Report to the

MASSACHUSETTS BAYS PROGRAM

ORGANIC LOADINGS FROM THE MERRIMACK RIVER TO MASSACHUSETTS BAY

Prepared by

Menzie-Cura & Associates, Inc.
One Courthouse Lane, Suite Two
Chelmsford, Massachusetts 01824

with

Arthur D. Little, Inc.
Bigelow Laboratory for Ocean Sciences
Energy & Environmental Engineering, Inc.
TG & B, Inc.
University of Massachusetts - Boston Harbor Campus
Wade Research, Inc.

APRIL, 1995

MBP-95-04

Printed and Distributed by the Massachusetts Bays Program, a cooperative venture of Massachusetts Coastal Zone Management Office and the U.S. Environmental Protection Agency. Funded under U.S. Environmental Protection Agency Cooperative Agreement CEOO1534-01.

ORGANIC LOADINGS
FROM THE MERRIMACK RIVER
TO MASSACHUSETTS BAY

Prepared for:

Massachusetts Bays Program
Massachusetts Executive Office of Environmental Affairs
Coastal Zone Management Office
U.S. Environmental Protection Agency - Water Management Division

Prepared by:

Menzie-Cura & Associates, Inc.
One Courthouse Lane, Suite Two
Chelmsford, Massachusetts 01824

with
Arthur D. Little, Inc.
Bigelow Laboratory for Ocean Sciences
Energy & Environmental Engineering, Inc.
TG&B, Inc.
University of Massachusetts - Boston, Harbor Campus
Wade Research, Inc.

April, 1995

MASSACHUSETTS BAYS PROGRAM
100 Cambridge Street, Room 2006, Boston, Massachusetts 02202 (617) 727-9530 *fax (617) 727-2754*

FOREWORD

The roots of the Massachusetts Bays Program extend back to 1982, when the City of Quincy filed suit against the Metropolitan District Commission and the Boston Water and Sewer Commission over the chronic pollution of Boston Harbor, Quincy Bay, and adjacent waters. Outdated and poorly maintained sewage treatment plants on Deer Island and Nut Island were being overwhelmed daily by sewage from the forty-three communities in the Metropolitan Boston area. Untreated and partially treated sewage were spilling into Boston Harbor.

Litigation over the pollution of Boston Harbor culminated in 1985 when the United States Attorney filed suit on behalf of the Environmental Protection Agency against the Commonwealth of Massachusetts for violations of the Federal Clean Water Act. The settlement of this suit resulted, in 1988, in the creation of the Massachusetts Water Resources Authority, the agency currently overseeing a multi-billion dollar project to repair and upgrade Metropolitan Boston's sewage treatment system. In addition, the settlement resulted in the establishment of the Massachusetts Environmental Trust - an environmental philanthropy dedicated to improving the Commonwealth's coastal and marine resources. $2 millon in settlement proceeds were administered by the Trust to support projects dedicated to the restoration and protection of Boston Harbor and Massachusetts Bay.

The Trust provided $1.6 million to establish the Massachusetts Bays Program, a collaborative effort of public officials, civic organizations, business leaders, and environmental groups to work towards improved coastal water quality. The funding was used to support both a program of public education and a scientific research program focussing on the sources, fate, transport and effects of contaminants in the Massachusetts and Cape Cod Bays ecosystem. To maximize the efficiency of limited research funding, the sponsored research program was developed in coordination with research funded by the MWRA, the United States Geological Survey, and the Massachusetts Institute of Technology Sea Grant Program.

In April, 1990, following a formal process of nomination, the Massachusetts Bays Program became part of the National Estuary Program. The additional funding provided as part of this joint program of the Environmental Protection Agency and the Commonwealth of Massachusetts has been used to continue a coordinated program of research in the Massachusetts Bays ecosystem, as well as supporting the development of a Comprehensive Conservation and management plan for the coastal and marine resources of Massachusetts and Cape Cod Bays. The study described in this report examines the loading of polycyclic aromatic hydrocarbons to the Massachusetts Bays from the Merrimack River.

The information in this document has been subject to Massachusetts Bays Program peer and administrative review and has been accepted for publication as a Massachusetts Bays Program document. The contents of this document do not necessarily reflect the views and policies of the Management Conference.

The Massachusetts Bays Program is sponsored by the Massachusetts Executive Office of Environmental Affairs through the Coastal Zone Management Office and the U.S. Environmental Protection Agency Region I John F. Kennedy Federal Building Boston MA 02203

TABLE OF CONTENTS

EXECUTIVE SUMMARY

TABLE OF CONTENTS (continued)

TABLES

TABLES (continued)

FIGURES

FIGURES (continued)

FIGURES (continued)

APPENDICES

EXECUTIVE SUMMARY

Previous studies have documented the importance of Merrimack River flow to the hydrography and circulation of Massachusetts Bay (Butman, 1976). In assessing the sources and loadings of pollutants to Massachusetts Bay, Menzie-Cura & Associates, Inc., (1991) found little data on typical concentrations of organic pollutants discharged to Massachusetts Bay from rivers, wastewater treatment plants, urban runoff, and other sources. This project was conducted to quantify and assess the significance of loadings of organic contaminants from the Merrimack River to Massachusetts Bay. To accomplish this we:

used satellite images to assess the frequency with which the Merrimack River plume (as identified by sea surface temperature) impinges upon the sill north of Stellwagen Bank. (Twenty-five of these satellite images are on file at the Massachusetts Bays Program office);

made five seasonal cruises and collected samples from the sediments and the water column at and near the mouth of the Merrimack River and analyzed them for polynuclear aromatic hydrocarbons (PAH) and chlorinated organic compounds (polychlorinated biphenyls (PCBs) and pesticides) to measure the range of organic compound concentrations in this source;

combined daily and average flow data in the Merrimack River with the daily and average concentrations of selected organic compounds to calculate potential loadings from the Merrimack River;

developed a simple model, which combined various measured and estimated terms (i.e., river flow, concentration, and frequency of impingement on the sill north of Stellwagen) to estimate dilution and calculate expected concentrations of selected organic compounds in northern Massachusetts Bay due to loadings from the Merrimack River; and, made two cruises to northern Massachusetts Bay and collected seawater particulate samples from the water column to measure the concentrations of PAHs in the Bay to allow comparison of modeled and field measured concentrations.

Results from this study indicate that the Merrimack River Estuary is a strongly stratified, salt wedge estuary in all seasons. The concentrations of organic compounds below the pycnocline are generally low, relative to concentrations in the thin (often less than one meter deep), well-mixed surface layer.

Observations made in the lower reaches of the Merrimack River indicate that the estuary is generally non-depositional from at least as far north as the Route 95 Bridge. For the most part these sediment samples were sandy, and it appears that the fine suspended load leaves the estuary and enters the coastal water.

Satellite images of sea surface temperature showed a plume of water from the coastal current and the Merrimack River extending into Massachusetts Bay several times during 1990 to 1993 for 3 to 5 days. This usually occurred during April to June but occurred once in October 1990. This indicates that conditions may be favorable for advection of Merrimack River water into Massachusetts Bay for about half of each year. This supports information presented by Geyer et al. (1992) and others that indicates a coastal current flowing toward Massachusetts Bay during peak discharge from the Maine Rivers in the spring.

The measured total PAH concentration in Merrimack River freshwater discharge varied by only a factor of about four (from 122 ng/l to 459 ng/l). The daily total PAH loadings calculated as the product of the concentration and the river flow varied by an order of magnitude. The variation in river flow resulted in the greater range in total PAH loadings. The daily loadings were lowest during low flow conditions in the autumn. Assuming that the water from the Merrimack River reaches Massachusetts Bay for approximately half the year results in a loading estimate from the Merrimack River to the Bay of 1,035 kg/year (using concentrations obtained from this study and annual average river flow for 1992).

The predicted concentrations in northern outer Massachusetts Bay (based on measured concentrations in the Merrimack River, dilution of the Merrimack River plume, and conservation of mass of the PAHs) agree with measured concentrations in northern outer Massachusetts Bay. The measured and predicted concentrations of individual and aggregated PAHs in Massachusetts Bay were similar, indicating that the Merrimack River may be an important source of waterborne PAH compounds to northern, outer Massachusetts Bay. The analysis was not extended to other organic compounds because concentrations of PCBs and pesticides were generally below detection limits in the water column.

The results of this work and a companion study performed by Menzie-Cura & Associates, Inc. (1995) indicate that based on the assumption that conditions are favorable for the Merrimack River and coastal current flow to enter Massachusetts Bay for approximately half the year and that this occurs, the Merrimack River could contribute as much as 8% of the estimated total PAH loadings to Massachusetts Bay. Table ES-1 compares this loading from the Merrimack River to Massachusetts Bay and loadings from other sources (Menzie-Cura & Associates, Inc., 1995).

TABLE ES-1
SUMMARY OF TOTAL PAH LOADS TO MASSACHUSETTS BAY[1]
IN KG/YR

SOURCE	Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Total
Coastal NPDES	561	346	8,126	95		9,128
Coastal Runoff	6	308	282	22	24	642
Coastal CSO			31			31
River Discharge	1,184	253	2,523	83		4,043
TOTAL	1,751	907	10,962	198	24	13,844

[1]Refer to: Menzie-Cura & Associates, 1995. Non-point Source Runoff PAH Loading Analysis, Massachusetts Bays Program. for description of PAH loadings calculations to Massachusetts Bay from all sources.

1.0 INTRODUCTION

1.1 PURPOSE AND GENERAL SCOPE OF WORK

The purpose of this work is to quantify and assess the significance of loadings of organic contaminants from the Merrimack River to Massachusetts Bay. Previous work by Butman (1976) indicated that the Merrimack River may have an important influence of hydrography and circulation in northern Massachusetts Bay.

To assess the importance of organic contaminant loadings from the Merrimack River to Massachusetts Bay, we:

used satellite images to assess the frequency with which the Merrimack River plume (as identified by sea surface temperature) impinges upon the sill north of Stellwagen Bank;

made five seasonal cruises and collected samples from the sediments and the water column at and near the mouth of the Merrimack River and analyzed them for polynuclear aromatic hydrocarbons (PAH) and chlorinated organic compounds (polychlorinated biphenyls (PCBs) and pesticides) to measure the range of organic compound concentrations in this source;

combined daily and average flow data in the Merrimack River with the daily and average concentrations of selected organic compounds to calculate potential loadings from the mouth of the Merrimack River;

developed a simple model, which combined various measured and estimated terms (i.e., river flow, concentration, and frequency of impingement on the sill north of Stellwagen) to estimate dilution and calculate expected concentrations of selected organic compounds in northern Massachusetts Bay due to loadings from the Merrimack River; and, made two cruises to northern Massachusetts Bay and collected samples from the water column to measure the concentrations of the selected organic compounds in the Bay to allow comparison of modeled and field measured concentrations.

1.2 SUMMARY OF RESULTS

Results from this study indicate that the Merrimack River Estuary is a strongly stratified, salt wedge estuary in all seasons. The concentrations of organic compounds below the pycnocline are generally low, relative to concentrations in the thin (often less than one meter deep), well-mixed surface layer.

We selected a location just downstream of the City of Newburyport to measure water concentrations of organic compounds for use in calculating loadings (Station 3 on Figure 1). This location is downstream of urban areas on the Merrimack, and at low tide, the water column is relatively fresh (i.e., there is relatively little impact on salinity from offshore) and is well mixed from surface to bottom. For two sampling dates, we measured concentrations both upstream (Station 3) and downstream (Station 3A) of the Newburyport Wastewater Treatment Plant outfall.

The Merrimack River Estuary is generally non-depositional from at least as far north as the Route 95 Bridge, based on qualitative observations of sediment grabs which we took approximately every 200 meters over this area. For the most part these sediment samples were sandy, and it appears that the fine suspended load leaves the estuary and enters the coastal water. Three sediment samples were collected for chemical analysis from typically sandy areas along the shore (Figure 1).

Satellite images of sea surface temperature indicate that conditions may be favorable for advection of Merrimack River water into Massachusetts Bay for about half of each year.

The predicted concentrations in northern outer Massachusetts Bay (based on measured concentrations in the Merrimack River, dilution of the Merrimack River plume, and conservation of mass of the PAHs) agree with measured concentrations in northern outer Massachusetts Bay. The measured and predicted concentrations of individual and aggregated PAHs in Massachusetts Bay were similar, indicating that the Merrimack River may be an important source of waterborne PAH compounds to northern, outer Massachusetts Bay. The analysis was not extended to other organic compounds because concentrations of PCBs and pesticides were generally below detection limits in the water column.

The results of this work and a companion study performed by Menzie-Cura & Associates, Inc. (1995) indicate that assuming that conditions are favorable for Merrimack River and coastal current flow to enter Massachusetts Bay for approximately one half the year and that this occurs, the Merrimack River could contribute as much as 8% of the estimated total PAH loadings to Massachusetts Bay.

