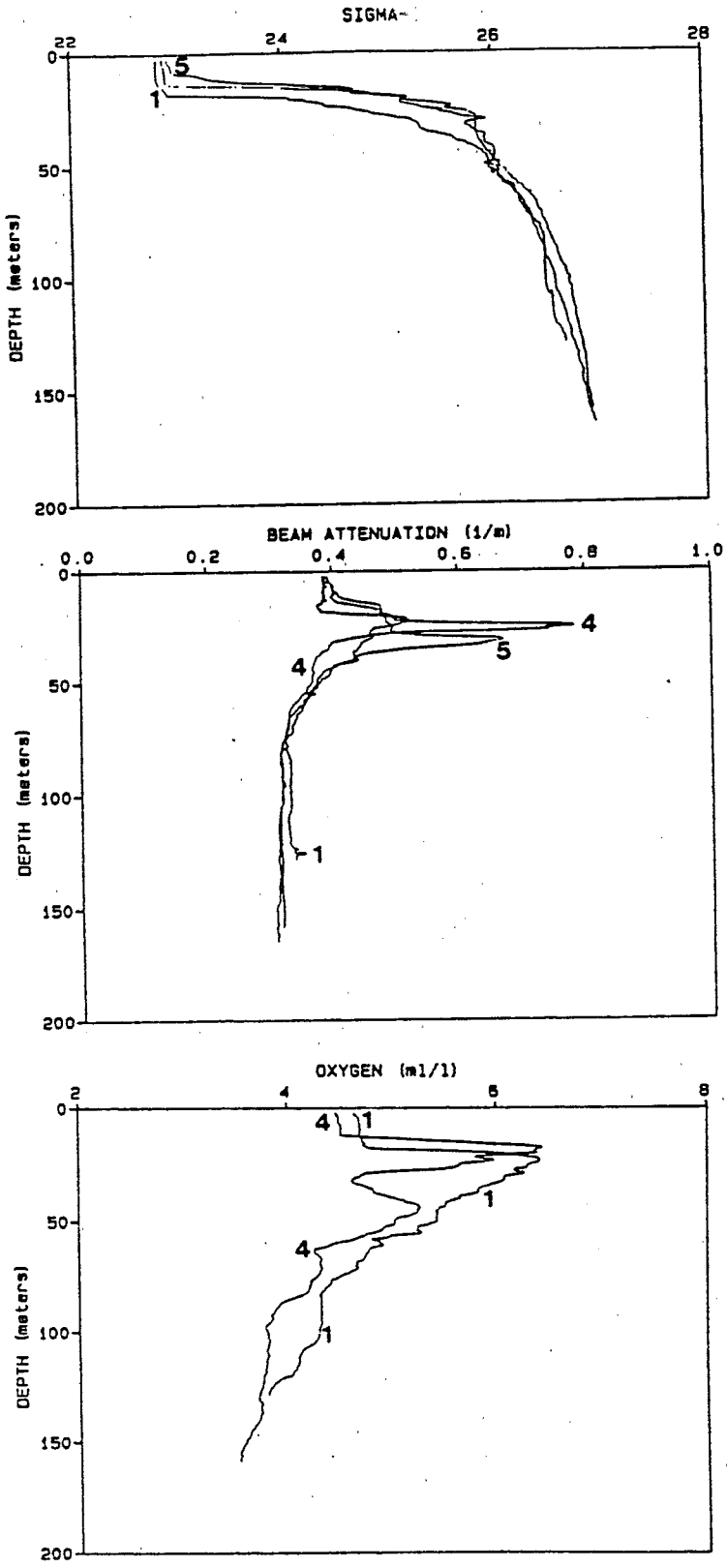

FIGURE B-3. COMPOSITE OF HYDROGRAPHIC PROFILE RESULTS FROM STATIONS 1, 4 AND 5: SIGMA-T PROFILES (UPPER); BEAM ATTENUATION PROFILES (MIDDLE); OXYGEN PROFILES (LOWER).

the CTD profiling system measured the percent extinction of light along a 25-cm pathlength, but light extinction (L) is exponentially related to total suspended solids and is, therefore, misleading for quantitative interpretations of sludge concentrations. The relationship between the beam attenuation coefficient (A) and measured light extinction (L) is given by the expression:

$$L = e^{-0.25A}$$

or

$$A = -4 \ln L$$

where L ranges from 0 to 1.0, 0.25 represents the pathlength in meters, and A is expressed in units of meters^{-1} (m^{-1}).

The vertical profiles of beam attenuation shown in Figure B-3 exhibit consistent values within the surface mixed layer and below 50 m but, within the seasonal pycnocline, a great deal of variability was observed among the three transect stations. Between 20 and 50 m, beam attenuation was significantly greater than values above and below the pycnocline, and at the offshore stations (4 and 5), a very thin (<10 m) layer of relatively high-beam attenuation was highly pronounced. These high values were associated with the base of the seasonal pycnocline and, at Station 4, the highest values were observed at the upper boundary of the "cold pool" water.

Relatively high values of beam attenuation in the seasonal pycnocline off the U.S. east coast have been observed by other investigators. As part of the Shelf Edge Exchange Program (SEEP), Churchill et al. (1988) reported similar values along a cross-slope transect south of New England. The relatively high beam attenuation values were attributed to natural particulate matter, but additional sampling and laboratory analyses are required to ascertain the composition of this material. From the work of Churchill et al. (1988), it can be determined that beam attenuation values of 0.7 m^{-1} correspond to suspended particulate concentrations on the order of 0.5 mg/L. These concentrations are low compared to suspended loads in coastal and shelf waters, but in a water column composed of relatively clear slope water, elevated concentrations of particulates are an excellent

indication of physical and biological processes governing the vertical transport of particulate material.

Vertical profiles of dissolved oxygen concentration at Stations 1 and 4 are presented in the lower panel of Figure B-3. These profiles illustrate that mixed-layer oxygen concentrations are on the order of 4.5 ml/l, but within the seasonal pycnocline (at 20 to 25 m) oxygen concentrations exceed 6 ml/l. These oxygen concentrations represent approximately 110 percent saturation which is maintained by high biological productivity within the pycnocline. Below this near-surface oxygen maximum, concentrations at Station 1 decrease nearly monotonically to 150 m. In contrast, oxygen concentrations below the pycnocline at Station 4 exhibit large inversions due to lateral interleaving of water masses. Note, for example, that the oxygen minimum near 35 m coincides with the cold, fresh water of the "cold pool" water mass discussed above. Relatively low oxygen concentrations within the "cold pool" are consistent with the hypothesis that this water parcel has "aged" since contact with the sea surface during the prior winter, and that biological consumption has significantly reduced its dissolved oxygen concentration.

It is important to point out that dissolved oxygen concentrations within and below the seasonal pycnocline at the 106-Mile Site (in summer) are highly variable due to natural biological processes and water mass advection. Horizontal variations within the mixed layer may be small, but variations of 0.5 mL/L over horizontal distances of a few kilometers may be expected beneath the pycnocline. This background variability must be better understood if estimates are to be made of the depletion of oxygen due to the discharge of sludge at the 106-Mile Site.

To illustrate the vertical and horizontal variations in hydrographic properties along the eastbound CTD transect, Figure B-4 presents vertical sections of temperature (top), salinity (middle), and sigma-t (bottom) along a line connecting Stations 1 through 6 (see Figure B-1 for positions). These two-dimensional diagrams have been objectively contoured using a spline function for vertical and horizontal smoothing. Consequently, some of the most extreme (and thin) property anomalies have been smoothed out, but the general characteristics of each property field are well represented.

The temperature section presented in Figure B-3 illustrates the sharp seasonal thermocline situated between approximately 15 and 30 m. Vertical temperature gradients vary somewhat across the transects, but the near-surface thermocline is relatively horizontal across the entire transect. The only major temperature feature that is evident beneath the thermocline is the parcel of "cold pool" water situated at 35 m beneath Stations 4 and 5. This coincides with the low-salinity feature observed in the salinity section (middle panel) of Figure B-4. In general, salinities increase with depth over the upper 150 m of the water column in this region. The increase in near-surface salinities from Station 1 to Station 3 represents the boundary between shelf and slope waters along the transect.

The lower panel of Figure B-4 presents the two-dimensional density (sigma-t) field along the eastbound CTD transect. Sharp vertical density gradients between 15 and 35 m correspond with the seasonal pycnocline; vertical gradients below this level are much weaker. The density transect reveals a relatively consistent pycnocline across the entire transect from Station 1 to Station 6. Only a gradual rise in the pycnocline depth can be detected from Station 1 to Station 5. If there were no currents in the lower part of the water column, then the offshore rise of the pycnocline would be indicative of a southward current within the near-surface layers across the transect, but additional, wide-area current information would be required to resolve this current structure. Likewise, deepening of the pycnocline from Station 5 to Station 6 may represent northward near-surface flow, but a longer transect would be required to support this assumption. Both the temperature and density fields do, however, clearly illustrate that a warm-core Gulf Stream eddy did not occupy the northern portion of the 106-Mile Site on August 31, 1987. Had an eddy been present, isotherms and isopycnals would have sloped sharply downward due to the relatively warm and less-dense waters contained within warm-core eddies.

Figure B-5 presents vertical sections of beam attenuation and dissolved oxygen similar to those presented in Figure B-4. The upper panel clearly illustrates that beam attenuation (natural turbidity) is highest within the seasonal pycnocline (20 to 40 m). Maximum values are observed at Stations 4 and 5, in association with the "cold pool" as discussed previously.