2.0 METHODS

2.1 SATELLITE IMAGERY

The Bigelow Laboratory for Ocean Sciences provided sea surface temperature images of the Gulf of Maine, obtained by the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA satellites, which were reviewed to assess the contribution of Merrimack River water to Massachusetts Bay. Images contained in an archive held at Bigelow Laboratory, together with images collected during the present study through the NOAA Coastwatch Program (Narragansett, Rhode Island), provided coverage for the 1990 to 1993 period. Table 1 summarizes the satellite images reviewed for this project. Imagery was collected to Julian day 123 in 1993.

We originally proposed to acquire near real-time imagery for six months from the Rosenstiel School of Marine and Atmospheric Sciences at the University of Miami, however, the availability of Coastwatch imagery enabled us to expand acquisition to one full year.

The Gulf of Maine is imaged twice daily by AVHRR, at 0700-0900 and 1800-2000 GMT. Coastwatch posted 1 km resolution images on an electronic bulletin board, accessible in the evenings via telephone hook-up. Processing was performed using the NOAA supplied IDIDAS software, on an IBM compatible 286 based PC. Full Gulf of Maine scenes are for the region covering 41 to 46° latitude and 65° to 71° longitude. Scenes that were zoomed in extend from 41°30' to 43°30' latitude and 68°30' to 71° longitude.

Of the 582 images reviewed for the years 1990 to 1993, 208 were clear or partially clear and useful for the present study. Clear or partial images for the Merrimack River/Massachusetts Bay region were processed further. This processing included fitting the images to a grid of latitude and longitude, applying land and coastline features and adding the date and Julian calendar day. Sea surface temperature features were enhanced by standard color slicing, using a 21 color pallet developed to provide a 1°C temperature range per color. This pallet was applied to all images throughout the seasonal cycle, permitting direct comparisons. Archived images had been previously processed in a similar fashion, using University of Miami DSP software. Table 1 provides a summary of the selected images by year.

2.2 MERRIMACK RIVER FIELD WORK

2.2.1 Sampling Dates

We made five cruises to the Merrimack River with the *R/V Surveysa*, a 25-foot fiberglass privateer operated by personnel from TG&B, Inc. The cruises were made during five different river flow regimes within a twelve-month period to measure hydrographic conditions and to collect samples to determine the distribution of organic contaminants (PAHs and PCBs/pesticides) in the water column throughout the year and to identify any seasonal differences.

Table 2 lists the cruise dates and the samples collected for chemical analysis during each cruise. Note that on most Merrimack River cruises additional water samples were collected for analysis for total organic carbon (TOC), total suspended solids (TSS), and oil and grease (O&G). We collected and analyzed these "unfunded" water quality parameters to provide some consistency between this measurement program and the Massachusetts Bay Non-Point Source Program. (These data are in Appendix A, although this report does not address these additional parameters.)

2.2.2 Hydrographic Measurements and Sampling Station Selection

We measured temperature and salinity by depth along cross-river transects at Buoy 13, Buoy 15, and under the power cables (Figure 1) using a YSI salinometer. This instrument had an analog deck readout, a metered cable, and a probe weighted with a dive weight extending one and one-half feet below the probe. Measurements were taken at the surface, at 0.5 foot intervals throughout the mixed surface layer, and below the surface layer at intervals of approximately every 3 feet to the bottom.

We established three primary water column sampling stations, based on the hydrographic data (Figure 1):

Station 1, approximately 400 m south of Buoy 13 in the relatively fresh water layer at high tide;

Station 2, at Buoy 13, in the salt water layer at high tide;

Station 3, under the cables just downstream of Newburyport Center.

Station 3 was downstream of Newburyport but still in relatively fresh water. Water samples were always collected from this station from the fresh water layer at low tide.

During the April 1992 and the May 1992 cruises, an additional sample (called "Station 3A") was collected from near Station 3 but downstream of the nearby Newburyport Wastewater Treatment Plant outfall to assess the contribution of the plant's discharges to the Merrimack River water.

Data from the freshwater layer at Stations 3 and 3A provided information on the loadings from upstream. Data from the freshwater layer sampled at Station 1 and the deeper, salt layer sampled at Station 2 provided rough estimates of the immediate mixing of PAH compounds between the incoming salt water and the estuary's freshwater layer.

Appendix B contains transcripts of the cruise logs with the latitude and longitude of the sampling stations, the sampling depths and the hydrographic data. These data are also summarized in Appendix C.

2.2.3 Sediment Sampling

During the first and second cruises, we obtained petit ponar grab samples for qualitative estimates of sediment type (sand, silt, clay) in the Merrimack River Estuary from the Route 95 bridge to the river mouth. The samples were from transects spaced approximately 200 meters apart.

Nearly all of the sediment samples were sandy. Small depositional areas occurred in subtidal to intertidal areas along the shore downstream of Newburyport. Three sediment grab samples were collected from the top 10 cm of sediment in these depositional areas: one each from subtidal near-shore areas north and south of Buoy 13 during the first cruise (SED-1 and SED-2); and one from a near-shore area south of Buoy 13 during the second cruise (SED-3).

The sediment samples were held at approximately 4°C and shipped within 24 hours under chain-of-custody to ADL laboratory for organic compound analyses.

2.2.4 Water Column Sampling

During each of the five cruises, whole water column samples were obtained from the freshwater layer at high tide at Station 1, just south of Buoy 13; within the salt wedge layer at high tide at Station 2, at Buoy 13; and at Station 3, at the power cables where the water remained relatively fresh at low tide (with salinities generally between zero and 1.5 PSU). On the first two cruises, water column samples were also collected downstream of the Newburyport Wastewater Treatment Plant outfall (Station 3A). Sediments are sandy in these areas indicating that sediment settling or deposition is not occurring to an appreciable extent.

We obtained water column samples for organic compound analyses using a stainless steel cage sampler which collected water directly into the sample bottles. The sampler was used to collect a vertically-integrated sample of the water column. Use of this sampler avoided on-board transfer of water from sampler to bottle, thus reducing the chance of incidental contamination with trace organic compounds.

Samples for conventional water quality analyses (TOC, TSS and O&G) were collected into a methanol-washed 4 liter bottle with the cage sampler and decanted into appropriate sample bottles on-board.

Water samples were held at approximately 4°C and shipped within 24 hours under chain-of-custody to the appropriate analytical laboratory. Organic compound analyses were completed by ADL. TOC, TSS and O&G analyses were conducted by E^3I.

2.3 MASSACHUSETTS BAY FIELD WORK

We completed hydrographic measurements and water column sampling in Massachusetts Bay along an established UMass-Boston research transect on two cruises, one in May 1992 and one in October 1992. Table 3 lists the cruise dates and the samples collected for chemical analysis during each cruise. Sample latitude, longitude, and depth are in Appendix C.

The May 1992 survey included measurements along a single transect from the Boston Harbor entrance to the northern end of Stellwagen Bank. This transect was selected to provide data on PAH concentrations in Massachusetts Bay during an event when there was satellite or hydrographic evidence that the coastal current was entering the bay. This transect also provided data on water particulate chemistry influenced by Boston Harbor (at the west end of the transect) and the Merrimack River (at the east end) without losing information on the influence of the Merrimack River. Five seawater particulate samples were collected for analysis during this hydrographic survey. (Note that whole water samples were collected from the Merrimack River.) The October 1992 survey was conducted in conjunction with a Bay-wide survey, supported by MIT Sea Grant funding. One additional seawater particulate sample was collected during this hydrographic survey. Figure 2 provides approximate hydrographic measurement and seawater sampling station locations.

2.3.1 Hydrographic Field Measurements In Massachusetts Bay

The hydrographic measurements were made with a Sea-Bird Electronics SBE 9/11 CTD system equipped with a Sea Tech *in situ* fluorometer and a Sea Tech transmissometer. Data were stored on IBM-PC compatible floppy disks for later processing and analysis.

2.3.2 Collection of Seawater Particulate Samples from Massachusetts Bay

We collected samples from the surface mixed layer for analysis of particulate-bound PAH and chlorinated hydrocarbons (pesticides and PCBs) during the two Massachusetts Bay cruises.

During the May 1992 cruise, we collected samples of seawater particulate matter at five stations (Stations 2,4,5,6,8). Each of these samples was obtained from 100 liters of seawater.

Based on results from the May samples which indicated that a larger sample size would provide better detection limits, we collected one particulate sample from 300 liters of seawater from the surface mixed layer during the October, 1992 cruise.

To collect the particulate samples, seawater was pumped into on-board stainless steel extraction containers either using a stainless steel or Teflon pumping system held in place at depth by a stainless steel hydrowire. Particulates were collected by filtering the water onto a pre-combusted glass fiber (0.5 um pore size) filter using a solvent-cleaned stainless steel system. Note that whole water samples were collected from the Merrimack River.

2.4 CHEMICAL ANALYSIS

All of the water column and sediment samples collected during this study were analyzed for: the priority pollutant PAHs (listed in EPA Methods 625 and 8270), additional PAHs and heterocyclic compounds (e.g., dibenzothiophene and its alkylated homologues), and chlorinated hydrocarbons (PCBs and pesticides). Selected water column samples collected during the Merrimack River field work were also analyzed for TOC, TSS and O&G.

A full list of analytes, together with the abbreviations used in some of the figures in this report, are provided in Appendix A.

2.4.1 Organic Compound Analyses of Sediment and Water Samples

The ADL laboratory logged all reagents and solvents, and recorded lot number, purity, and chemical descriptions. Standard preparation was documented and the records maintained in separate three-ring binders. Laboratory notebooks or log sheets for all sample preparation activities were maintained (log sheets in separate three-ring binders). Balances used to weigh materials were calibrated according to standard procedures.

Water samples were processed as a batch, upon receipt. The sample batch included a procedural blank, duplicate spiked blanks (i.e., a solvent spiked with surrogates and natural compounds), and/or duplicate matrix spike samples. The analytical results from these quality assurance samples are in Appendix A. Holding times for sample extraction did not exceed 14 days for water, stored at 4°C in the dark.

Quality control procedures followed by the laboratory are included in the work plan. Laboratory data quality objectives for the program were met or exceeded. Field replicate samples were not collected because samples from Station 3A were analyzed instead of replicate samples.

Chemical Analysis of Sediment Samples

The chemical analysis of sediment samples was accomplished with standard ADL operating procedures (SOP) using standard analytical methods developed by the U.S. Environmental Protection Agency.

The sediment samples were thawed at room temperature, and the contents extracted. Each sample was placed in a 200 ml Teflon® jar, homogenized with any overlying water, and dried with sodium sulfate. The sediment sample was extracted three times with 100 ml of 1:1 methylene chloride/acetone by sonication for three minutes. After extraction, the solvent was decanted and dried through sodium sulfate. The extract was concentrated to 5-10 ml by Kuderna-Danish evaporation, transferred to a 25-ml vial, further concentrated to 1-2 ml by nitrogen evaporation, and then transferred to a 4-ml vial.

A measured portion of the extract was completely transferred to a preparator high performance liquid chromatograph (HPLC). The extract was then gradient eluted to separate the f1 and the f2 fractions: the f1 fraction contained saturated and some unsaturated hydrocarbons and all of the chlorinated hydrocarbons, and the f2 fraction contained PAH.

The f1 and f2 fractions were concentrated by Kuderna-Danish evaporation followed by nitrogen evaporation to a volume of 1 ml, and transferred to 4-ml glass vials with Teflon®-lined caps for storage at 4°C until analysis.

Before analysis, internal standards were added to the extract fractions and the sample fractions submitted for instrumental analysis for chlorinated and aromatic hydrocarbons.

Analysis of the f1 fraction containing chlorinated hydrocarbons

Data on chlorinated hydrocarbons (pesticides and PCBs) in sediment were acquired using gas chromatography/electron capture detector technology. Chlorinated target analytes were determined in the concentration range of parts per billion (ng/g) for sediment and particulate samples.

The injection port was designed for splitless injection onto a capillary column. The gas chromatograph (GC) was equipped with an electron capture detector (ECD), and is interfaced to a data acquisition system for examining the chromatograms. A 30-m long x 0.25-mm inside diameter fused-silica capillary column with DB5 bonded phase was used.

The GC was equipped with an autosampler, capable of making 1 ul to 5 ul injections. The identification of individual chlorinated hydrocarbons was based on retention time comparisons, using the corresponding analytes in the calibration standards. Commercially-available computer data system software was used to automate the identification and quantification of the analytes in the sample extracts. In addition, the supervisory analyst personally verified identification of each analyte in each sample. To facilitate this procedure, a calibration standard chromatogram was overlayed using computer graphic techniques on the sample chromatogram, allowing direct comparison between sample analytes and authentic compounds in a standard solution.

The detection limit achieved for individual PCBs and pesticides in sediment was 0.1 ng/g.

Analysis of the f2 fraction containing PAH

Polynuclear aromatic hydrocarbons (PAH) and selected heterocyclic compounds were determined by gas chromatography/mass spectrometry in the selected ion monitoring mode (GC/MS SIM). Target analytes were determined in the concentration range of parts per billion (ng/g) for sediment and particulate samples.

The analytical system included a temperature programmable gas chromatograph equipped with an injection port designed for splitless injection onto a capillary column. The GC capillary column was fed directly into the ion source of the mass spectrometer. A computer system interfaced to the mass spectrometer allowed the continuous acquisition and storage on machine-readable media of all mass spectra obtained throughout the duration of the chromatographic program. The computer software allowed searching any GC/MS data file for ions of a specific mass and plotting such ion abundances versus time or scan number. The computer acquired data at pre-selected mass windows for selected ion monitoring.

All information on field and laboratory identifications, surrogate and internal standard spiking amounts, extract and fraction weights, sample and extract splits, were entered into the GC/MS data system. This was used in reducing raw data into quantitation reports containing concentration values for the target analytes. These preliminary quantitation reports were transferred to the database for further analysis and presentation.

The detection limit achieved for individual PAHs in sediment was 1 ng/g.

Chemical Analysis of Seawater

Seawater samples were extracted with methylene chloride after acidification to a $pH<2$, following the procedure in EPA Method 3510 (EPA SW-846, 1986). The extract was dried with sodium sulfate and concentrated under a stream of nitrogen. The extract was concentrated to 5-10 ml by Kuderna-Danish evaporation, transferred to a 25-ml vial, further concentrated to 1-2 ml by nitrogen evaporation. N-hexane was substituted for methylene chloride by nitrogen evaporation, and the extract was submitted for HPLC fractionation as described above. The f1 and f2 fractions were collected and analyzed as described for sediments. For whole water samples, detection limits were 0.5 ng/l for individual PAHs and 0.3 ng/l for PCBs and pesticides.

Particulate material was extracted in a manner similar to the processing of sediment samples. The glass fiber filters were placed (folded) into a bottle and extracted as though they were sediment samples. Individual PAHs and pesticides were not detected in filter blanks. PCB 209 was the only PCB congener detected in the filter blanks and samples for the 100 liter samples. A review of these results indicated that the detection of this congener was a false-positive.

Chemical analyses for the target analytes of PAH and pesticides/PCBs were conducted as previously described for the sediment analyses.

Detection limits for seawater particulates were 0.03 ng/l for individual PAHs in samples collected in May 1992 (100 liter samples) and 0.01 ng/l for the sample collected in October 1992 (300 liter sample). Individual PCB and pesticide detection limits for these samples were 0.02 ng/l for 100 liter samples and 0.008 ng/l for the 300 liter sample.

2.4.2 Conventional Water Quality Programs

The methods for conventional water quality parameters used by E^3I were:

> Total Organic Carbon by EPA Method 415.1, Wet Chemical Oxidation, Infrared (U.S. EPA, 1983);
>
> Total Suspended Solids by Standard Methods for the Examination of Water and Wastewater 2540D, Gravimetric (APHA, 1989); and
>
> Oil & Grease by EPA Method 413.1, Gravimetric (U.S. EPA, 1983).

3.0 RESULTS

3.1 SATELLITE DATA

The rationale for using the satellite products was to observe the occurrence and seasonality of the conditions whereby Merrimack River water is advected around Cape Ann into Massachusetts Bay. Satellite observations can be made at larger spatial scales and at longer temporal scales than can be made with shipboard operations. Archived images plus images collected as part of this project for the years 1990 to 1993 were screened for use in this analysis. Sea surface temperature images do not directly provide information concerning surface flow. However, certain types of physical features known to indicate coastal flow in this region can be monitored.

Types of features observed were:

> an isolated temperature plume (June 4, 1992) or pocket (March 26, 1993) north of Cape Ann extending around the cape;
>
> a coastal current originating in southern Maine, driven by cooler Bay of Fundy water (August 30, 1992); and,
>
> isothermal coastal conditions (January 16, 1993).

While it is not possible to monitor daily conditions using Coastwatch images because of cloud cover and fog, useful scenes were obtained for an average of 24% of the days listed in Table 1 (180 days of coverage out of 739 days of monitoring). Numerous two to seven consecutive day series were obtained as well as two images for the same day whereby the persistence of specific features could be determined.

Pockets of isothermal water appear to occur north of Cape Ann throughout the year, and were observed in numerous images in all years. Plumes of water extending from the mouth of the Merrimack River around Cape Ann were rare events, but did occur at least several times each year (primarily in April to

June) although one event was observed in late October, 1990. These features typically persisted for 3-5 days, before dramatic change or disappearance.

The coastal current has been observed by satellite imagery and described previously (Keafer and Anderson, 1993). In our data set, it appears around Julian day 100 (mid-April) and persists in one form or another until around Julian day 275 (late September). Again, the current was observed extending around Cape Ann in each year, with each event lasting 3-5 days.

In winter, bands of isothermal water lie along the coast, presumably formed by cooling and convective overturn associated with bathymetry. Whether the general wintertime circulation in the Gulf permits transport from the Merrimack River, south around Cape Ann, is uncertain. However, these conditions persist for several months each year.

The 208 clear or partially clear images from 1990 to 1993 were reviewed to evaluate when water from the Coastal Current and Merrimack River enter into Massachusetts Bay. Of these, twenty-five Coastwatch images (approximately one image every 10 to 14 days) were selected to represent the 1992-1993 monitoring period of this study. The images were reproduced directly from the video monitor as 35mm slides. Six of these images were close to project sampling dates. Table 4 lists the image dates and includes specific comments.

The full Gulf of Maine images show the general oceanographic processes occurring within the Gulf, while zoomed images provide greater detail for the coastal region north of Cape Ann and Massachusetts Bay. (Copies of both sets are included with the original copy of this report filed at the Massachusetts Bays Program office.)

To summarize, several conditions indicating possible advection of Merrimack River water into Massachusetts Bay were observed using satellite sea surface temperature images for the years 1990-1993. Actual temperature features extending around Cape Ann were intermittent, and persisted for an average of 3-5 days per event. The satellite images indicated that conditions may be favorable for Merrimack River and coastal current water to enter Massachusetts Bay for approximately half of each year, from April though October in the case of the coastal current. This is consistent with information presented by Geyer et al. (1992) which indicates that a coastal current is more likely in the spring when peak flow occurs in the Maine rivers.

3.2 MERRIMACK RIVER CHEMICAL AND PHYSICAL MEASUREMENTS

3.2.1 Hydrographic Structure of Merrimack River

The temperature and salinity data provided in Appendix B indicate that the Merrimack River Estuary is a strongly stratified salt wedge estuary from the mouth of the river to Newburyport Center. High tide stratification may extend to Newburyport, but low tide conditions reveal a relatively fresh, well-mixed water column from surface to bottom.

3.2.2 Chemical Analysis Results

Results of the chemical analyses of the sediment and water samples are provided in Appendix A. The PAH listing provides the individual compound results, plus two aggregate measurements. "Total PAHs" was calculated as the sum of all detected individual compounds (i.e., non-detects were considered to be zero).

"Carcinogenic PAHs" was calculated as the sum of nine of the heavier molecular weight compounds which are generally considered to have some carcinogenic potency (U.S. EPA, 1995): pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene and benzo(g,h,i)perylene. Pyrene and benzo(g,h,i)perylene were conservatively included in this group, although the evidence on their carcinogenicity is equivocal. As with total PAH, non-detects were considered to be zero.

The PCB/pesticide listing provides the individual compound results, plus two aggregate measurements. "Total PCBs" and "Total Pesticides" were calculated as the sum of all detected individual compounds in the PCBs and pesticides classes, respectively.

TSS, TOC and O&G results are also provided for selected water samples.

Interpretation of Sediment Sample Results

We analyzed three sediment samples collected from the mouth of the Merrimack River for PAHs and chlorinated hydrocarbons (pesticides and PCBs) to assess whether there is deposition of these compounds in this area. Because qualitative observations indicate that sediments in the lower reach of the Merrimack River consist mostly of sand, we concluded that little sediment deposition occurs in this area.

We assumed that compounds detected in sediment in this area came from upstream and would serve as an indicator of whether they might also be present in the water column.

Review of NOAA Data. Historical data on organic contaminants in Merrimack River sediments was obtained from the National Oceanic and Atmospheric Administrations (NOAA) National Status and Trends Benthic Surveillance Project (NOAA, 1992). The closest NOAA sampling station is MER (latitude: 42° 48' 0", longitude 70° 46' 0"), approximately 3.5 kilometers southeast of the mouth of the Merrimack (Figure 1).

The total PAH from this station ranged from 0.082 to 3.3 ug/g dry weight. Concentrations of individual PAH in sediments were in the general range of 0.002 to 1.6 ug/g dry weight, with most PAH identified from the phenanthrene to chrysene range. The NOAA data also indicated lower concentrations of 5-ring PAH such as benzo(a)pyrene, in the general range of 0.003 to 0.060 ug/g dry weight, and that phenanthrene was the PAH present in the sediment at the highest concentrations.

Total PCB concentrations as isomer classes (diphenyls to octaphenyls) ranged from 11 to 82 ng/g dry weight. There were some selected chlorinated pesticides identified as well (hexachlorobenzene and lindane), at low concentrations of 0.12 to 1.4 ng/g dry weight. Based on these existing data, we decided to analyze for PAH and chlorinated hydrocarbons in sediments and river water.

Results of Current Analyses. Total PAH sediment concentrations at three stations in the Merrimack ranged from 1.42 to 5.5 ug/g dry weight. Individual PAH concentrations ranged from 0.004 to 0.460 ug/g dry weight. In all three sediment samples, fluoranthene was the individual PAH present at the highest concentration, with the total C1- and C2- alkyl phenanthrenes/anthracenes and C1- fluoranthenes/pyrenes present at the highest concentrations for total alkyl PAH homologues. Figure 3 provides the PAH distribution of each of these three samples.

Concentrations of organic hydrocarbons in sediments at these three stations were in the same general analytical range, but generally somewhat higher, than those reported in the NOAA database. These analyses identified more individual PAHs above detection limits, but the detection limits were lower for this study (0.001 ug/kg) in comparison with those reported by NOAA (in the range of 0.01 ug/kg depending on the PAH compound and year of analysis).

Concentrations of total PCBs in the sediment samples ranged from 15 to 33 ng/g dry weight. Figure 4 shows the distribution of PCB compounds in the three sediment samples.

Results of the measurement of chlorinated pesticides showed low but measurable levels of hexachlorobenzene, chlordane, DDD, and DDE at concentrations generally similar to those reported in the NOAA Benthic Surveillance database. Concentrations of total chlorinated pesticides ranged from 3.1 to 20 ng/g dry weight.

Interpretation of Merrimack River Water Sample Results

Generally, total PAH in the water column ranged from 10 to 460 ng/l depending on whether the sample came from the freshwater or saltwater layer. Table 5 summarizes the concentrations of total PAH, total suspended solids, salinity, total organic carbon, and temperature.

Results of the analyses of individual PAH (Appendix A) showed that the contributors to the total PAH concentrations were generally the same individual PAH as analyzed in the sediment samples, with the general exception that the higher alkyl homologues (C3- and C4-) were normally not detected in water samples. Total concentrations of individual PAH ranged from a low of 2 to a high of 50 ng/L.

Figure 5 presents the distribution of individual PAH, from naphthalene to benzo(g,h,i)perylene, from fresh water samples collected at low tide near Newburyport (Station 3). These distribution plots show a similar, but not identical, distribution to Merrimack River sediment. The additional contribution of the lighter molecular weight PAH in the naphthalene family is present in the total water sample plots, compared to the PAH distribution plot from the Merrimack River sediment (Figure 3).

Figure 6 presents the same PAH distribution information for water samples collected from the surface layer at Station 1 south of Buoy 13 at high tide. The concentrations of almost all individual PAH are lower than those observed in the fresh water sample collected further upstream at Newburyport, but the overall distribution patterns are almost identical.

Figure 7 presents the PAH distribution pattern from the well mixed salt water collected at high tide at Buoy 13 (Station 2). The individual PAH identified are similar to those collected in fresh water, with concentrations somewhat lower compared to freshwater PAHs.

Figures 8 and 9 provide the comparison of PAH distribution of total water samples collected above and below the Newburyport Wastewater Treatment Plant outfall. As can be seen from the data plotted in each figure, it appears that the same PAH compounds were present upstream and downstream of the plant discharge point; however, concentrations in the water column were greater in the downstream samples.

Except for a very few compounds (Appendix A), PCBs and pesticides were generally below detection limits.

3.3 MASSACHUSETTS BAY CHEMICAL AND PHYSICAL MEASUREMENTS

3.3.1 Physical Measurements

May 1992 Hydrographic Survey Results

Figures 10 and 11 present vertical sections of temperature and salinity along the Boston-Stellwagen Bank transect for May 20, 1992. Note the appearance of two regions of relatively warm, low salinity water, separated by upward sloping isopycnals near 20 kilometers off shore.

The spatial coverage of the hydrographic survey was inadequate to determine unambiguously the presence and extent of combined Merrimack River and coastal current water within Massachusetts Bay. However, the distributions of salinity and temperature are consistent with a coastal current source in the outer region of the transect, with the inner 10-15 km portion strongly influenced by flow from Boston Harbor.