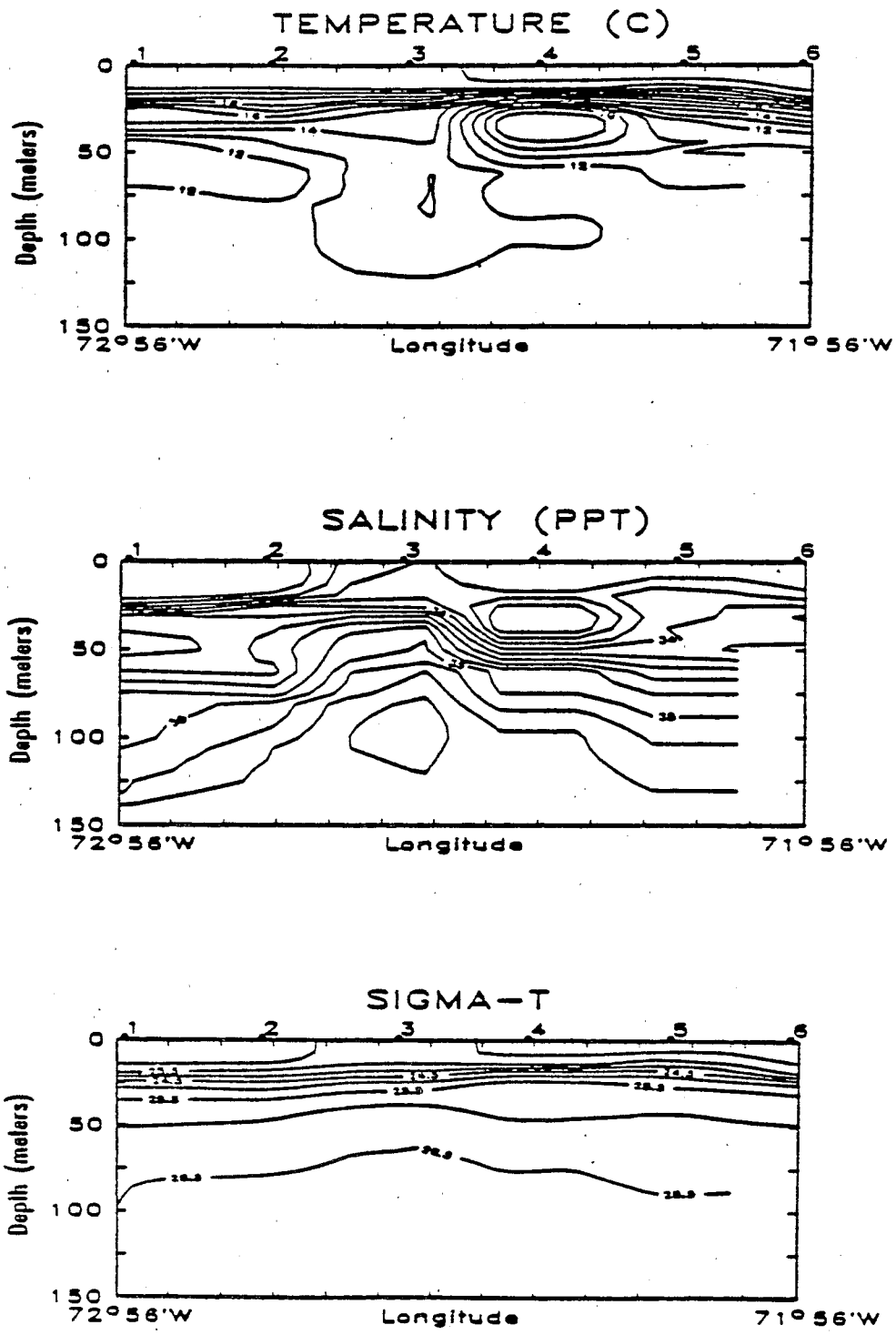

FIGURE B-4. VERTICAL TRANSECT OF HYDROGRAPHIC PROPERTIES ALONG EASTBOUND CTD TRANSECT (SEE FIGURE 4.1 FOR STATION LOCATIONS): TEMPERATURE (UPPER); SALINITY (MIDDLE); SIGMA-T (LOWER).

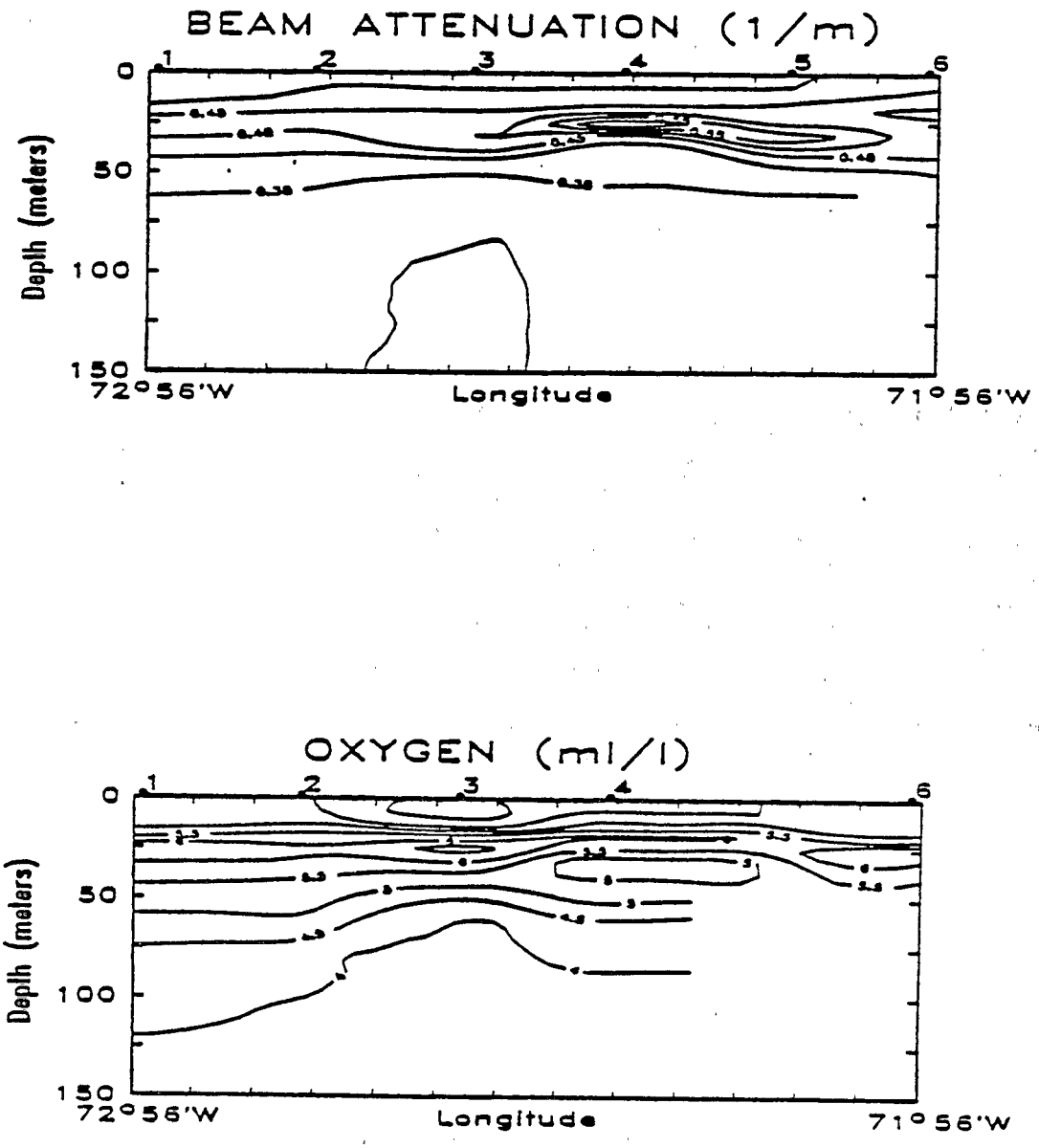

FIGURE B-5. VERTICAL TRANSECT OF HYDROGRAPHIC PROPERTIES ALONG EASTBOUND CTD TRANSECT: BEAM ATTENUATION (UPPER); OXYGEN (LOWER).

The lower panel of Figure B-5 presents oxygen data for Stations 1 through 4 and Station 6 (oxygen data are not available from Station 5 due to a problem with the pump which delivers water to the oxygen sensor of the Sea Bird CTD system). The highest oxygen concentrations (>6 ml/l) are found within a thin layer that coincides with the seasonal pycnocline. Horizontal gradients are rather weak, as observed for the other water properties.

To summarize, the hydrographic data collected along the eastbound CTD transect to the 106-Mile Site revealed the following background conditions:

- All hydrographic observations were typical for summer conditions at the 106-Mile Site, as deduced by comparison with past studies along the U.S. East Coast.
- A sharp seasonal pycnocline was situated between roughly 20 and 40 m along the entire transect that included the northern portion of the 106-Mile Site.
- The upper 150 m of the water column at the 106-Mile Site was composed of slope water; only a thin (20 m) layer of shelf water was observed east (inshore) of 72°40'W longitude, a distance of 25 nm west of the 106-Mile Site.
- Temperature/salinity and oxygen analyses indicated extensive lateral (isopycnal) mixing of water masses within and below the seasonal pycnocline.
- Natural turbidity levels were highest within the seasonal pycnocline.
- The water column structure and properties in the vicinity of the 106-Mile Site indicate that a warm-core Gulf Stream eddy was not present, at least during the first day of the survey (August 31, 1987).

Water Masses During Plume-Tracking Surveys

Because the primary objective of the hydrographic profiling made during the individual plume tracking surveys was to acquire data within the sludge plumes, few hydrographic profiles were made in "clean" background water. It is, however, informative to look at data from a few stations during each of the three days of survey operations for the purpose of illustrating the variability in background properties of temperature, salinity, density, and

dissolved oxygen. Figure B-6 presents a composite of four density (sigma-t) profiles, each obtained during one of the four plume tracking surveys (DB-1, DB-2, DB-3, and DB-4). The individual profiles were separated by roughly 20 h as indicated below:

Survey	CTD Profile	Profile Depth (m)	Date	Time
DB-1	1-5	59	9-1-87	1710
DB-2	2-1	67	9-2-87	1556
DB-3	3-6	55	9-3-87	1140
DB-4	4-2	56	9-4-87	0639

Figure B-6 illustrates that the depth (thickness) of the surface mixed layer remained very constant (between 11 and 14 m) over the four days of surveying. The shape of the seasonal pycnocline varied somewhat but, in general, strong vertical density gradients were evident between 15 and 35 m. It will be shown in Section 4.3.3 that initial mixing within the sludge plumes penetrated to the base of the mixed layer, but the sludge was apparently less dense than the waters of the seasonal pycnocline and, consequently, plume waters were not observed below approximately 20 m.