A satellite-derived sea surface temperature image obtained for May 21, provides support for the presence of Merrimack plume within the Bay. At this time, a relatively warm region of water extended from north of the Merrimack through Massachusetts Bay. The higher temperature water near Boston was also evident. The temperature distribution further offshore is patchy. There appeared to be a cooler area in mid-bay as seen in the hydrographic data. The satellite-derived temperatures are 9-10 °C, in agreement with the hydrographic data.

October 1992 Hydrographic Survey Data

The chemical sample for October was obtained in conjunction with a larger survey conducted under funding from the MIT Sea Grant Program. Figures 12 and 13 summarize temperature and salinity distributions. These are contour plots from vertical sections near Cape Ann, Boston, and Scituate, with horizontal contours of the average property between 1 and 3 meters (approximately the surface conditions).

Surface conditions were very uniform in the northern portion of the Bay, except for a band of cold water along the northern shore. This feature is most likely due to upwelling. Note that the vertical plots show shallower depths for the pycnocline at the inshore stations as would be expected for upwelling conditions. The distribution of temperature and salinity is strongly suggestive of the coastal current within the bay. The relatively saline water at the outer end of the Scituate transect may represent an intrusion of Gulf of Maine water, with the coastal current flowing south-westward past Cape Ann, and then curving southeastward through Massachusetts Bay.

A satellite image obtained on October 12 (2 days before the survey) did not show a clear boundary for the coastal current. The temperature was relatively uniform throughout the southwestern portion of the Gulf of Maine. This does not necessarily mean that the coastal current/Merrimack River water was not within Massachusetts Bay, only that there was not a clear temperature signature at the time of the image. The distinct halocline present in the Cape Ann and Boston transects is convincing evidence for the influence of the Merrimack, since sources within Massachusetts Bay are inadequate to account for the observed salinity. The decreasing depth of (and the salinity gradient within) the halocline between Cape Ann and Scituate lend support to the hypothesis that the surface water has a source to the north of the Bay, with a significant contribution from the Merrimack River.

3.3.2 Chemical Measurements

Results of the analyses of the 100-liter samples collected during the May 1992 cruise indicated that the concentration of total PAH in suspended particulate material in the surface mixed layer in Massachusetts Bay seawater was 1.3 to 4.95 ng/L. Individual PAH compounds were determined to be in the range of 0.03 to 0.5 ng/L. The total PAH concentrations were highest in the near-shore region (4.95 ng/l at 10 km off shore). At the four stations beyond 20 km from shore, the concentrations were lower and reasonably consistent, with total PAH concentrations between 1.27 and 1.95 ng/l.

Note that while concentrations were higher near Boston Harbor, the larger volume of water in the offshore region may indicate a greater total loading from the more remote source (i.e., the coastal current).

The 100-liter results were considered to be close to the absolute detection limits for many of the individual PAH. In addition, it was felt that the artificial parameter total PAH was comprised of too many near-detection limit results.

Results of the filtration and analysis of the 300 liter sample collected during the October cruise showed that the lowest detection limit of individual PAH was somewhat extended to the 0.01 ng/L level and that most individual PAH fell into the 0.1 to 0.01 ng/L range. The total PAH value was 0.63 ng/L, a value that was felt to have much more reliability. Unfortunately, it is a single sample and there is no measure of variability for this number.

Concentrations of particulate PCBs and pesticides were determined in the 100-liter and the 300-liter samples. In the 100-liter samples, it was determined that the decachlorobiphenyl congener (PCB-209) that was identified during the analyses was a false-positive response, and was skewing the data. All five sample results were reviewed and determined to be close to, but not identical to, the required response for the peak. Accordingly, it is felt that the 100-liter PCB sample results are not analytically valid. The 300 liter sample produced what was felt to be an analytically-reliable value of total PCB of 0.134 ng/L, with almost half of the total concentration coming from the 2,4'-dichlorobiphenyl congener (PCB-8) at a concentration of 0.078 ng/L.

4.0 DATA ANALYSIS

4.1 CALCULATION OF LOADINGS FROM THE MERRIMACK RIVER

We used the PAH data obtained from the low-tide, relatively fresh water, surface to bottom well-mixed stations (regardless of location relative to the treatment plant; i.e., from Stations 3 and 3A) to calculate loadings of PAH compounds from the Merrimack River to the coastal zone. (Note that we did not calculate loadings of PCBs and pesticides based on their being generally below detection limits in water). In making these calculations, we:

assumed that the compounds of concern are the PAH compounds;

used measured PAH concentrations to calculate daily loadings on the day of sampling and an arithmetic average concentration for the five sampling rounds to calculate a yearly loading for 1992; and,

used the average daily flow in the Merrimack River on the sampling dates to calculate a daily loading for those dates and the average annual flow from the Merrimack for 1992. These flow rates were for the USGS gaging station in Lowell, Massachusetts (USGS, 1992) corrected to account for the increment in flow from the gaging station to the mouth of the river. The flow at the gaging station was corrected by multiplying it by the ratio of the total drainage area of the river to the drainage area above the gaging station (Shepard, 1993).

We calculated daily and yearly loadings as the product of daily or average flow and the measured or average PAH concentration in the fresh water, low-tide samples. Daily flows in the Merrimack River for river sampling dates are in Table 6. The average yearly flow for 1992 was 213 m^3/sec.

The concentrations of total PAH in Merrimack river water (fresh water, well mixed layer) varied by a factor of four (range 122 ng/l to 459 ng/l). Within a given season, the ranges were even narrower. The range in spring values was 234 to 459 (n=5), and the range in autumn/winter values was 122 to 282 (n=2). Within season and given the limited measurements, the range appears to be about a factor of two. The average total PAH concentration estimated from these data is 308 ng/l.

Loadings of PAH from the Merrimack River calculated on a daily basis ranged from 1 kg/day in the autumn when the river flow was the lowest to 18 kg/day in May of 1993 when the river flow was highest. These results are presented on Table 7. Note that although the PAH concentrations vary slightly, daily PAH loadings vary by an order of magnitude. This is due to the variation in Merrimack River flow. The lowest PAH loadings coincided with low flow conditions in the autumn. Using the upstream, freshwater, average total PAH concentration from these data and the annual average river flow, we calculated an average annual loading of total PAHs of 2,069 kg/year. Assuming that water from the Merrimack River reaches Massachusetts Bay for approximately half the year results in a loading estimate from the Merrimack River to the Bay of 1,035 kg/year.

These results indicate that the 50 ng/l PAH river water concentration estimate used in 1991 to estimate loadings from this source (Menzie-Cura & Associates, Inc., 1991) resulted in *underestimation* of the actual loading from the Merrimack River to Massachusetts Bay. The 50 ng/l value was estimated from a range of PAH concentrations in U.S. rivers reported in the literature of 10 to 100 ng/l.

4.2 PREDICTED CONCENTRATIONS IN MASSACHUSETTS BAY

We attempted to estimate the importance of the Merrimack River as a source of PAH compounds to Massachusetts Bay by predicting a concentration in the Bay based on the measured Merrimack River concentrations, and an estimate of the dilution of the Merrimack water in transiting from the River to the Bay. In the absence of knowledge of the salinity of the coastal current north of the Merrimack for the period of interest (which would allow a direct estimate of dilution based on that salinity and the salinity of the Bay), we took a less direct approach.

The residence time of surface water within Massachusetts Bay was estimated as part of an earlier Massachusetts Bay project (Geyer et al., 1992). This estimate was based on the flow of all rivers entering the western Gulf of Maine, with an assumption that the coastal current enters Massachusetts Bay approximately 50% of the time. The freshwater fraction was estimated from the salinity distribution in the Bay compared to the salinity in the Gulf of Maine.

To use the residence time to estimate the dilution, we assumed that the Merrimack water mixes completely with the Coastal Current by the time it reaches Massachusetts Bay. The dilution is then

$$D = Q_m/Q_{cc}$$

where D is the dilution, Q_m is the flux from the Merrimack, and Q_{cc} is the flux from the coastal current. The coastal current flux is estimated by dividing the volume of Massachusetts Bay above 20 m (V) by half the residence time (T):

$$Q_{cc} = 2V/T.$$

The factor of two incorporates the assumption, made in estimating the residence time, that the coastal current actually enters the bay only 50% of the time. Therefore, the dilution is estimated as:

$$D=TQ_m/2V$$

with T and V obtained from Geyer et al. (1992) and Q_m from the USGS gaging station in Lowell corrected to account for the increment in flow between Lowell and the river mouth (Shepard, 1993). Table 6 summarizes the model parameters.

The predicted PAH concentrations for offshore northern Massachusetts Bay are the product of the dilution, the term D from above, and the PAH concentration measured at Station 3 or the average of Stations 3 and 3A on the sampling dates or the average measured concentration for the appropriate season (spring or autumn). We did this for individual PAH compounds, total PAH, and total carcinogenic PAH. The average spring concentration was calculated from the data from Stations 3 and 3A from April 29 and May 9, 1992 and May 1, 1993. The average autumn/winter concentration was calculated from the data for Station 3 from October 10, 1992 and January 8, 1993. We did not account for any potential contribution from the Gulf of Maine and Maine rivers. (Note that the equations are linear, and any change in one parameter would result in a corresponding linear change in the result.)

4.3 COMPARISON OF PREDICTED AND MEASURED CONCENTRATIONS

Tables 8 and 9 provide PAH concentrations in Merrimack River water on individual sampling dates, predicted bay concentrations based on the dilution calculations in section 4.2, and measured concentrations in Massachusetts Bay for individual PAH compounds, total PAH, and total carcinogenic PAH, for the spring and autumn seasons, respectively. (Note that average measured Massachusetts Bay concentrations calculated from four samples collected during the May cruise are provided for the spring comparison. The data from Station 2 were not included in the average because of the potential influence of Boston Harbor at this station. Analytical results from the single measurement collected during the October Bay cruise were used for the autumn comparison.)

Tables 10 and 11 provide the average river concentrations for spring and autumn/winter, the predicted Bay concentrations based on the average and the dilution calculations in section 4.2, and the measured concentrations in Massachusetts Bay for individual PAH compounds, total PAH, and total carcinogenic PAH, for the spring and autumn seasons, respectively.

In general, the predicted concentrations of total PAH compounds are similar to the measured concentrations. Total predicted PAH concentrations for spring sampling dates ranged from 2.3 and 2.7 ng/l in spring 1992 to 3.7 ng/l in May 1993 with a spring predicted average of 2.2 ng/l; the total PAH concentrations measured in the bay in spring 1992 is 1.7 ng/l. For autumn, the predicted concentration is 0.42 ng/l compared with a measured value of 0.63 ng/l. The average predicted autumn/winter concentration is 0.83 ng/l.

Also, the predicted concentrations of total carcinogenic PAH compounds are similar to the measured concentrations. The predicted range for the spring is 0.50 to 0.84 ng/l with an average predicted value of 0.56 ng/l, and the measured bay concentration is 0.30 ng/l. For autumn, the predicted concentration is 0.07, the average autumn/winter predicted concentration is 0.35 ng/l, while the measured autumn concentration is 0.22 ng/l.

For individual PAH compounds detected in the Bay during spring, the ratio of predicted to measured values was always within a factor of 5. Naphthalenes were the highest predicted and measured concentrations, and the two values were within a factor of 1 to 3. During the autumn/winter, the ratio of predicted to measured individual PAH compounds was always within a factor of 3, with the exception of chrysene (a factor of 4). In this season, naphthalenes, phenanthrene, pyrene, and benzo(b)fluoranthene were the highest measured individual PAH and differed from the predicted values by no more than a factor of three. This indicates that the method used is a reasonable predictor of individual PAH compounds, and further supports the idea that the Merrimack River is an important potential source of PAH compounds to the northern outer Massachusetts Bay.

5.0 CONCLUSIONS AND DISCUSSION

A previous study estimated the contributions of rivers, NPDES sources, CSOs, stormwater, and groundwater to Massachusetts Bay in general (Menzie-Cura & Associates, Inc., 1991). This study indicated that the Merrimack River is probably the major riverine source of PAH compounds to Massachusetts Bay, but is at most about 10% of the waterborne sources when all waterborne sources are considered.

The present analysis demonstrates that:

the average PAH concentrations measured in the Merrimack River were higher than those used in prior estimates of loadings;

the measured range of total PAH concentrations in the freshwater portions of the Merrimack River was narrow, 122 ng/l to 459 ng/l;

although the annual range in concentrations was narrow, the higher measured total PAH concentrations occurred in samples collected during spring;

daily PAH loadings from the Merrimack River varied by an order of magnitude and were dependent on Merrimack River flow. Loadings were lowest during low flow conditions;

predicted concentrations in northern outer Massachusetts Bay (based on measured concentrations in the Merrimack River, dilution of the Merrimack River plume, and conservation of mass of the PAHs) agree with measured concentrations in northern outer Massachusetts Bay; and

the generally close agreement between individual predicted and measured PAH compounds indicates that the close prediction for total PAH is not due to large errors among individual compounds cancelling one another, nor is it dependent upon any individual PAH compound.

It is important to note that these conclusion made in this study are based on a one year sampling program in which a limited number of samples were taken from the freshwater layer near the mouth of the Merrimack River.

The agreement between predicted and measured concentrations in outer northern Massachusetts Bay indicates that the Merrimack River may be an important source of PAH compounds to this specific region. The data do not allow us to extend this conclusion to Massachusetts Bay generally. The PAH load in the entire bay is probably also affected by contributions from other urban sources such as the Danvers River and Boston Harbor.

The agreement between measured and predicted total PAH concentrations holds for carcinogenic PAH and individual PAH compounds, within a factor of five. It is interesting that the agreement also holds for naphthalene even though this compound has the shortest estimated half-life in surface water.

There are some obvious sources of uncertainty in the calculations used to make the predictions. These sources of uncertainty include the range of flow in the Merrimack River, the range of residence time for water in Massachusetts Bay, the estimate of 50% as the fraction of time that the Merrimack River may reach Massachusetts Bay, and the range in riverine concentrations. In general, the effects of these uncertainties on the predicted concentrations will be linear. For example, if residence time is two times higher, then the dilution factor and hence the estimated bay concentration will be doubled.

We assumed no degradation or volatilization of PAHs during transport to Mass Bay from the mouth of the Merrimack River. The effects of these individual mechanisms are difficult to estimate. However, Mackay et al. (1992) have reviewed the literature concerning environmental half-lives of PAH compounds and estimate that in water:

> lighter PAHs such as naphthalene have a half-life of 100 to 300 hours;
>
> mid-range PAHs, such as fluorene, phenanthrene, and anthracene, have a half-life of 300 to 1,000 hours; and,
>
> the heavier PAH compounds have a half-life of 1,000 to 3,000 hours.

These estimates indicate that, for most of the PAH compounds, there would be little loss due to degradation during the approximately 50 hour transit time from the Merrimack River to northern outer Massachusetts Bay. Naphthalene may degrade by half during this transit, but the concentrations of the other PAH compounds would be relatively unaffected during this transit. Therefore, degradation and volatilization are not likely to be major factors in the fate of PAHs over the relatively short transit time.

Settling during transit is a source of loss of PAH compounds which we were unable to estimate quantitatively.

The prediction equations assumed that Merrimack water enters Mass Bay 50% of the time. If this assumption is high, the calculated dilution term and predicted Massachusetts Bay concentrations will be proportionately smaller.

Additional uncertainty in the analysis results from the comparison of particulate phase only concentrations from Massachusetts Bay to whole water Merrimack River concentrations. However, the high sorption partition coefficients of PAH compounds (generally K_{ow} in the range of 4 to 6) indicate that these compounds will preferentially partition to the particulate phase (Mackay et al., 1992). Therefore, measurement of PAH in the particulate phase probably captures most of the mass of the contaminant in surface water.

5.1 MERRIMACK RIVER PAH LOADINGS COMPARED TO LOADINGS FROM OTHER SOURCES

Using measured upstream freshwater concentrations of PAHs (from Stations 3 and 3A) and average 1992 flow data for the Merrimack River resulted in a loading estimate of 2,069 kg/year. The satellite data collected as part of this study indicate that conditions may be favorable for the Merrimack River loadings to reach Massachusetts Bay for approximately half the year. Assuming that this is the case, the PAH loadings from the Merrimack River to Massachusetts Bay are approximately half the river loading or 1,035 kg/year.

Menzie-Cura & Associates, Inc. (1995) estimated PAH loadings to Massachusetts Bay from other sources including rivers, NPDES discharges, combined sewer overflows (CSOs), and runoff. Using the concentration data from the current study, an average river flow from Menzie-Cura & Associates, Inc. (1991) of 243.8 m^3/sec, and assuming that the loadings reach Massachusetts Bay for half of the year resulted in a PAH loading estimate of 1,184 kg/year. These loading calculations are in Appendix D. In comparison, the total PAH loading to Massachusetts Bay from river sources was 4,042 kg/year. The Merrimack River accounts for 29% of this estimated loading from rivers. This indicates that under certain conditions, the Merrimack River could be a significant source of river borne PAH loadings to Massachusetts Bay.

Table 12 compares loadings estimated by Menzie-Cura & Associates, Inc. (1995) from the sources described previously to Massachusetts Bay. The total loadings of PAHs from these sources are estimated as 13,844 kg/year. The total loadings from rivers constitutes approximately 29% of the total. Under the assumption that conditions are favorable for the Merrimack River and coastal current flow to enter Massachusetts Bay for approximately half the year and that this occurs, the Merrimack River could contribute as much as 8% of the estimated total PAH loadings to Massachusetts Bay.

REFERENCES

APHA, 1989. Standard Methods for the Examination of Water and Wastewater, 17th ed., APHA, Washington, D.C.

Butman, B., 1976. Hydrography and low-frequency currents associated with the spring runoff in Massachusetts Bay. Memoires Societe Royale des Sciences de Liege, 247-275.

Geyer, W.R., G.B. Gardner, W.S. Brown, J. Irish, B. Butman, T. Loder, and R.P. Signell, 1992. Physical Oceanographic Investigation of Massachusetts and Cape Cod Bays. Massachusetts Bay Program Report MBP-92-03. Boston, Massachusetts.

Keafer, B.A. and D.M. Anderson, 1993. "Use of remotely senses sea surface temperatures in studies of *Alexandrium tamarense* bloom dynamics." In: T.J. Smayda and Y. Shimizu (eds.), Toxic Phytoplankton Blooms in the Sea. Elsevier Science Publishers B.V., pp. 763-768.

Mackay, D., W.Y. Shiu and K.C. Ma, 1992. Illustrated Handbook of Physical-Chemical Properties for Organic Chemicals, Volume II: Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins and Dibenzofurans. Lewis Publishers, Chelsea, Michigan.

Menzie-Cura & Associates, Inc., 1991. Sources and Loading of Pollutants to Massachusetts Bay. Massachusetts Bay Program Report. Boston, Massachusetts. Report No. MBP 91-01.

Menzie-Cura & Associates, Inc., 1995. Non-point Source Runoff PAH Loading Analysis. Prepared for: Massachusetts Bays Program, Massachusetts Executive Office of Environmental Affairs, Coastal Zone Management and U.S. Environmental Protection Agency, Water Management Division.

NOAA, 1992. NOAA Status and Trends Database. NOAA ORCA Office. Silver Springs, Maryland.

Shepard, Thomas, 1993. Information specialist, USGS Water Resources Divsion, Marlborough, MA, personal communication.

U.S. EPA, 1983. Methods for Chemical Analysis of Water and Waste, EMSL Cincinnati, OH, EPA-600/4-79-020.

U.S. EPA, 1995. Integrated Risk Information System (IRIS) chemical files. On-line U.S. EPA Database.

U.S. Geological Survey, 1992. Average daily flow data from the Merrimack River gaging station at Lowell, MA (Provisional Data), Water Resources Division, Marlborough, MA.

TABLE 1
SUMMARY OF COASTWATCH SATELLITE IMAGES REVIEWED

YEAR	JULIAN DAYS	TOTAL IMAGES	CLEAR/PARTIAL IMAGES	DAYS OF COVERAGE
1990	152 - 211	33	17	15
	290 - 365	42	17	17
1991	1 - 237	139	55	53
1992	124 - 366	318	104	83
1993	1 - 123	50	15	12
TOTAL	739	582	208	180

TABLE 2
SUMMARY OF MERRIMACK RIVER FIELD WORK

Cruise	Sampling Station	Sample Description			PARAMETERS *				
		Type	Layer	Tide	PAH	PCBs	TSS	O&G	TOC
1st Cruise	1 - South of Buoy 13	River Water	Fresh Layer	High Tide	✓	✓	✓		✓
04/29/92	2 - Near Buoy 13	River Water	Salt Layer	High Tide	✓	✓	✓		✓
	3A - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
	3 - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
	SED-1 North of Buoy 13	Sediment	Sand		✓	✓			
	SED-2 South of Buoy 13	Sediment	Silt/Sand		✓	✓			
2nd Cruise	1 - South of Buoy 13	River Water	Fresh Layer	High Tide	✓	✓	✓		✓
05/09/92	2 - Near Buoy 13	River Water	Salt Layer	High Tide	✓	✓	✓		✓
	3A - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
	3 - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
	SED-3 South of Buoy 13	Sediment	Silt/Sand		✓	✓			
3rd Cruise	1 - South of Buoy 13	River Water	Fresh Layer	High Tide	✓	✓	✓	✓	✓
10/10/92	2 - Near Buoy 13	River Water	Salt Layer	High Tide	✓	✓	✓	✓	✓
	3 - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓	✓	✓
4th Cruise	1 - South of Buoy 13	River Water	Fresh Layer	High Tide	✓	✓	✓		✓
01/8/93	2 - Near Buoy 13	River Water	Salt Layer	High Tide	✓	✓	✓		✓
	3 - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
5th Cruise	1 - South of Buoy 13	River Water	Fresh Layer	High Tide	✓	✓	✓		✓
05/1/93	2 - Near Buoy 13	River Water	Salt Layer	High Tide	✓	✓	✓		✓
	3 - Upstream	River Water	Fresh Layer	Low Tide	✓	✓	✓		✓
	3 - Upstream (Duplicate)	River Water	Fresh Layer	Low Tide			✓		✓

* Analytical Parameters in whole water:

PAH	Polynuclear Aromatic Hydrocarbons
PCBs	PCBs and Pesticides
TSS	Total Suspended Solids
O&G	Oil and Grease
TOC	Total Organic Carbon

Results are presented in Appendix A. Hydrographic data from these cruises are in Appendices B and C.

TABLE 3
SUMMARY OF MASSACHUSETTS BAY FIELD WORK

Cruise	Sampling Station	Sample Description	PARAMETERS *				
			PAH	PCBs	TSS	O&G	TOC
1st Cruise 05/21/92	Station 2	Seawater Particulate (100 liter sample)	✓	✓			
	Station 4	Seawater Particulate (100 liter sample)	✓	✓			
	Station 5	Seawater Particulate (100 liter sample)	✓	✓			
	Station 6	Seawater Particulate (100 liter sample)	✓	✓			
	Station 8	Seawater Particulate (100 liter sample)	✓	✓			
2nd Cruise 10/15/92	Station 6	Seawater Particulate (300 liter sample)	✓	✓			

* Analytical Parameters in particulates:

PAH	Polynuclear Aromatic Hydrocarbons
PCBs	PCBs and Pesticides
TSS	Total Suspended Solids
O&G	Oil and Grease
TOC	Total Organic Carbon

Results are in Appendix A. Sample locations and depths are in Appendix C.

TABLE 4
DESCRIPTION OF THE SUBSET OF 25 COASTWATCH IMAGES SELECTED FOR ANALYSIS

DATE	JULIAN DAY	COMMENT
05/06/92	127	field sampling date (minus 3 days)
05/21/92	142	field sampling date
06/04/92	156	localized plume
06/12/92	164	white = clouds
06/24/92	176	clouds Massachusetts Bay
07/03/92	185	
07/20/92	202	clouds in western Gulf of Maine
07/29/92	211	clouds Penobscot Bay
08/07/92	220	
08/21/92	234	small cloud east of Cape Ann
08/30/92	243	coastal upwelling
09/10/92	254	false temperature in Bay of Fundy
09/20/92	264	missing data southwest of Cape Cod
09/30/92	274	cloud north of Merrimack River
10/12/92	286	field sampling date (plus 2 days)
10/20/92	294	coastal feature
10/28/92	302	
11/20/92	325	field sampling date (minus 3 days), missing scan lines
12/06/92	341	
01/16/93	016	field sampling date (plus 8 days), white regions along coast < 1 deg. C
02/04/93	035	white regions along coast < 1 deg. C
03/03/93	062	white regions along coast < 1 deg. C
03/18/93	077	white regions along coast < 1 deg. C
03/26/93	085	warm region Cape Cod to Cape Sable = fog
04/29/93	119	field sampling date (minus 3 days)

TABLE 5
SUMMARY OF LABORATORY AND FIELD CHEMISTRY DATA FROM THE MERRIMACK RIVER WATER COLUMN SAMPLES

Cruise	Sampling Station	Water	Tide	Matrix	TPAHs* ng/l	TSS* mg/l	TOC* mg/l	T** ° C	S** PSU
1st Cruise	1 - South of Buoy 13	Fresh	High	River Water	93.3	4	2.7	11	0.5
04/29/92	2 - Near Buoy 13	Salt	High	River Water	43.5	2.5	1	14	25
	3A - Upstream	Fresh	Low	Downstream of Outflow	323	11	2.3	11	0
	3 - Upstream	Fresh	Low	Upstream of Outflow	234.2	11	2.8	11	0
2nd Cruise	1 - South of Buoy 13	Fresh	High	River Water	166.6	8	2	13	3.5
05/09/92	2 - Near Buoy 13	Salt	High	River Water	26.9	5	1	8.5	26
	3A - Upstream	Fresh	Low	Downstream of Outflow	459.4	15	3	11.5	0.4
	3 - Upstream	Fresh	Low	Upstream of Outflow	290.2	12	3	11.5	3.6
3rd Cruise	1 - South of Buoy 13	Fresh	High	River Water	36.8	5	1.7	11.5	14.5
10/10/92	2 - Near Buoy 13	Salt	High	River Water	9.8	5	1	11.5	25.5
	3 - Upstream	Fresh	Low	Upstream of Outflow	121.5	6	2.8	14	7
4th Cruise	1 - South of Buoy 13	Fresh	High	River Water	80.3	10	4	3	0
01/8/93	2 - Near Buoy 13	Salt	High	River Water	294	189	2	3.5	20
	3 - Upstream	Fresh	Low	Upstream of Outflow	282	8	4	2	2
5th Cruise	1 - South of Buoy 13	Fresh	High	River Water	262.7	5	5	11	5
05/1/93	2 - Near Buoy 13	Salt	High	River Water	203.7	5	5	6.5	27.5
	3 - Upstream	Fresh	Low	Upstream of Outflow	443.6	6	5	12	1

NOTES:
- TPAH Total PAHs - the sum of all detected individual compounds
- TSS Total Suspended Solids
- TOC Total Organic Carbon
- T Temperature
- S Salinity

* Summary of data presented in Appendix A.