Figure B-7 presents a composite of temperature/salinity (T/S) profiles from each of the four plume surveys. These profiles demonstrate that near-surface T/S properties varied greatly during individual plume surveys, as well as from survey to survey (day to day). Profile depths and times are given below:

Survey	CTD Profile	Profile Depth (m)	Date	Time
DB-1	1-2	45	9-1-87	1407
DB-1	1-6	26	9-1-87	1732
DB-2	2-1	67	9-2-87	1556
DB-2	2-3	67	9-2-87	2054
DB-3	3-1	67	9-3-87	0816
DB-3	3-6	55	9-3-87	1140
DB-4	4-2	56	9-4-87	0639

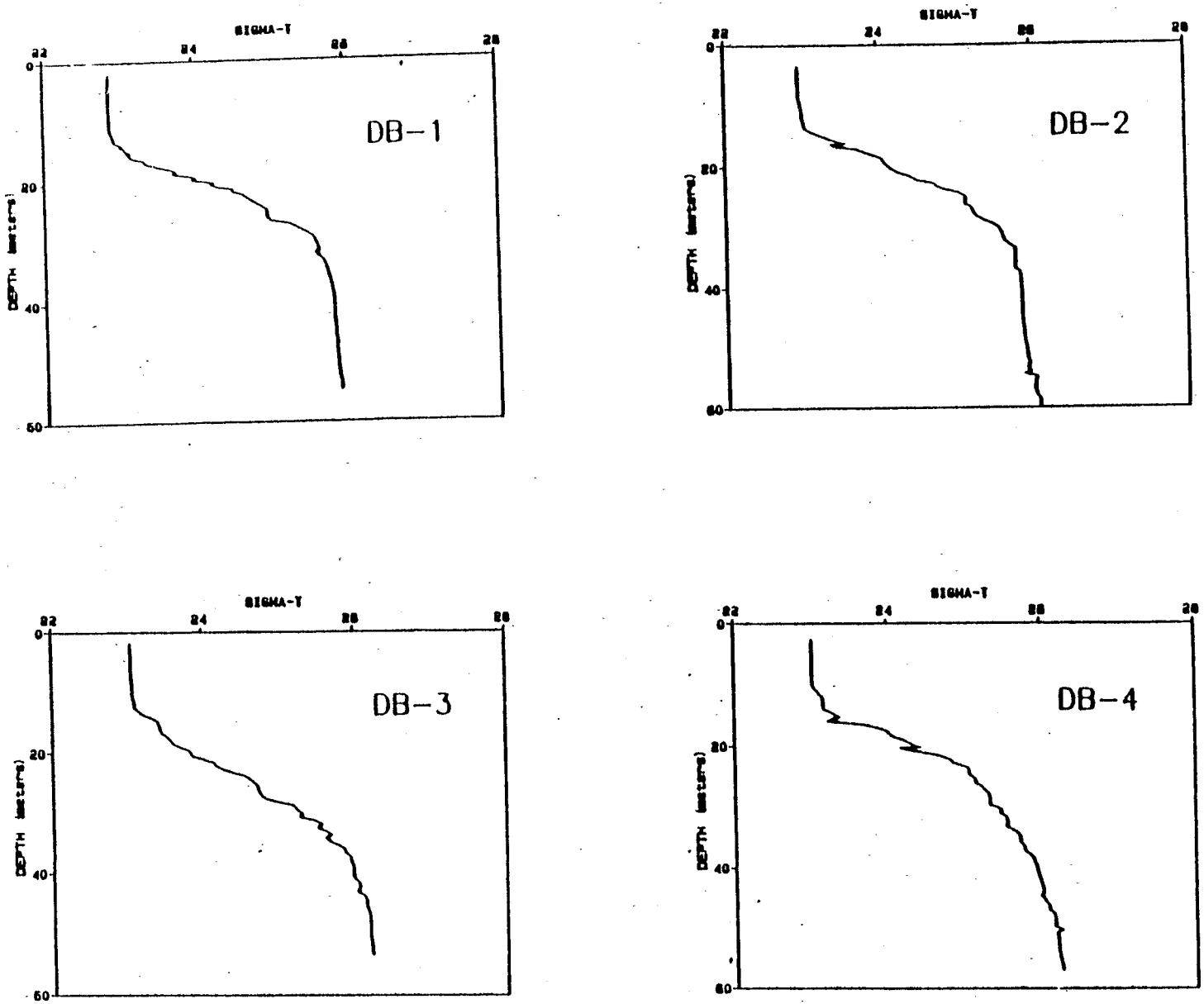

FIGURE B-6. COMPOSITE OF REPRESENTATIVE SIGMA-T (DENSITY) PROFILES FOR THE FOUR PLUME SURVEYS (DB-1 THROUGH DB-4).

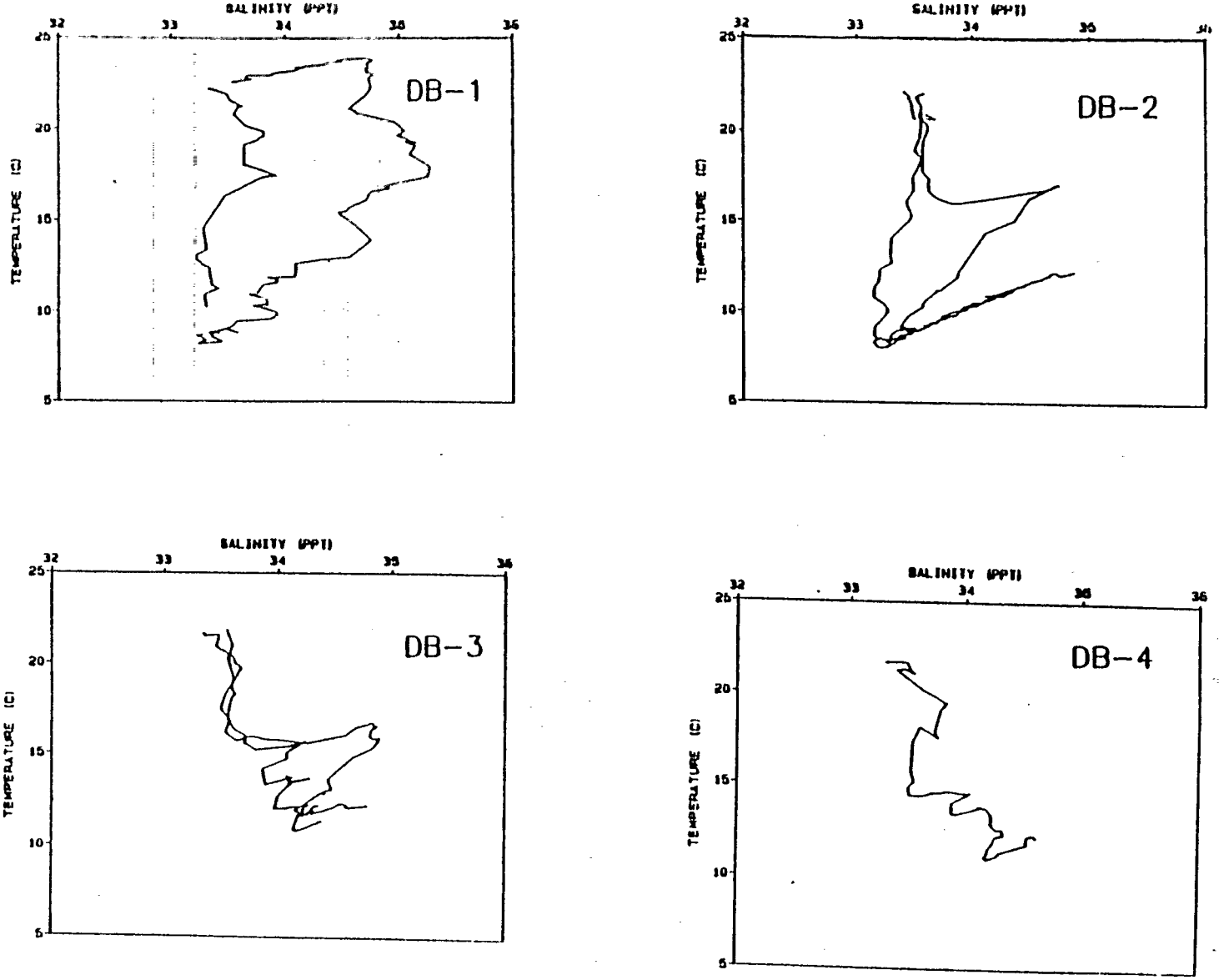

FIGURE B-7. COMPOSITE OF REPRESENTATIVE TEMPERATURE/SALINTIY DIAGRAMS FROM STATIONS MADE DURING EACH OF THE FOUR PLUME SURVEYS.

During the first plume survey (DB-1), seven of nine total CTD profiles exhibited nearly isohaline (constant salinity) properties from the surface to approximately 40 m (a temperature range from 22 to 10°C). These characteristics are represented by profile 1-6. Profile 1-2, which was made a few hours earlier and 4 miles to the south of profile 1-6, had near-surface salinities that were more than 1 ppt greater than shown by the other profiles. These high salinities indicate that waters of Gulf Stream origin resided within the 106-Mile Site on September 1, 1987, most likely as a result of water that had been advected into the region during the earlier passage of warm-core eddy "87-E," (Note that the two profiles shown for survey DB-1 did not extend as deep as those shown for other surveys in Figure B-8.)

The near-surface T/S profiles obtained during plume survey DB-2 exhibited a similar trend of normal slope water (nearly isohaline from 22 to 8°C) interrupted by subsurface layers of relatively saline Gulf Stream waters within the temperature range from 9 to 17°C. The upper right panel of Figure B-8 illustrates a typical slope water T/S profile (2-1) and a profile with highly saline waters from 17 to 9°C (2-3). The T/S properties at the surface and at depths greater than 40 m were, however, the same at both stations. The L-shaped T/S profile of cast 2-1, having temperature and salinity minima near 8°C, is typical of slope water characteristics during summer.