** Summarized from hydrographic data in Appendix B.

TABLE 6
PARAMETERS FOR CALCULATION OF DILUTION IN THE SURFACE 20 METERS OF MASSACHUSETTS BAY

Date	T	Q_M	V	D
Spring Average	30 days	321 m^3/s	$6.5 * 10^{10}$ m^3	0.0064
Autumn/Winter Average	60 days	102 m^3/s	$6.5 * 10^{10}$ m^3	0.0041
April 29, 1992	30 days	416 m^3/s	$6.5 * 10^{10}$ m^3	0.0083
May 9, 1992	30 days	355 m^3/s	$6.5 * 10^{10}$ m^3	0.0071
October 10, 1992	60 days	87 m^3/s	$6.5 * 10^{10}$ m^3	0.0035
January 8, 1993	*	407 m^3/s	$6.5 * 10^{10}$ m^3	*
May 1, 1993	30 days	471 m^3/sec	$6.5 * 10^{10}$ m^3	0.0094

* indicates not estimated
T = Residence Time from Geyer et al., 1992.
Q_M = flow from the USGS gaging station on the Merrimack River in Lowell corrected for difference in watershed between Lowell and river mouth (USGS, 1993).
V = Volume of Massachusetts Bay above 20 m (Geyer et al., 1992).
D = dilution factor

TABLE 7A
DAILY PAH LOADINGS FROM THE MERRIMACK RIVER

Q_M in m^3/sec	416	355	87	407	471
	Daily PAH Loading kg/day 4/29/92	**Daily PAH Loading kg/day 5/9/92**	**Daily PAH Loading kg/day 10/10/92**	**Daily PAH Loading kg/day 1/8/93**	**Daily PAH Loading kg/day 5/1/93**
Naphthalene	1.77	0.98	0.17	0.00	5.01
C1-Naphthalene	1.48	0.47	0.24	0.00	0.36
C2-Naphthalene	1.06	0.24	0.20	0.00	0.26
C3-Naphthalene	0.00	0.00	0.00	0.00	0.00
C4-Naphthalene	0.00	0.00	0.00	0.00	0.00
Acenaphthylene	0.28	0.20	0.00	0.00	0.11
Acenaphthene	0.09	0.18	0.00	0.00	0.13
Biphenyl	0.19	0.08	0.02	0.00	2.52
Fluorene	0.06	0.13	0.00	0.00	0.13
C1-Fluorene	0.00	0.00	0.00	0.00	0.00
C2-Fluorene	0.00	0.00	0.00	0.00	0.00
C3-Fluorene	0.00	0.00	0.00	0.00	0.00
Phenanthrene	0.49	0.52	0.04	1.02	2.93
Anthracene	0.21	0.20	0.01	0.00	0.11
C1-Phenanthrene/Anthracene	0.56	0.61	0.00	0.00	0.41
C2-Phenanthracene/Anthracene	0.00	0.47	0.00	0.00	0.45
C3-Phenanthrene/Anthracene	0.00	0.30	0.00	0.00	0.26
C4-Phenanthrene/Anthracene	0.00	0.75	0.00	0.00	0.00
Dibenzothiophene	0.02	0.05	0.00	0.00	0.13
C1-Dibenzothiophene	0.00	0.00	0.00	0.00	0.00
C2-Dibenzothiophene	0.00	0.00	0.00	0.00	0.00
C3-Dibenzothiophene	0.00	0.00	0.00	0.00	0.00
Fluoranthene	0.67	0.96	0.06	1.83	1.14
Pyrene	0.56	0.81	0.04	1.34	0.69
C1-Fluoranthene/Pyrene	0.73	0.95	0.00	0.00	0.41
Benzo(a)anthracene	0.23	0.40	0.03	0.00	0.29
Chrysene	0.36	0.51	0.03	0.00	0.61
C1-Chrysene	0.00	0.32	0.00	0.39	0.23
C2-Chrysene	0.00	0.00	0.00	0.77	0.00
C3-Chrysene	0.00	0.00	0.00	0.00	0.00
C4-Chrysene	0.00	0.00	0.00	0.00	0.00
Benzo(b)fluoranthene	0.25	0.42	0.02	1.34	0.49
Benzo(k)fluoranthene	0.24	0.41	0.00	0.53	0.19
Benzo(e)pyrene	0.21	0.33	0.01	0.67	0.26
Benzo(a)pyrene	0.19	0.42	0.02	0.63	0.31
Perylene	0.03	0.11	0.00	0.00	0.10
Indeno(1,2,3-cd)pyrene	0.16	0.30	0.00	0.60	0.23
Dibenzo(a,h)anthracene	0.00	0.07	0.00	0.00	0.06
Benzo(g,h,i)perylene	0.16	0.32	0.01	0.81	0.22
Total PAHs	10.01	11.50	0.91	9.92	18.05
Carcinogenic PAHs	2.15	3.65	0.15	5.24	3.09

Zero = compound not detected. Detection limit of 0.5 ng/l.
Q_M is Merrimack River flow at USGS gaging station corrected for river mouth (USGS, 1993). These loadings do not account for flow away from Mass. Bay.

TABLE 7B
AVERAGE ANNUAL PAH LOADINGS
FROM THE MERRIMACK RIVER

Q_M in m^3/sec 213

	Annual Average Concentration ng/l	1992 Average Annual Loading Kg/yr
Naphthalene	44.1	296
C1-Naphthalene	22.0	148
C2-Naphthalene	15.4	104
C3-Naphthalene	ND	0.00
C4-Naphthalene	ND	0.00
Acenaphthylene	4.43	29.8
Acenaphthene	2.81	18.9
Biphenyl	11.6	78.1
Fluorene	2.11	14.2
C1-Fluorene	ND	0.00
C2-Fluorene	ND	0.00
C3-Fluorene	ND	0.00
Phenanthrene	23.9	161
Anthracene	4.09	27.5
C1-Phenanthrene/Anthracene	11.6	78.2
C2-Phenanthrene/Anthracene	5.95	40.0
C3-Phenanthrene/Anthracene	3.73	25.0
C4-Phenanthrene/Anthracene	6.95	46.7
Dibenzothiophene	1.13	7.62
C1-Dibenzothiophene	ND	0.00
C2-Dibenzothiophene	ND	0.00
C3-Dibenzothiophene	ND	0.00
Fluoranthene	26.8	180
Pyrene	20.7	139
C1-Fluoranthene/Pyrene	16.1	108
Benzo(a)anthracene	7.05	47.4
Chrysene	10.3	69.2
C1-Chrysene	5.37	36.0
C2-Chrysene	3.14	21.1
C3-Chrysene	ND	0.00
C4-Chrysene	ND	0.00
Benzo(b)fluoranthene	13.5	90.8
Benzo(k)fluoranthene	8.48	56.9
Benzo(e)pyrene	8.63	57.9
Benzo(a)pyrene	9.34	62.7
Perylene	1.63	11.0
Indeno(1,2,3-cd)pyrene	7.31	49.1
Dibenzo(a,h)anthracene	0.85	5.71
Benzo(g,h,i)perylene	8.56	57.5
Total PAHs	308	2,067
Carcinogenic PAHs	**86.1**	**578**

ND or zero indicate not detected. Detection limit of 0.5 ng/l.
QM is Merrimack River flow at USGS gaging station corrected for river mouth (USGS, 1993). These loadings do not account for flow away from Mass. Bay.

TABLE 8
MEASURED PAH CONCENTRATIONS IN THE MERRIMACK RIVER AND PREDICTED AND MEASURED PAH CONCENTRATIONS IN MASSACHUSETTS BAY - SPRING

	Measured River Concentration* 4/29/92	Predicted Bay Concentration 4/29/92 Dilution Factor = D 0.0083	Measured Average Bay Concentration Spring** 5/21/92
Units	ng/L	ng/L	ng/L
Naphthalene	49.4	0.410	0.370
C1-Naphthalene	41.1	0.341	0.248
C2-Naphthalene	29.6	0.246	0.368
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	7.7	0.064	ND
Acenaphthene	2.4	0.020	ND
Biphenyl	5.4	0.045	ND
Fluorene	1.5	0.013	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthrene	13.6	0.113	0.036
Anthracene	5.8	0.048	ND
C1-Phenanthrene/Anthracene	15.7	0.130	0.045
C2-Phenanthrene/Anthracene	ND	ND	0.093
C3-Phenanthrene/Anthracene	ND	ND	ND
C4-Phenanthrene/Anthracene	ND	ND	ND
Dibenzothiophene	0.6	0.005	0.018
C1-Dibenzothiophene	ND	ND	0.065
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	18.8	0.156	0.057
Pyrene	15.5	0.129	0.043
C1-Fluoranthene/Pyrene	20.3	0.169	ND
Benzo(a)anthracene	6.5	0.054	0.120
Chrysene	10.1	0.084	0.043
C1-Chrysene	ND	ND	ND
C2-Chrysene	ND	ND	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	7.1	0.059	0.042
Benzo(k)fluoranthene	6.6	0.055	0.035
Benzo(e)pyrene	5.9	0.049	ND
Benzo(a)pyrene	5.2	0.043	ND
Perylene	0.9	0.007	ND
Indeno(1,2,3-cd)pyrene	4.5	0.038	0.023
Dibenzo(a,h)anthracene	ND	ND	ND
Benzo(g,h,i)perylene	4.5	0.037	ND
Total PAHs	279	2.31	1.66
Carcinogenic PAHs	59.9	0.50	0.30

* Average of Merrimack River Stations 3 and 3A.
** Average of Mass Bay Stations 4, 5, 6, and 8.
ND indicates not detected. Detection limits for Merrimack River samples of 0.5 ng/l; for Bay samples 0.03 ng/l.

TABLE 8 (continued)
MEASURED PAH CONCENTRATIONS IN THE MERRIMACK RIVER AND PREDICTED AND MEASURED CONCENTRATIONS IN MASSACHUSETTS BAY - SPRING

	Measured River Concentration* 5/9/92	Predicted Bay Concentration 5/9/92 Dilution Factor = D 0.0071	Measured Average Bay Concentration Spring** 5/21/92
Units	ng/L	ng/L	ng/L
Naphthalene	31.9	0.226	0.370
C1-Naphthalene	15.4	0.109	0.248
C2-Naphthalene	7.7	0.055	0.368
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	6.4	0.046	ND
Acenaphthene	5.8	0.041	ND
Biphenyl	2.7	0.019	0.060
Fluorene	4.2	0.030	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthrene	17.0	0.121	0.036
Anthracene	6.5	0.046	ND
C1-Phenanthrene/Anthracene	20.0	0.142	0.045
C2-Phenanthrene/Anthracene	15.3	0.109	0.093
C3-Phenanthrene/Anthracene	9.8	0.070	ND
C4-Phenanthrene/Anthracene	24.3	0.173	ND
Dibenzothiophene	1.8	0.013	0.018
C1-Dibenzothiophene	ND	ND	0.065
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	31.3	0.222	0.057
Pyrene	26.6	0.189	0.043
C1-Fluoranthene/Pyrene	31.1	0.221	ND
Benzo(a)anthracene	13.0	0.092	0.120
Chrysene	16.5	0.117	0.043
C1-Chrysene	10.4	0.074	ND
C2-Chrysene	ND	ND	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	13.7	0.097	0.042
Benzo(k)fluoranthene	13.2	0.094	0.035
Benzo(e)pyrene	10.6	0.075	ND
Benzo(a)pyrene	13.6	0.096	ND
Perylene	3.6	0.025	ND
Indeno(1,2,3-cd)pyrene	9.7	0.069	0.023
Dibenzo(a,h)anthracene	2.2	0.016	ND
Benzo(g,h,i)perylene	10.4	0.074	ND
Total PAHs	375	2.66	1.66
Carcinogenic PAHs	119	0.84	0.30

* Average of Merrimack River Stations 3 and 3A.