The T/S characteristics during plume surveys DB-3 and DB-4 (lower panels of Figure B-7) indicate that, within the upper 60 m of the water column, slope waters had been displaced by relatively saline waters of Gulf Stream origin. For survey DB-3, all 16 CTD profiles had T/S properties that were bracketed by the properties of the two profiles shown (3-1 and 3-6). The temperature and salinity minima of the slope water were clearly absent, and the highest salinities were observed near 16°C, similar to profile 2-3 made during survey DB-2. Only one CTD profile (No. 4-2) to a depth of 50 m was obtained during survey DB-4, but it also had T/S characteristics similar to those of survey DB-3.

These T/S results illustrate that, during the 4-day period from September 1 through 4, 1987, near-surface waters of Gulf Stream origin entered the northern portion of the 106-Mile Site, probably as a result of

warm-core eddy "87-E" that was situated southeast of the site and presumably moving toward the southwest.

Although the T/S properties of the upper 50 m of the water column at the 106-Mile Site varied greatly during the 4-day survey, temporal variations in the dissolved oxygen profile were small, as had been observed for density (sigma-t) profiles shown in Figure B-6. For example, Figure B-8 presents vertical profiles of oxygen and percent oxygen saturation for profile 1-1 of survey DB-1 and for profile 3-6 of survey DB-3. Small variations can be observed in the thickness of the subsurface oxygen maximum (near 20 m depth), but oxygen concentrations above and below this level were very similar. Oxygen characteristics of the other 28 CTD profiles made during the four-day survey were very similar to those shown in Figure B-8.

Profiles of percent oxygen saturation, calculated from the equation of Weiss (1970), are shown in the two right panels of Figure B-8. For these and other profiles, surface oxygen concentrations were roughly 90 percent saturated, whereas, at the depth of the subsurface oxygen maximum, saturation values exceeded 110 percent. This is a common feature within the seasonal pycnocline of the slope water and the entire northwestern Atlantic during summer. The high oxygen concentrations are simply a result of exceptionally high photosynthetic productivity within the nutrient-rich seasonal pycnocline.

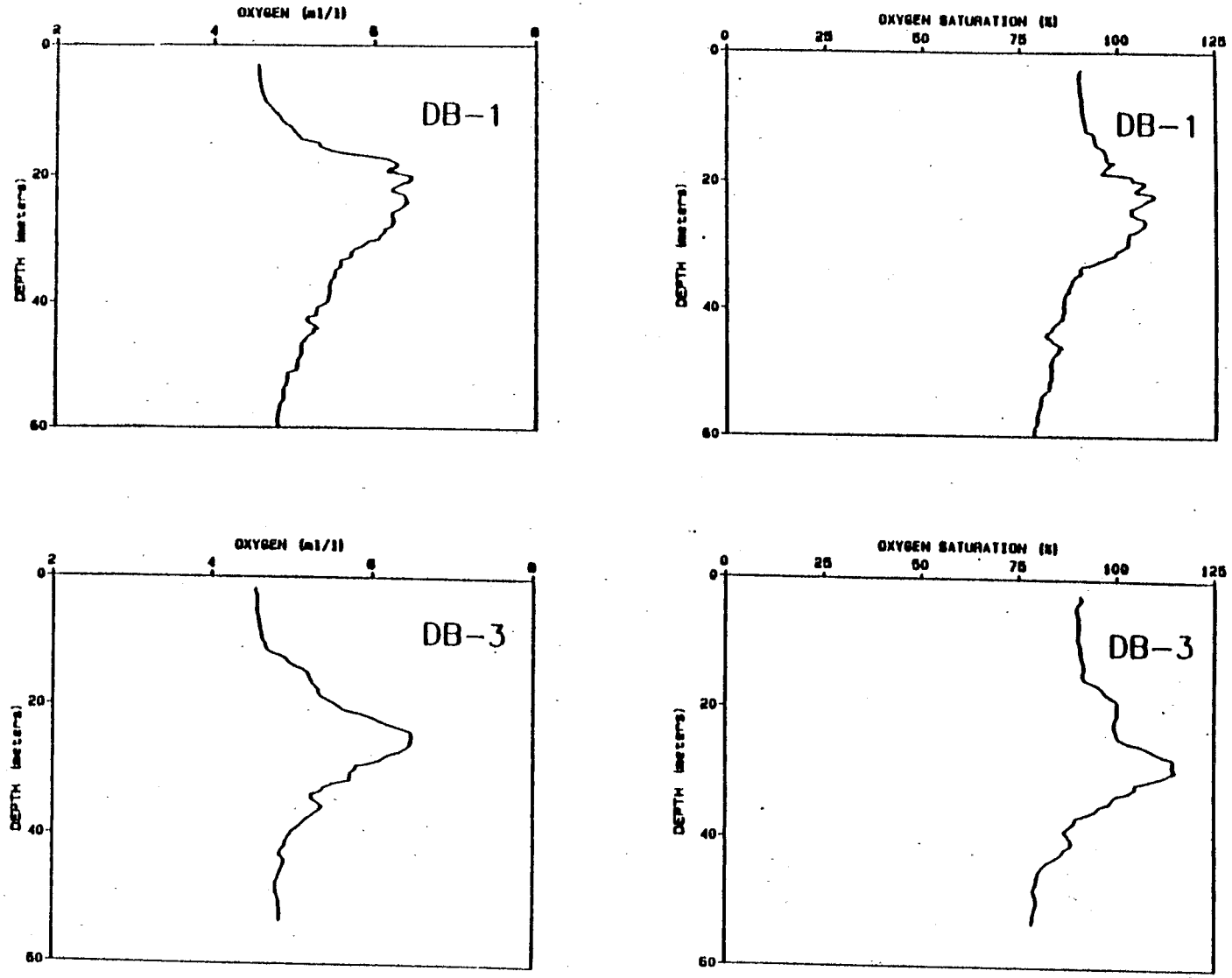

FIGURE B-8. COMPOSITE OF REPRESENTATIVE OXYGEN AND OXYGEN SATURATION PROFILES FROM PLUME SURVEYS DB-1 AND DB-3.

APPENDIX C

BACKGROUND DATA

TABLE C-1. TOTAL SUSPENDED SOLIDS, TURBIDITY, AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FOR BACKGROUND DATA DURING THE SEPTEMBER PLUME TRACKING

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD (m^{-1})
S-8	6.0	1	AAD855	2119	NA	0.36		NA	NA	NA	NA
S-8	6.0	2	AAD855	2119	NA	0.42		NA	NA	NA	NA
S-8	6.0	3	AAD855	2119	NA	0.32		NA	NA	NA	NA
S-8	41.0	1	AAD856	2048	NA	0.40		11.38	2.72	0.68	0.11
S-8	41.0	2	AAD856	2048	NA	0.35		12.21	0.098	0.52	0.004
S-8	41.0	3	AAD856	2048	NA	0.93		12.3	0.078	0.53	0.003
DB-1	6.0	1	AAD857	0758	-8.83	0.20		NA	NA	NA	NA
DB-1	6.0	2	AAD857	0758	-8.83	0.17		NA	NA	NA	NA
DB-1	6.0	3	AAD857	0758	-8.83	0.16		NA	NA	NA	NA
DB-1	19.4	1	AAD858	0818	-8.50	0.28		11.28	0.12	0.48	0.005
DB-1	19.4	2	AAD858	0818	-8.50	0.26		11.08	0.73	0.47	0.003
DB-1	19.4	3	AAD858	0818	-8.50	0.28		11.45	0.68	0.49	0.027
DB-1	33.0	1	AAD859	0826	-8.37	0.38		13.96	0.52	0.60	0.021
DB-1	33.0	2	AAD859	0826	-8.37	0.46		13.44	0.65	0.58	0.026
DB-1	33.0	3	AAD859	0826	-8.37	0.41		14.45	0.45	0.62	0.018
DB-2	6.0	1	AAD874	0752	-2.58	1.29		NA	NA	NA	NA
DB-2	6.0	2	AAD874	0752	-2.58	R	a	NA	NA	NA	NA
DB-2	6.0	3	AAD874	0752	-2.58	4.19		NA	NA	NA	NA
DB-2	20.4	1	AAD879	2108	a	R	b	11.74	0.13	0.50	0.005
DB-2	20.4	2	AAD879	2108	a	0.27		11.74	0.13	0.50	0.005
DB-2	20.4	3	AAD879	2108	a	0.29		11.83	0.09	0.50	0.004
DB-2	24.0	1	AAD883	2118	a	0.22	c	12.92	0.47	0.55	0.019
DB-2	24.0	2	AAD883	2118	a	0.26	c	13.45	8.8	0.58	0.369
DB-2	24.0	3	AAD883	2118	a	0.76	c	12.51	0.19	0.53	0.008

TABLE C-2. BACKGROUND WATER QUALITY *C.perfringens* ANALYSES, 106-MILE SITE, SEPTEMBER 1987

Sample ID	Plume or Event	Rep. No.	Depth (m)	Start Time	Time After T=0 (h)	*C. perfringens* (Counts/100 mL)
AAD855	S-8	1	6.0	2119	NA	0.00
AAD855	S-8	2	6.0	2119	NA	0.00
AAD855	S-8	3	6.0	2119	NA	0.00
AAD856	S-8	1	41.0	2048	NA	0.00
AAD856	S-8	2	41.0	2048	NA	0.00
AAD856	S-8	3	41.0	2048	NA	0.00
AAD857	DB-1	1	6.0	0758	-8.83	0.00
AAD857	DB-1	2	6.0	0758	-8.83	0.00
AAD857	DB-1	3	6.0	0758	-8.83	0.00
AAD859	DB-1	1	33.0	0826	-8.37	0.00
AAD859	DB-1	2	33.0	0826	-8.37	0.00
AAD859	DB-1	3	33.0	0826	-8.37	0.00
AAD874	DB-2	1	6.0	0752	-2.58	17.94
AAD874	DB-2	2	6.0	0752	-2.58	29.31
AAD874	DB-2	3	6.0	0752	-2.58	82.94
AAD879	DB-2	1	20.4	2108	a	1.31
AAD879	DB-2	2	20.4	2108	a	5.13
AAD879	DB-2	3	20.4	2108	a	9.31
AAD883	DB-2	1	24.0	2118	a	4.81
AAD883	DB-2	2	24.0	2118	a	1.44
AAD883	DB-2	3	24.0	2118	a	5.63
AAD884	DB-3	1	6.0	0839	-2.53	1.44
AAD884	DB-3	2	6.0	0839	-2.53	1.38
AAD884	DB-3	3	6.0	0839	-2.53	1.06
AAD916	DB-4	1	6.0	0640	b	0.00
AAD916	DB-4	2	6.0	0640	b	0.00
AAD916	DB-4	3	6.0	0640	b	0.00
AAD917	DB-4	1	12.0	0650	b	0.06
AAD917	DB-4	2	12.0	0650	b	0.13
AAD917	DB-4	3	12.0	0650	b	0.06
AAD918	DB-4	1	19.1	0701	b	0.00
AAD918	DB-4	2	19.1	0701	b	0.13
AAD918	DB-4	3	19.1	0701	b	0.00

[a]Intitial Sampling For Plume DB-2.
[b]Initial Sampling For Plumes DB-3 and DB-4.