** Average of Mass Bay Stations 4, 5, 6, and 8.

ND indicates not detected. Detection limits for Merrimack River samples of 0.5 ng/l; for Bay samples 0.03 ng/l.

TABLE 8 (continued)
MEASURED PAH CONCENTRATIONS IN THE MERRIMACK RIVER AND PREDICTED AND MEASURED CONCENTRATIONS IN MASSACHUSETTS BAY - SPRING

	Measured River Concentration Station 3 5/1/93	Predicted Bay Concentration 5/1/93 Dilution Factor = D 0.0094	Measured Average Bay Concentration Spring** 5/21/92
Units	ng/L	ng/L	ng/L
Naphthalene	123.0	1.021	0.370
C1-Naphthalene	8.9	0.074	0.248
C2-Naphthalene	6.5	0.054	0.368
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	2.8	0.023	ND
Acenaphthene	3.2	0.027	ND
Biphenyl	62.0	0.515	0.060
Fluorene	3.3	0.027	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthrene	72.0	0.598	0.036
Anthracene	2.7	0.022	ND
C1-Phenanthrene/Anthracene	10.0	0.083	0.045
C2-Phenanthrene/Anthracene	11.0	0.091	0.093
C3-Phenanthrene/Anthracene	6.5	0.054	ND
C4-Phenanthrene/Anthracene	ND	ND	ND
Dibenzothiophene	3.1	0.026	0.018
C1-Dibenzothiophene	ND	ND	0.065
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	28.0	0.232	0.057
Pyrene	17.0	0.141	0.043
C1-Fluoranthene/Pyrene	10.0	0.083	ND
Benzo(a)anthracene	7.1	0.059	0.120
Chrysene	15.0	0.125	0.043
C1-Chrysene	5.7	0.047	ND
C2-Chrysene	ND	ND	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	12.0	0.100	0.042
Benzo(k)fluoranthene	4.7	0.039	0.035
Benzo(e)pyrene	6.5	0.054	ND
Benzo(a)pyrene	7.6	0.063	ND
Perylene	2.5	0.021	ND
Indeno(1,2,3-cd)pyrene	5.6	0.046	0.023
Dibenzo(a,h)anthracene	1.5	0.012	ND
Benzo(g,h,i)perylene	5.4	0.045	ND
Total PAHs	444	3.68	1.66
Carcinogenic PAHs	75.9	0.63	0.30

* Average of Merrimack River Stations 3 and 3A.
** Average of Mass Bay Stations 4, 5, 6, and 8.
ND indicates not detected. Detection limits for Merrimack River samples of 0.5 ng/l; for Bay samples 0.03 ng/l.

TABLE 9
MEASURED PAH CONCENTRATIONS IN THE MERRIMACK RIVER
AND PREDICTED AND MEASURED PAH CONCENTRATIONS
IN MASSACHUSETTS BAY - AUTUMN

	Measured River Concentration Autumn Station 3 10/10/92	Predicted Bay Concentration Autumn Dilution Factor= D 0.0035	Measured Bay Concentration Autumn Station 6 10/15/92
Units	ng/L	ng/L	ng/L
Naphthalene	23.0	0.081	0.130
C1-Naphthalene	32.0	0.112	0.079
C2-Naphthalene	27.0	0.095	0.039
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	ND	ND	ND
Acenaphthene	ND	ND	ND
Biphenyl	3.1	0.011	0.021
Fluorene	ND	ND	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthracene	5.3	0.019	0.049
Anthracene	1.4	0.005	ND
C1-Phenanthracene/Anthracene	ND	ND	ND
C2-Phenanthracene/Anthracene	ND	ND	0.024
C3-Phenanthracene/Anthracene	ND	ND	ND
C4-Phenanthracene/Anthracene	ND	ND	ND
Dibenzothiophene	ND	ND	0.028
C1-Dibenzothiophene	ND	ND	ND
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	7.6	0.027	ND
Pyrene	5.7	0.020	0.036
C1-Flouranthene/Pyrene	ND	ND	0.025
Benzo(a)anthracene	3.4	0.012	0.024
Chrysene	4.0	0.014	0.035
C1-Chrysene	ND	ND	ND
C2-Chrysene	ND	ND	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	3.1	0.011	0.030
Benzo(k)fluoranthene	ND	ND	0.013
Benzo(e)pyrene	1.9	0.007	0.016
Benzo(a)pyrene	2.3	0.008	0.025
Perylene	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	0.022
Dibenzo(a,h)anthracene	ND	ND	0.008
Benzo(g,h,i)perylene	1.7	0.006	0.026
Total PAHs	121.5	0.425	0.630
Carcinogenic PAHs	20.2	0.071	0.219

ND indicates not detected. Detection limits for Merrimack River sample of 0.5 ng/l; for Bay sample of 0.01 ng/l.

TABLE 10
AVERAGE SPRING PAH CONCENTRATIONS IN THE MERRIMACK RIVER AND PREDICTED AND MEASURED PAH CONCENTRATIONS IN MASSACHUSETTS BAY

	Measured Average River Concentration Spring*	Predicted Bay Concentration Dilution Factor = D 0.0064	Measured Average** Bay Concentration 5/21/92
Units	ng/L	ng/L	ng/L
Naphthalene	57.1	0.365	0.370
C1-Naphthalene	24.4	0.156	0.248
C2-Naphthalene	16.2	0.104	0.368
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	6.2	0.040	ND
Acenaphthene	3.9	0.025	ND
Biphenyl	15.7	0.100	0.060
Fluorene	3.0	0.019	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthracene	26.6	0.170	0.036
Anthracene	5.4	0.035	ND
C1-Phenanthracene/Anthracene	16.3	0.104	0.045
C2-Phenanthracene/Anthracene	8.3	0.053	0.093
C3-Phenanthracene/Anthracene	5.2	0.033	ND
C4-Phenanthracene/Anthracene	9.7	0.062	ND
Dibenzothiophene	1.6	0.010	0.018
C1-Dibenzothiophene	ND	ND	0.065
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	25.6	0.164	0.057
Pyrene	20.2	0.129	0.043
C1-Flouranthene/Pyrene	22.6	0.145	ND
Benzo(a)anthracene	9.2	0.059	0.120
Chrysene	13.6	0.087	0.043
C1-Chrysene	5.3	0.034	ND
C2-Chrysene	ND	ND	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	10.7	0.069	0.042
Benzo(k)fluoranthene	8.9	0.057	0.035
Benzo(e)pyrene	7.9	0.051	ND
Benzo(a)pyrene	9.0	0.058	ND
Perylene	2.3	0.015	ND
Indeno(1,2,3-cd)pyrene	6.8	0.044	0.023
Dibenzo(a,h)anthracene	1.2	0.008	ND
Benzo(g,h,i)perylene	7.1	0.045	ND
Total PAHs	350.1	2.241	1.663
Carcinogenic PAHs	86.7	0.555	0.305

ND indicates not detected.
* Average of results from Merrimack River Stations 3 and 3A sampled on April 29 and May 9, 1992 and May 1, 1993.
**Average of results from Mass Bay Stations 4, 5, 6, and 8.

TABLE 11
AVERAGE AUTUMN/WINTER PAH CONCENTRATIONS IN THE MERRIMACK RIVER AND PREDICTED AND MEASURED PAH CONCENTRATIONS IN MASSACHUSETTS BAY

	Measured Average River Concentration*	Predicted Bay Concentration Dilution Factor = D 0.0041	Measured Average Bay Concentration Station 6 10/15/92
Units	ng/L	ng/L	ng/L
Naphthalene	11.5	0.047	0.130
C1-Naphthalene	16.0	0.066	0.079
C2-Naphthalene	13.5	0.055	0.039
C3-Naphthalene	ND	ND	ND
C4-Naphthalene	ND	ND	ND
Acenaphthylene	ND	ND	ND
Acenaphthene	ND	ND	ND
Biphenyl	1.6	0.006	0.021
Fluorene	ND	ND	ND
C1-Fluorene	ND	ND	ND
C2-Fluorene	ND	ND	ND
C3-Fluorene	ND	ND	ND
Phenanthracene	17.2	0.070	0.049
Anthracene	0.7	0.003	ND
C1-Phenanthracene/Anthracene	ND	ND	ND
C2-Phenanthracene/Anthracene	ND	ND	0.024
C3-Phenanthracene/Anthracene	ND	ND	ND
C4-Phenanthracene/Anthracene	ND	ND	ND
Dibenzothiophene	ND	ND	0.028
C1-Dibenzothiophene	ND	ND	ND
C2-Dibenzothiophene	ND	ND	ND
C3-Dibenzothiophene	ND	ND	ND
Fluoranthene	29.8	0.122	ND
Pyrene	21.9	0.090	0.036
C1-Flouranthene/Pyrene	ND	ND	0.025
Benzo(a)anthracene	1.7	0.007	0.024
Chrysene	2.0	0.008	0.035
C1-Chrysene	5.5	0.023	ND
C2-Chrysene	11.0	0.045	ND
C3-Chrysene	ND	ND	ND
C4-Chrysene	ND	ND	ND
Benzo(b)fluoranthene	20.6	0.084	0.030
Benzo(k)fluoranthene	7.5	0.031	0.013
Benzo(e)pyrene	10.5	0.043	0.016
Benzo(a)pyrene	10.2	0.042	0.025
Perylene	ND	ND	ND
Indeno(1,2,3-cd)pyrene	8.5	0.035	0.022
Dibenzo(a,h)anthracene	ND	ND	0.008
Benzo(g,h,i)perylene	12.4	0.051	0.026
Total PAHs	201.8	0.827	0.630
Carcinogenic PAHs	84.6	0.347	0.219

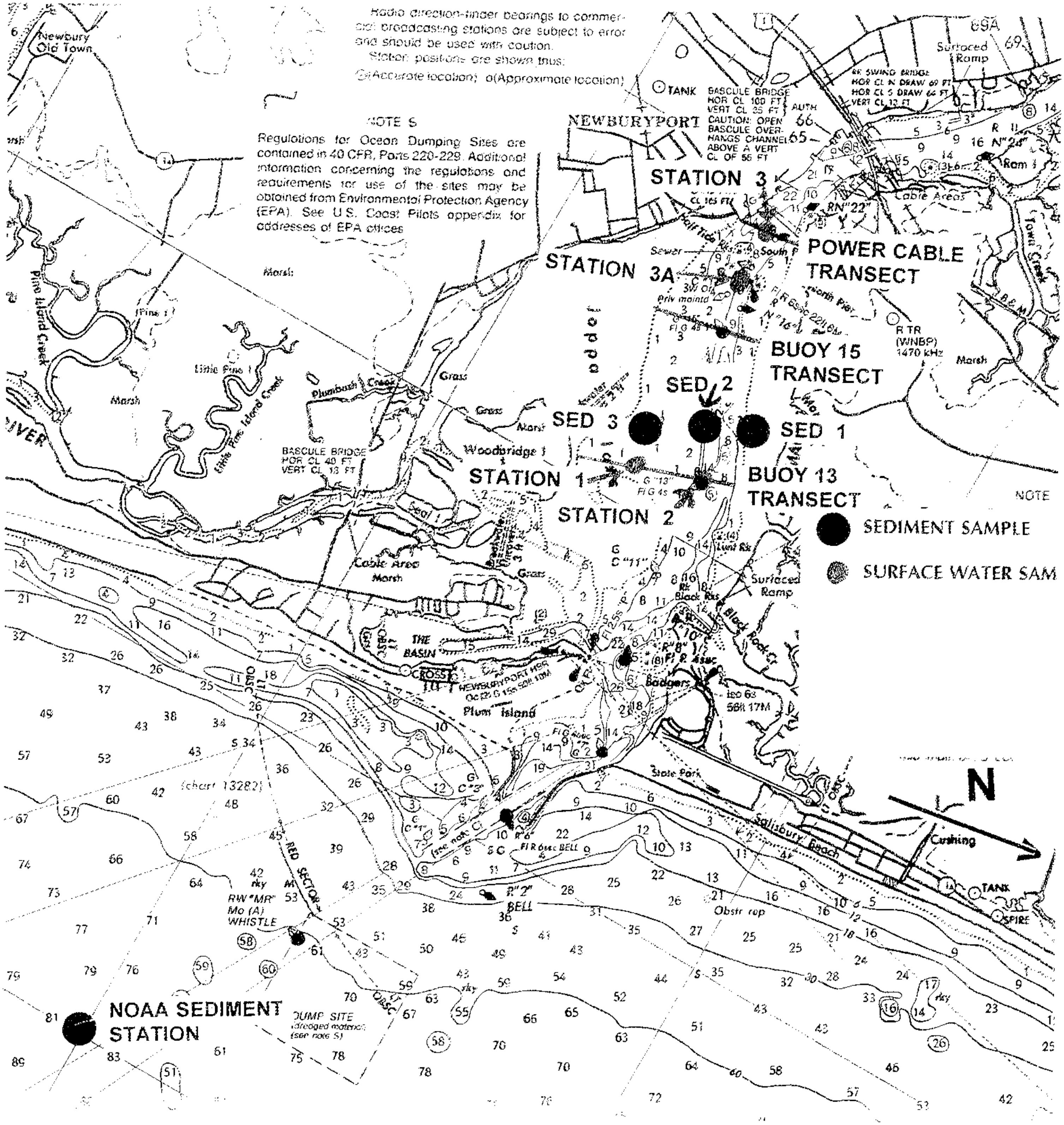
ND indicates not detected.
*Average of results from Merrimack River Station 3 sampled on October 10, 1992 and January 8, 1993. Detection limit of 0.5 ng/l. Detection limit for Mass Bays sample of 0.01 ng/l.