TABLE C-1. (Continued).

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD (m^{-1})
DB-3	6.0	1	AAD884	0839	-2.53	0.17		NA	NA	NA	NA
DB-3	6.0	2	AAD884	0839	-2.53	0.13		NA	NA	NA	NA
DB-3	6.0	3	AAD884	0839	-2.53	0.23		NA	NA	NA	NA
DB-4	6.0	1	AAD916	0640	b	0.43	d	10.06	0.03	0.42	0.001
DB-4	6.0	2	AAD916	0640	b	0.16	d	10.06	0.03	0.42	0.001
DB-4	6.0	3	AAD916	0640	b	0.42	d	10.06	0.03	0.42	0.001
DB-4	12.0	1	AAD917	0650	b	0.19		10.04	0.027	0.42	0.001
DB-4	12.0	2	AAD917	0650	b	0.11		10.04	0.027	0.42	0.001
DB-4	12.0	3	AAD917	0650	b	0.25		10.04	0.027	0.42	0.001
DB-4	19.1	1	AAD918	0701	b	0.18		10.56	0.048	0.45	0.002
DB-4	19.1	2	AAD918	0701	b	0.14		10.56	0.048	0.45	0.002
DB-4	19.1	3	AAD918	0701	b	0.25		10.56	0.048	0.45	0.002

[a]Invalid tare weight, no apparent explanation, data rejected.
[b]Unknown particle contamination, data rejected.
[c]Unexplained sample heterogeneity for these replicates.
[d]Amount of material on filter varies visibly in proportion to the TSS value for these samples.

TABLE C-3. BACKGROUND WATER QUALITY METALS ANALYSES, 106-MILE SITE, SEPTEMBER 1987

Sample Depth (m)	Time After T=0 (h)	Rep. No.	Ag[a]	As[b]	Cd[a]	Cr[a]	Cu	Fe[a]	Ni	Pb	Se[b]	Zn[a]	Hg
			(µg/L)										(ng/L)
S-8, Out-of-Site Control													
6.0	NA	2	0.002	1.02	0.013	0.148	0.176	0.246	0.265	0.020	<0.03	0.034	c
6.0	NA	3	0.013	0.95	0.013	0.132	0.171	0.202	0.251	0.024	<0.03	0.034	4.72
DB-2, Predump Control													
6.0	-2.58	1	0.006	1.18	0.014	0.142	0.227	0.938	0.240	0.033	<0.03	0.091	7.03
6.0	-2.58	2	0.013	1.04	0.022	0.224	0.508	3.437	0.261	0.083	<0.03	0.312	3.88
6.0	-2.58	3	c	1.06	0.033	0.284	1.026	7.696	0.347	0.180	<0.03	0.761	8.30
24.0	d	1	c	1.04	0.021	0.129	0.150	0.579	0.228	0.015	<0.03	0.210	8.49
24.0	d	2	0.005	1.29	0.028	0.153	0.160	0.727	0.239	0.012	<0.03	0.178	5.84
24.0	d	3	0.012	1.15	0.027	0.115	0.159	0.701	0.245	0.012	<0.03	0.164	12.8
DB-3, Predump Control													
6.0	-2.53	1	c	0.99	0.015	0.108	0.173	0.267	0.263	0.022	<0.03	0.021	8.65
6.0	-2.53	2	0.003	0.93	0.013	0.128	0.164	0.224	0.272	0.021	<0.03	0.021	11.43
6.0	-2.53	3	0.020	0.95	0.010	0.125	0.258	0.231	0.245	0.015	<0.03	0.001	8.40

NA = Not applicable.
[a]Blank corrected.
[b]Analyzed by hydride generation.
[c]Concentration less than procedural blank.
[d]Initial sampling for DB-2 and DB-3.

TABLE C-4. TOTAL SUSPENDED SOLIDS, TURBIDITY, AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FROM SEWAGE PLUME DB-4 AT THE 106-MILE SITE DURING SEPTEMBER, 1987.

Plume or %	Depth (m)	Rep No.	Sample Time	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD
DB4	6.0	1	AAD912	0001	0.00	13.00		42.02	0	2.18	0
DB4	6.0	2	AAD912	0001	0.00	24.01		42.02	0	2.18	0
DB4	6.0	3[a]	AAD912	0001	0.00	0.34	b	NA	NA	NA	NA
DB4	6.0	1	AAD913	0443	4.72	3.49	c	17.84	0.25	0.79	0.010
DB4	6.0	2	AAD913	0443	4.72	0.17		17.84	0.25	0.79	0.010
DB4	6.0	3	AAD913	0443	4.72	1.47		17.84	0.25	0.79	0.018
DB4	10.5	1	AAD914	0443	4.72	1.57	c	15.46	0.75	0.67	0.030
DB4	10.5	2	AAD914	0443	4.72	0.79		15.46	0.75	0.67	0.030

NA = Not available.
[a]Mean of duplicate analysis.
[b]Sampled at plume periphery.
[c]Appearance of filtered material is in proportion to variability in turbidity.

TABLE C-5. BACKGROUND WATER QUALITY PESTICIDE ANALYSES, 106-MILE SITE, SEPTEMBER 1987

Event	Depth (m)	Rep. No.	Time After T=0	α-BHC	γ-BHC
S8	6.0	1	BKG	0.068	0.046
S8	6.0	2	BKG	-	-
DB-2	6.0	1	BKG	1.10	0.65
DB-2	6.0	2	BKG	1.05	0.47
DB-2	6.0	3	BKG	1.24	0.72
DB-2	24.5	1	BKG	1.15	0.99
DB-2	24.5	2	BKG	0.26	0.46
DB-2	24.5	3	BKG	0.16	0.31
DB-3	6.0	1	BKG	3.41	1.74
DB-3	6.0	2	BKG	9.41	2.52
DB-3	6.0	3	BKG	2.20	1.22

BKG denotes background samples.

Compounds not found: heptachlor, aldrin, heptachlor epoxide, α-endosulfan, dieldrin, p,p'-DDE, endrin aldehyde, β-endosulfan sulfate, p,p'-DDD, endrin, endosulfan, p,p'-DDT,

TABLE C-6. CONCENTRATION OF PCBs FOUND AT BACKGROUND STATIONS AT THE 106-MILE SITE, SEPTEMBER 1987 (ng/L)

Plume	Depth (m)	Rep. No.	Time After T=0 (h)	Cl_9(206)
S8	6.0	1	BKG	-
S8	6.0	2	BKG	-
DB-2	6.0	1	BKG	-
DB-2	6.0	2	BKG	-
DB-2	6.0	3	BKG	-
DB-2	24.5	1	BKG	0.035
DB-2	24.5	2	BKG	-
DB-2	24.5	3	BKG	0.027
DB-3	6.0	1	BKG	0.055
DB-3	6.0	2	BKG	0.066
DB-3	6.0	3	BKG	0.062

Compounds not found: Cl_2(08), Cl_3(18), Cl_3(18), Cl_4(52), Cl_4(44), Cl_4(66), Cl_5(101), Cl_5(118), Cl_6(153), Cl_5(105), Cl_6(138), Cl_6(187), Cl_6(128), Cl_7(180), Cl_7(170), Cl_8(195)

APPENDIX D

SUMMARY OF LABORATORY ANALYSES FOR DUMPING EVENTS DB-1, DB-2, AND DB-3, 106-MILE SITE, SEPTEMBER 1987

TABLE D-1. TOTAL SUSPENDED SOLIDS, TURBIDITY AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FROM SEWAGE PLUME DB-1 AT THE 106-MILE SITE DURING SEPTEMBER, 1987

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD (m^{-1})
DB-1	6.0	1	AAD869	1648	0.00	11.39		46.3	11.13	2.49	0.47
DB-1	6.0	2	AAD869	1648	0.00	17.38		46.3	11.13	2.49	0.47
DB-1	6.0	3	AAD869	1648	0.00	-	a	46.3	11.13	2.49	0.47
DB-1	6.0	1	AAD870	1702	0.23	7.42		NA	NA	NA	NA
DB-1	6.0	2	AAD870	1702	0.23	6.88		NA	NA	NA	NA
DB-1	6.0	3	AAD870	1702	0.23	-	b	NA	NA	NA	NA
DB-1	6.0	1	AAD866	1738	0.83	5.81		40.00	1.12	2.01	0.045
DB-1	6.0	2	AAD866	1738	0.83	6.59		40.00	1.12	2.01	0.045
DB-1	6.0	3	AAD866	1738	0.83	5.14		40.00	1.12	2.01	0.045
DB-1	21.8	1	AAD867	1740	0.87	0.20	c	12.85	0.046	0.55	0.002
DB-1	21.8	2	AAD867	1740	0.87	0.72		12.89	0.074	0.55	0.003
DB-1	21.8	3	AAD867	1740	0.87	1.04		13.00	0.16	0.56	0.007
DB-1	6.0	1	AAD871	1823	1.55	1.59		23.89	1.42	1.09	0.057
DB-1	6.0	2	AAD871	1823	1.55	2.28		23.89	1.42	1.09	0.057
DB-1	6.0	3	AAD871	1823	1.55	1.56		23.89	1.42	1.09	0.057
DB-1	22.3	1	AAD872	1826	1.60	0.17		12.76	0.05	0.55	0.002
DB-1	22.3	2	AAD872	1826	1.60	0.32		12.72	0.08	0.54	0.003
DB-1	22.3	3	AAD872	1826	1.60	0.30		12.31	0.31	0.53	0.012
DB-1	6.0	1	AAD875	1843	1.92	3.40		NA	NA	NA	NA
DB-1	6.0	2	AAD875	1843	1.92	2.52		NA	NA	NA	NA
DB-1	6.0	3	AAD875	1843	1.92	2.26		NA	NA	NA	NA
DB-1	6.0	1	AAD876	1941	2.88	1.06		17.27	0.27	0.76	0.011
DB-1	6.0	2	AAD876	1941	2.88	1.03		17.27	0.27	0.76	0.011
DB-1	6.0	3	AAD876	1941	2.88	0.65	d	17.27	0.27	0.76	0.011
DB-1	20.3	1	AAD877	1950	3.03	0.37		13.73	0.73	0.59	0.029

[a]Invalid tare weight, data rejected.
[b]Filter torn, data rejected.
[c]Appearance of filtered material is in proportion to variability in turbidity.
[d]Sampled at plume periphery.
NA = Not Available.

TABLE D2. TOTAL SUSPENDED SOLIDS, TURBIDITY AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FROM SEWAGE PLUME DB-2 AT THE 106-MILE SITE ON SEPTEMBER 2, 1987

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m-1)	Beam Attenuation SD (m-1)
DB-2	6.0	1	AAD878	1027	0.00	19.23	a	46.02	4.16	2.47	0.170
DB-2	6.0	2	AAD878	1027	0.00	7.31	a	41.21	14.19	2.12	0.612
DB-2	6.0	3	AAD878	1027	0.00	4.39	a	NA	NA	NA	NA
DB-2	6.0	1	AAD881	1445	4.30	0.95	a	NA	NA	NA	NA
DB-2	6.0	2	AAD881	1445	4.30	0.31	a	NA	NA	NA	NA
DB-2	6.0	3	AAD881	1445	4.30	0.49	a	NA	NA	NA	NA
DB-2	10.7	1	AAD882	1742	7.25	0.54		15.33	1.84	0.67	0.075
DB-2	10.7	2	AAD882	1742	7.25	0.39	b	16.35	0.28	0.71	0.011
DB-2	10.7	3	AAD882	1742	7.25	0.84		16.09	0.77	0.70	0.031
DB-2	34.0	1	AAD880	1927	9.00	0.59		16.31	0.31	0.71	0.015
DB-2	34.0	2	AAD880	1927	9.00	0.39		16.01	0.33	0.70	0.013
DB-2	34.0	3	AAD880	1927	9.00	0.39		15.46	0.21	0.67	0.008

[a]Appearance of filtered material is in proportion to variability in turbidity.
[b]Sampled at plume periphery.

TABLE D-3. TOTAL SUSPENDED SOLIDS, TURBIDITY AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FROM SEWAGE PLUME DB-3 AT THE 106-MILE SITE DURING SPETEMBER 1987

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD (m^{-1})
DB-3	6.0	1	AAD885	1111	0.00	32.62		72.5	0.02	5.16	0.001
DB-3	6.0	2	AAD885	1111	0.00	-	a	NA	NA	NA	NA
DB-3	6.0	3	AAD885	1111	0.00	17.23	b	68.5	0.05	4.62	0.002
DB-3	6.0	1	AAD886	1130	0.32	34.30	c	67.6	0.097	4.51	0.004
DB-3	6.0	2	AAD886	1130	0.32	6.06	c	NA	NA	NA	NA
DB-3	6.0	3	AAD886	1130	0.32	3.70	c	NA	NA	NA	NA
DB-3	6.0	1	AAD900	1147	0.60	10.21		53.1	0.99	3.03	0.040
DB-3	6.0	2	AAD900	1147	0.60	9.43		53.1	0.99	3.03	0.040
DB-3	6.0	3	AAD900	1147	0.60	1.01	a	53.1	0.99	3.03	0.040
DB-3	20.0	1	AAD887	1148	0.62	0.53	b	11.17	0.12	0.47	0.005
DB-3	20.0	2	AAD887	1148	0.62	0.79		11.72	0.1	0.50	0.004
DB-3	20.0	3	AAD887	1148	0.62	0.82		11.5	0.19	0.49	0.008
DB-3	6.0	1	AAD891	1211	1.00	0.45	a	32.3	2.9	1.56	0.117
DB-3	6.0	2	AAD891	1211	1.00	1.12	a	32.3	2.9	1.56	0.117
DB-3	6.0	3	AAD891	1211	1.00	3.20		32.3	2.9	1.56	0.117
DB-3	20.6	1	AAD889	1222	1.18	0.16		11.08	0.05	0.47	0.002
DB-3	20.6	2	AAD889	1222	1.18	0.29		11.11	0.06	0.47	0.002
DB-3	20.6	3	AAD889	1222	1.18	-	d	11.13	0.08	0.47	0.002
DB-3	35.8	1	AAD890	1233	1.37	-	d	10.76	0.06	0.46	0.002
DB-3	35.8	2	AAD890	1233	1.37	0.06		11.18	0.47	0.47	0.019
DB-3	35.8	3	AAD890	1233	1.37	0.47		11.79	0.1	0.50	0.004
DB-3	6.0	1	AAD901	1242	1.35	1.62		21.09	0.46	0.95	0.019
DB-3	6.0	2	AAD901	1242	1.35	1.50		21.09	0.46	0.95	0.019
DB-3	6.0	3	AAD901	1242	1.35	1.75		21.09	0.46	0.95	0.019
DB-3	20.3	1	AAD902	1252	1.68	0.49		10.8	0.22	0.46	0.002
DB-3	20.3	2	AAD902	1252	1.68	0.29		11.17	0.25	0.47	0.009
DB-3	20.3	3	AAD902	1252	1.68	1.36	e	11.63	0.18	0.47	0.010

TABLE D-3. (Continued)

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m^{-1})	Beam Attenuation SD (m^{-1})
DB-3	36.2	1	AAD903	1247	1.77	0.31		10.69	0.05	0.45	0.002
DB-3	36.2	2	AAD903	1247	1.77	-	e	10.69	0.05	0.45	0.002
DB-3	36.2	3	AAD903	1247	1.77	0.33		10.68	0.05	0.45	0.002
DB-3	6.0	1	AAD892	1311	2.00	7.38		25.91	3.87	1.20	0.158
DB-3	6.0	2	AAD892	1311	2.00	1.63	b	25.91	3.87	1.20	0.158
DB-3	6.0	3	AAD892	1311	2.00	7.79		25.91	3.87	1.20	0.158
DB-3	20.1	1	AAD893	1326	2.25	0.21		12.24	1.28	0.52	0.052
DB-3	20.1	2	AAD893	1326	2.25	0.69	f	12.96	0.94	0.56	0.038
DB-3	20.1	3	AAD893	1326	2.25	0.21		12.24	0.34	0.52	0.014
DB-3	33.2	1	AAD894	1314	2.05	-	e	10.22	0.19	0.43	0.012
DB-3	33.2	2	AAD894	1314	2.05	-	e	10.9	0.57	0.46	0.037
DB-3	33.2	3	AAD894	1314	2.05	0.14		10.69	0.56	0.45	0.036
DB-3	6.0	1	AAD895	1347	2.60	0.80		21.5	0.68	0.97	0.027
DB-3	6.0	2	AAD895	1347	2.60	-	e	21.5	0.68	0.97	0.027
DB-3	6.0	3	AAD895	1347	2.60	0.71		21.5	0.68	0.97	0.027
DB-3	19.9	1	AAD896	1355	2.73	-	e	NA	NA	NA	NA
DB-3	19.9	2	AAD896	1355	2.73	0.42		NA	NA	NA	NA
DB-3	19.9	3	AAD896	1355	2.73	0.34		NA	NA	NA	NA
DB-3	36.7	1	AAD897	1348	2.62	0.20		NA	NA	NA	NA
DB-3	36.7	2	AAD897	1348	2.62	0.47		NA	NA	NA	NA
DB-3	36.7	3	AAD897	1348	2.62	0.31		NA	NA	NA	NA
DB-3	6.0	1	AAD904	1416	3.08	0.48		NA	NA	NA	NA
DB-3	6.0	2	AAD904	1416	3.08	0.44		NA	NA	NA	NA
DB-3	6.0	3	AAD904	1416	3.08	1.33	f	NA	NA	NA	NA
DB-3	10.7	1	AAD898	1431	3.33	1.26		21.66	1.78	0.98	0.072
DB-3	10.7	2	AAD898	1431	3.33	2.89		28.62	4.62	1.35	0.189
DB-3	10.7	3	AAD898	143[illegible]	3.33	1.90		23.28	4.96	1.06	0.204
DB-3	20.7	1	AAD899	1418	3.12	0.32	e	12.00	0.095	0.51	0.004
DB-3	20.7	2	AAD899	1418	3.12	-	e	12.00	0.095	0.51	0.004
DB-3	20.7	3	AAD899	1418	3.12	0.10	e	11.95	0.071	0.51	0.003

TABLE D-3. (Continued)

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m-1)	Beam Attenuation SD (m-1)
DB-3	6.0	1	AAD905	1455	3.73	0.95		20.87	0.22	0.94	0.009
DB-3	6.0	2	AAD905	1455	3.73	1.40		20.87	0.22	0.94	0.009
DB-3	6.0	3	AAD905	1455	3.73	-	e	20.87	0.22	0.94	0.009
DB-3	12.1	1	AAD906	1505	3.90	0.15		26.49	1.37	1.23	0.055
DB-3	12.1	2	AAD906	1505	3.90	-	e	26.49	1.37	1.23	0.055
DB-3	12.1	3	AAD906	1505	3.90	0.34		26.49	1.37	1.23	0.055
DB-3	20.8	1	AAD907	1456	3.75	2.99		10.94	0.12	0.46	0.005
DB-3	20.8	2	AAD907	1456	3.75	1.29		10.94	0.12	0.46	0.005
DB-3	20.8	3	AAD907	1456	3.75	0.47	b	10.94	0.12	0.46	0.005
DB-3	6.0	1	AAD908	1522	4.18	0.97		NA	NA	NA	NA
DB-3	6.0	2	AAD908	1522	4.18	1.44		NA	NA	NA	NA
DB-3	6.0	3	AAD908	1522	4.18	2.50		NA	NA	NA	NA
DB-3	10.4	1*	AAD909	1532	4.35	0.80		12.2	1.73	0.52	0.070
DB-3	10.4	2	AAD909	1532	4.35	0.45		24.2	1.74	1.11	0.074
DB-3	10.4	3	AAD909	1532	4.35	1.85		27.68	1.44	1.30	0.058
DB-3	20.2	3	AAD910	1525	4.23	0.24		11.68	0.59	0.50	0.024

NA = Not Available.
[a]Sampled at plume periphery.
[b]Filtered material is visibly less than other replicates.
[c]Unexplained heterogeneity.
[d]Invalid filter tare weight due to rapidly changing humidity, data rejected.
[e]Invalid tare weight, no explanation, data rejected.

TABLE D-4. TOTAL SUSPENDED SOLIDS, TURBIDITY, AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED FROM SEWAGE PLUME DB-4 AT THE 106-MILE SITE DURING SEPTEMBER, 1987

Plume or Event	Depth (m)	Rep No.	Sample ID	Start Time	Time After T=0 (h)	TSS (mg/L)	Comments	Turbidity Mean (Percent)	Turbidity SD (Percent)	Beam Attenuation Mean (m-1)	Beam Attenuation SD (m-1)
DB-4	6.0	1	AAD912	0001	0.00	13.00		42.02	0	2.18	0
DB-4	6.0	2	AAD912	0001	0.00	24.01		42.02	0	2.18	0
DB-4	6.0	3[c]	AAD912	0001	0.00	0.34	a	NA	NA	NA	NA
DB-4	6.0	1	AAD913	0443	4.72	3.49	b	17.84	0.25	0.79	0.010
DB-4	6.0	2	AAD913	0443	4.72	0.17		17.84	0.25	0.79	0.010
DB-4	6.0	3	AAD913	0443	4.72	1.47		17.84	0.25	0.79	0.018
DB-4	10.5	1	AAD914	0443	4.72	1.57	b	15.46	0.75	0.67	0.030
DB-4	10.5	2	AAD914	0443	4.72	0.79		15.46	0.75	0.67	0.030

NA = Not available.
[a]Sampled at plume periphery.
[b]Appearance of filtered material is in proportion to variability in turbidity.
[c]Mean of duplicate analysis.

TABLE D-5. *C. perfringens* RESULTS FOR SAMPLES COLLECTED IN SEWAGE PLUME DB-1 AT THE 106-MILE SITE DURING SEPTEMBER 1987

Sample ID	Plume or Event	Rep. No.	Depth (m)	Start Time	Time After T=0 (h)	*C. perfringens* (Counts/ 100 mL)
AAD869	DB1	1	6.0	1648	0.00	TNTC
AAD869	DB1	2	6.0	1648	0.00	TNTC
AAD869	DB1	3	6.0	1648	0.00	TNTC
AAD870	DB1	1	6.0	1702	0.23	TNTC
AAD870	DB1	2	6.0	1702	0.23	TNTC
AAD870	DB1	3	6.0	1702	0.23	TNTC
AAD866	DB1	1	6.0	1738	0.83	TNTC
AAD866	DB1	2	6.0	1738	0.83	TNTC
AAD866	DB1	3	6.0	1738	0.83	TNTC
AAD871	DB1	1	6.0	1823	1.55	TNTC
AAD871	DB1	2	6.0	1823	1.55	TNTC
AAD871	DB1	3	6.0	1823	1.55	TNTC
AAD876	DB1	1	6.0	1941	2.88	TNTC
AAD876	DB1	2	6.0	1941	2.88	TNTC
AAD876	DB1	3	6.0	1941	2.88	361.00
AAD858	DB1	1	19.4	0818	-8.50	0.00
AAD858	DE	2	19.4	0818	-8.50	0.00
AAD858	DB1	3	19.4	0818	-8.50	0.00
AAD867	DB1	1	21.8	1740	0.87	87.38
AAD867	DB1	2	21.8	1740	0.87	17.56
AAD867	DB1	3	21.8	1740	0.87	26.94
AAD872	DB1	1	22.3	1826	1.60	3.06
AAD872	DB1	2	22.3	1826	1.60	3.00
AAD872	DB1	3	22.3	1826	1.60	3.81
AAD877	DB1	1	20.3	1950	3.03	33.19

TNTC= Too Numerous To Count

TABLE D-6. *C. perfringens* RESULTS FOR SAMPLES COLLECTED IN SEWAGE PLUME DB-2 AT THE 106-MILE SITE DURING SEPTEMBER 1987

Sample ID	Plume or Event	Rep No.	Depth (m)	Start Time	Time After T=0 (h)	*C. perfringens* (Counts/ 100 mL)
AAD878	DB-2	1	6.0	1027	0.00	TNTC
AAD878	DB-2	2	6.0	1027	0.00	207.00
AAD878	DB-2	3	6.0	1027	0.00	TNTC
AAD881	DB-2	1	6.0	1445	4.30	292.00
AAD881	DB-2	2	6.0	1445	4.30	71.17
AAD881	DB-2	3	6.0	1445	4.30	43.56
AAD882	DB-2	1	10.7	1742	7.25	201.44
AAD882	DB-2	2	10.7	1742	7.25	265.44
AAD882	DB-2	3	10.7	1742	7.25	299.75
AAD880	DB-2	1	34.0	1927	9.00	6.56
AAD880	DB-2	2	34.0	1927	9.00	16.00
AAD880	DB-2	3	34.0	1927	9.00	5.25

TNTC = Too Numerous To Count.

TABLE D-7. *C. perfringens* RESULTS FOR SAMPLES COLLECTED IN SEWAGE PLUME DB-3 AT THE 106-MILE DEEPWATER DUMPSITE DURING SEPTEMBER 1987

Sample ID	Plume or Event	Rep No.	Depth (m)	Start Time	Time After T=0 (h)	*C. perfringens* (Counts/ 100 mL)
AAD885	DB-3	1	6.0	1111	0.00	16.13
AAD885	DB-3	2	6.0	1111	0.00	0.44
AAD885	DB-3	3	6.0	1111	0.00	257.00
AAD886	DB-3	1	6.0	1130	0.32	231.00
AAD886	DB-3	2	6.0	1130	0.32	166.00
AAD886	DB-3	3	6.0	1130	0.32	187.00
AAD900	DB-3	1	6.0	1147	0.60	62.33
AAD900	DB-3	2	6.0	1147	0.60	171.00
AAD900	DB-3	3	6.0	1147	0.60	TNTC
AAD891	DB-3	1	6.0	1211	1.00	121.00
AAD891	DB-3	2	6.0	1211	1.00	100.00
AAD891	DB-3	3	6.0	1211	1.00	80.00
AAD892	DB-3	1	6.0	1311	2.00	TNTC
AAD892	DB-3	2	6.0	1311	2.00	43.40
AAD892	DB-3	3	6.0	1311	2.00	27.00
AAD904	DB-3	1	6.0	1416	3.08	20.00
AAD904	DB-3	2	6.0	1416	3.08	4.25
AAD904	DB-3	3	6.0	1416	3.08	33.94
AAD908	DB-3	1	6.0	1522	4.18	153.00
AAD908	DB-3	2	6.0	1522	4.18	149.00
AAD908	DB-3	3	6.0	1522	4.18	140.00
AAD909	DB-3	1	10.4	1532	4.35	0.25
AAD909	DB-3	2	10.4	1532	4.35	4.56
AAD909	DB-3	3	10.4	1532	4.35	21.38
AAD898	DB-3	1	10.7	1431	3.33	83.67
AAD898	DB-3	2	10.7	1431	3.33	280.00
AAD898	DB-3	3	10.7	1431	3.33	133.00
AAD887	DB-3	1	20.0	1148	0.62	0.81
AAD887	DB-3	2	20.0	1148	0.62	0.88
AAD887	DB-3	3	20.0	1148	0.62	1.06
AAD889	DB-3	1	20.6	1222	1.18	1.63
AAD889	DB-3	2	20.6	1222	1.18	1.75
AAD889	DB-3	3	20.6	1222	1.18	1.13
AAD893	DB-3	1	20.1	1326	2.25	4.00
AAD893	DB-3	2	20.1	1326	2.25	69.67
AAD893	DB-3	3	20.1	1326	2.25	29.31
AAD899	DB-3	1	20.7	1418	3.12	21.25
AAD899	DB-3	2	20.7	1418	3.12	22.00
AAD899	DB-3	3	20.7	1418	3.12	2.88

TABLE D-7. (Continued)

Sample ID	Plume or Event	Rep No.	Depth (m)	Start Time	Time After T=0 (h)	C. perfringens (Counts/ 100 mL)
AAD910	DB-3	1	20.2	1525	4.23	0.44
AAD910	DB-3	2	20.2	1525	4.23	0.31
AAD910	DB-3	3	20.2	1525	4.23	0.19
AAD890	DB-3	1	35.8	1233	1.37	2.31
AAD890	DB-3	2	35.8	1233	1.37	2.19
AAD890	DB-3	3	35.8	1233	1.37	1.88
AAD894	DB-3	1	33.2	1314	2.05	52.00
AAD894	DB-3	2	33.2	1314	2.05	57.67
AAD894	DB-3	3	33.2	1314	2.05	9.13

TNTC = Too Numerous To Count.

TABLE D-8. *C. perfringens* RESULTS FOR SAMPLES COLLECTED IN SEWAGE PLUME DB-4 AT THE 106-MILE SITE DURING SEPTEMBER 1987

Sample ID	Plume or Event	Rep No.	Depth (m)	Start Time	Time After T=0 (h)	*C. perfringens* (Counts/ 100 mL)
AAD912	DB-4	1	6.00	0001	0.00	TNTC
AAD912	DB-4	2	6.00	0001	0.00	TNTC
AAD912	DB-4	3	6.00	0001	0.00	110.00
AAD913	DB-4	1	6.00	0443	4.72	18.88
AAD913	DB-4	2	6.00	0443	4.72	21.19
AAD914	DB-4	1	10.50	0443	4.72	11.06
AAD914	DB-4	2	10.50	0443	4.72	12.75
AAD914	DB-4	3	9.50	0457	4.72	10.56

TNTC = Too Numerous To Count.

TABLE D-9. RESULTS OF TRACER SAMPLES ANALYZED FROM PLUME DB-2, 106-MILE SITE, SEPTEMBER 1987

Depth (m)	Time After T=0	Rep. No.	Cu (µg/L)	Fe[a] (µg/L)	Pb (µg/L)	Zn[a] (µg/L)
6.0	0.0	1	14.74	117.73	3.25	13.37
6.0	0.0	2	7.87	58.52	1.61	6.93
6.0	0.0	3	0.26	1.24	0.05	0.16
10.7	7.25	1	1.07	7.02	0.19	1.90
10.7	7.25	2	1.88	16.00	0.38	2.20
10.7	7.25	3[b]	2.00	15.85	0.38	2.00

[a]Samples are blank corrected.
[b]Value is an average of duplicate samples.

TABLE D-10. RESULTS FROM TRACER SAMPLES ANALYZED FROM PLUME DB-3, 106-MILE-SITE, SEPTEMBER 1987

Depth (m)	Time After T=0 (h)	Rep. No.	Cu (µg/L)	Fe[a] (µg/L)	Pb (µg/L)	Zn[a] (µg/L)
6.0	0.00	1	0.14	0.56	0.02	0.03
6.0	0.00	2	0.14	0.07	0.02	0.02
6.0	0.00	3	50.01	295.14	51.51	49.16
6.0	0.32	1	32.27	192.89	35.71	39.69
6.0	0.32	2	16.87	107.19	18.87	16.24
6.0	0.32	3	19.22	122.58	22.63	17.92
6.0	0.60	1	28.65	174.10	32.45	23.83
6.0	0.60	2	1.13	7.20	1.37	1.00
6.0	0.60	3	0.14	0.12	0.02	0.04
6.0	1.00	1	1.90	11.05	2.05	1.88
6.0	1.00	2	4.25	23.04	4.22	3.91
6.0	1.00	3[b]	14.39	92.54	16.07	14.60
6.0	2.00	1	17.00	98.21	19.78	16.26
6.0	2.00	2c	7.63	43.65	8.89	7.59
6.0	2.00	3	5.68	38.21	7.59	6.16
6.0	3.08	1	0.19	0.81	0.09	0.06
6.0	3.08	2	0.32	1.29	0.28	0.17
6.0	3.08	3	0.40	1.86	0.35	0.20
10.7	3.33	1	2.62	15.46	3.29	4.75
10.7	3.33	2	5.32	27.30	6.32	6.02
10.7	3.33	3	6.26	33.18	11.22	5.72
10.9	8.40	1	0.62	3.19	16.38	4.18
10.9	8.40	2	0.64	2.84	0.61	0.52
10.9	8.40	3	0.66	3.01	0.70	0.59
20.0	0.62	1	0.16	0.54	0.31	0.53
20.0	0.62	2	0.15	1.35	0.04	0.37
20.0	0.62	3	0.14	0.23	0.02	0.06
20.1	2.25	1	0.20	0.60	0.07	0.12
20.1	2.25	2	0.78	6.87	0.68	0.91
20.1	2.25	3	0.27	2.78	0.22	0.20
20.2	4.23	1	1.06	7.53	0.98	1.07
20.2	4.23	2	0.40	2.09	0.33	0.37
20.2	4.23	3c	0.55	2.74	0.49	0.60
20.6	1.18	1	0.14	0.25	0.03	0.08
20.6	1.18	2	0.15	0.40	0.04	0.10
20.6	1.18	3	0.13	0.22	0.02	0.03

TABLE D-10. (Continued)

Depth (m)	Time After T=0 (h)	Rep. No.	Cu (μg/L)	Fe[a] (μg/L)	Pb (μg/L)	Zn[a] (μg/L)
20.7	3.12	1	0.14	0.67	0.04	0.05
20.7	3.12	2	0.18	0.75	0.55	0.06
20.7	3.12	3	0.31	1.81	0.21	0.20
33.2	2.05	1	0.14	1.66	0.07	0.09
33.2	2.05	2	0.26	1.82	0.20	0.20
33.2	2.05	3	0.14	1.07	0.05	0.09
35.8	1.37	1	0.12	0.55	0.02	0.11
35.8	1.37	2	0.11	0.51	0.02	0.04
35.8	1.37	3	0.15	0.50	0.02	0.09

[a]Results are blank corrected.
[b]A hole was found in the neck of the sample bottle.
[c]Value is an average of duplicate samples analysis.

TABLE D-11. WATER QUALITY ANALYSIS, DUMPING EVENT DB-2, 106-MILE SITE, SEPTEMBER 1987.

Sample Depth (m)	Time After T=0	Rep. No.	Ag[a]	As[b]	Cd[a]	Cr[a]	Cu	Fe[a]	Ni	Pb	Se[b]	Zn[a]	Hg
			(µg/L)										(ng/L)
6.0	4.30	1[c]	0.006	0.93[d]	0.034	0.474	2.134	13.31	0.346	0.438	<0.03[d]	1.29	12.35
6.0	4.30	2	0.046	0.94	0.015	0.183	0.520	2.842	0.284	0.084	<0.03	0.255	21.73
6.0	4.30	3	0.005	0.97	0.014	0.200	0.453	2.392	0.250	0.086	<0.03	0.225	17.14
34.0	9.00	1	0.023	1.12	0.030	0.126	0.173	0.966	0.254	0.014	<0.03	0.206	6.66
34.0	9.00	2	e	1.15	0.032	0.127	0.178	0.833	0.272	0.019	<0.03	0.407	9.19
34.0	9.00	3	e	1.34	0.023	0.126	0.178	0.680	0.266	0.019	<0.03	0.411	7.50

[a]Blank corrected.
[b]Analyzed by hydride generation.
[c]Mean of replicate laboratory sample analysis.
[d]This sample was not analyzed in duplicate for As and Se.
[e]Concentration less than procedural blank.

TABLE D-12. WATER QUALITY METALS ANALYSIS, DUMPING EVENT DB-3, 106-MILE SITE, SEPTEMBER 1987

Sample Depth (m)	Time After T=0	Rep. No.	Ag[a]	As[b]	Cd[a]	Cr[a]	Cu	Fe[a]	Ni	Pb	Se[b]	Zn[a]	Hg
			(μg/L)										(ng/L)
6.0	4.18	1	0.075	0.99	0.131	2.061	3.225	13.277	0.610	2.549	<0.03	2.000	10.23
6.0	4.18	2	0.043	0.93	0.085	1.404	1.995	7.887	0.450	1.659	<0.03	1.257	10.59[c]
6.0	4.18	3	0.019	0.93	0.062	0.627	1.257	4.455	0.375	0.961	0.05	0.759	13.26
10.4	4.35	1	0.027	1.04	0.062	0.656	1.284	5.145	0.413	1.055	<0.03	0.895	12.30
10.4	4.35	2	0.008	0.99	0.039	0.425	0.810	2.697	0.337	0.543	<0.03	0.505	18.86
10.4	4.35	3	0.243	1.04	0.400	6.455	11.210	44.640	1.424	10.358	<0.03	7.960	14.72

[a]Blank corrected.
[b]Analyzed by hydride generation.
[c]Mean of duplicate analysis.

TABLE D-13. WATER QUALITY PESTICIDE ANALYSES, DUMPING EVENTS DB-2 AND DB-3, 106-MILE SITE, SEPTEMBER 1987

Plume	Depth (m)	Rep. No.	Time After T=0 (h)	α-BHC	γ-BHC	Dieldrin (ng/L)	p,p'-DDE
DB-2	6.0	1	4.5	-	1.95	-	-
DB-2	6.0	2	4.6	-	0.73	-	-
DB-2	6.0	3	4.7	-	0.27	-	-
DB-2	10.1	1	7.9	1.09	0.32	0.14	0.11
DB-2	10.5	2	8.1	1.35	0.41	0.16	0.16
DB-2	10.3	3	8.3	1.37	1.0	0.019	0.015
DB-3	6.0	1	4.4	-	1.59	-	-
DB-3	6.0	2	4.5	-	1.26	-	-
DB-3	6.0	3	4.7	-	0.52	-	-
DB-3	7.0	1	5.0	-	0.49[a]	-	-
DB-3	5 - 7	2	5.6	-	0.38	-	-

[a]Mean of two repicate analyses.
-Means Not detected.
Compounds not found: heptachlor, aldrin, heptachlor epoxide, α-endosulfan, endrin aldehyde, β-endosulfan sulfate, p,p'-DDD, endrin, β-endosulfan, p,p'-DDT.

TABLE D-14. WATER QUALITY PCB ANALYSES, DUMPING EVENTS DB-2 AND DB-3, 106-MILE SITE, SEPTEMBER 1987 (Concentration in ng/L)

Plume	Depth (m)	Rep. No.	Time After T=0 (h)	PCB Isomer					
				Cl_6(153)	Cl_6(138)	Cl_7(187)	Cl_7(180)	Cl_7(170)	Cl_9(206)
DB-2	6.0	1	4.5	-	-	-	-	-	-
DB-2	6.0	2	4.6	-	0.056	-	0.21	-	0.026
DB-2	6.0	3	4.7	-	0.024	-	-	-	0.21
DB-2	10.1	1	7.9	-	-	-	0.84	-	-
DB-2	10.5	2	8.1	-	-	-	-	-	-
DB-2	10.3	3	8.3	-	-	-	0.02	-	-
DB-3	6.0	1	4.4	-	-	-	0.22	0.21	-
DB-3	6.0	2	4.5	-	-	-	0.10	0.15	-
DB-3	6.0	3	4.7	-	0.08	0.032	0.08	0.08	-
DB-3[a]	7.0	1	5.0	0.16	0.12	0.048	0.14	-	-
DB-3	5-7	2	5.6	-	-	-	-	-	-

[a]Mean of two replicate analyses.
-Means Not Detected.
Compounds not found: Cl_2(08), Cl_3(18), Cl_3(18), Cl_4(52), Cl_4(44), Cl_4(66), Cl_5(101), Cl_5(105), Cl_5(118), Cl_6(128), Cl_8(195)