TABLE 12
SUMMARY OF TOTAL PAH LOADS TO MASSACHUSETTS BAY[1]
IN KG/YR

SOURCE	Merrimack	North Shore	Boston Harbor	South Shore	Cape Cod	Total
Coastal NPDES	561	346	8,126	95		9,128
Coastal Runoff	6	308	282	22	24	642
Coastal CSO			31			31
River Discharge	1,184	253	2,523	83		4,043
TOTAL	1,751	907	10,962	198	24	13,844

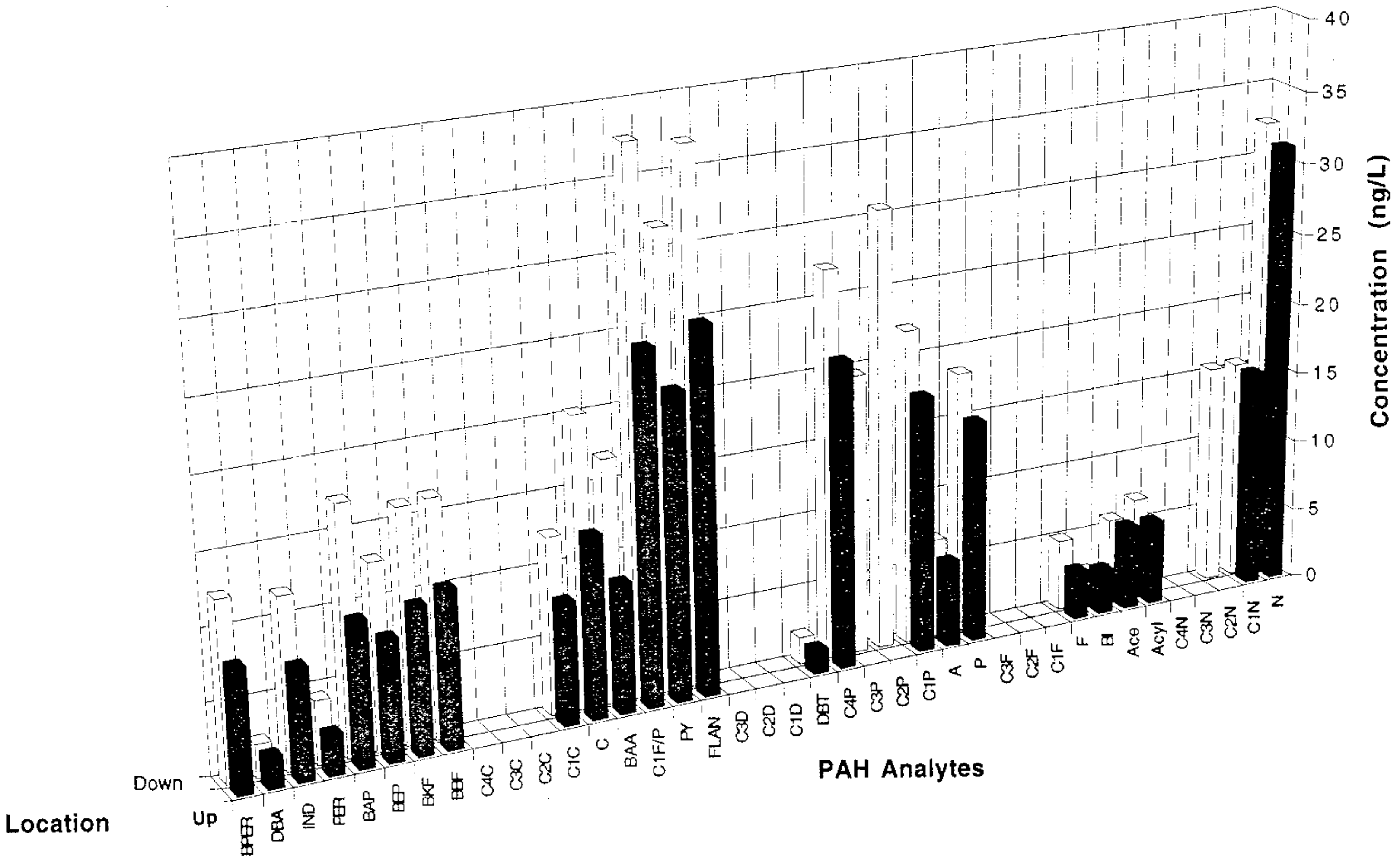
[1]Refer to: Menzie-Cura & Associates, 1995. Non-point Source Runoff PAH Loading Analysis, Massachusetts Bays Program. for description of PAH loadings calculations to Massachusetts Bay from all sources.

FIGURE 1
MERRIMACK RIVER SURFACE WATER AND SEDIMENT SAMPLING STATIONS



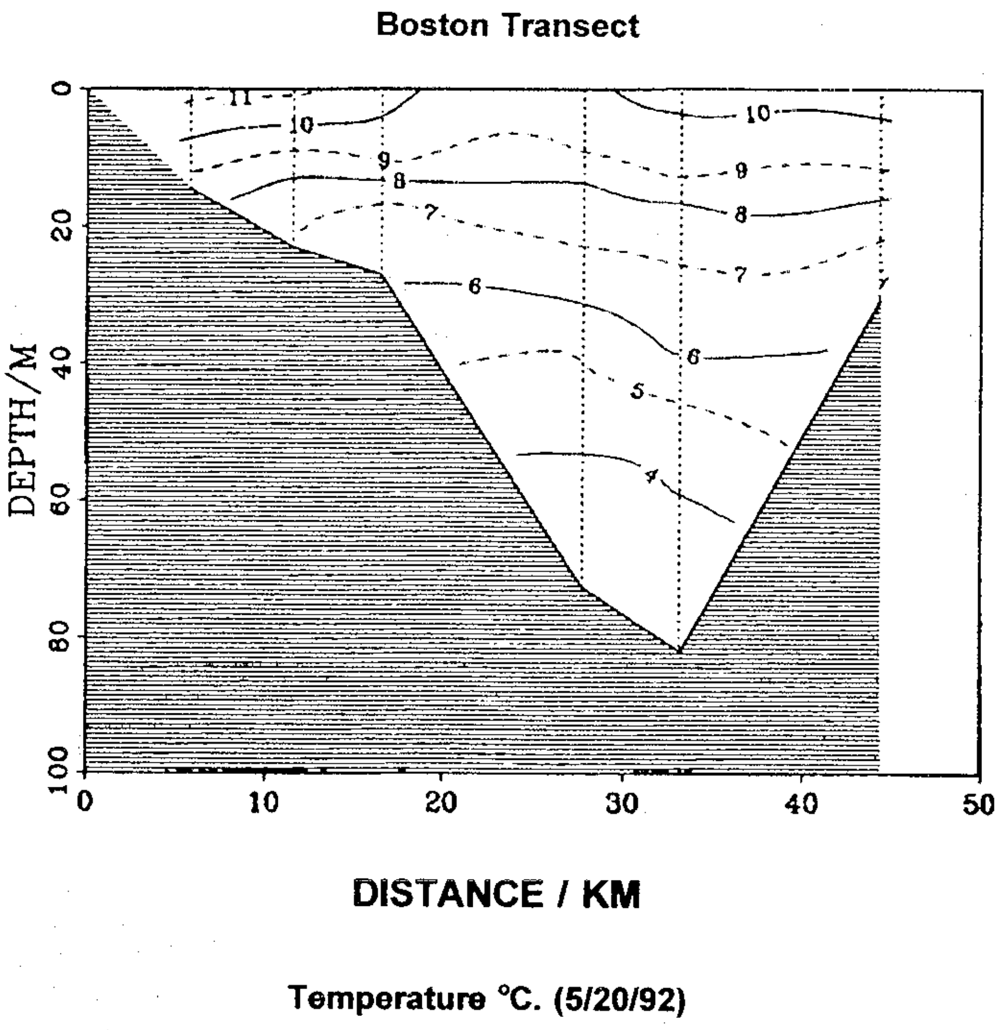
MAP SECTION FROM: NOAA NAUTICAL CHART 13274 - Portsmouth Harbor to Boston Harbor, Edition 20 - August 1992 - SCALE: 1:40,000

FIGURE 9
COMPARISON OF CONCENTRATIONS OF PAH COMPOUNDS DETECTED IN WHOLE WATER SAMPLES COLLECTED UPSTREAM (STATION 3) AND DOWNSTREAM (STATION 3A) OF THE NEWBRUYPORT WASTEWATER TREATMENT PLANT, CRUISE 2 (MAY 9, 1992)



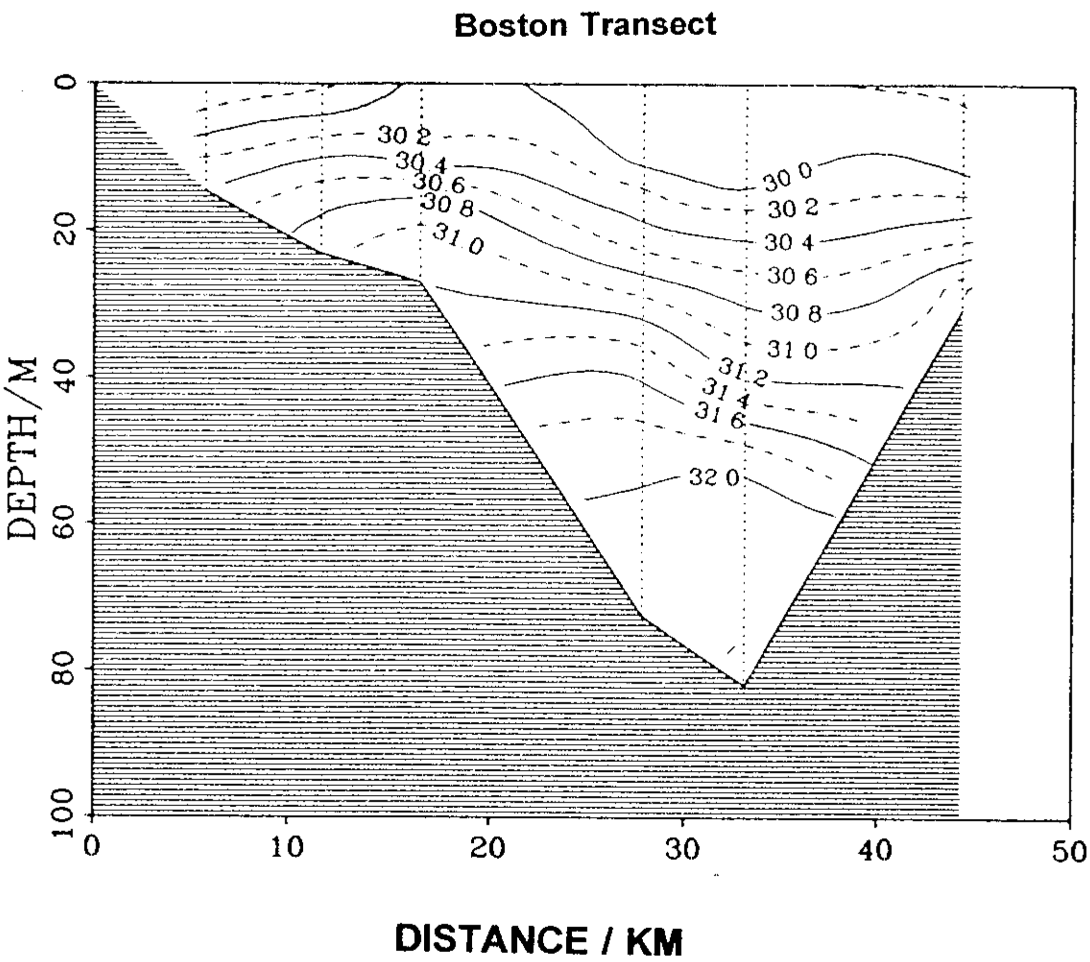
PAH Identifiers are listed in the front of Appendix A

FIGURE 10
TEMPERATURE PROFILE OF MASSACHUSETTS BAY AS MEASURED DURING MAY 1992 CRUISE



Refer to Figure 2 for Transect Location

FIGURE 11
SALINITY PROFILE OF MASSACHUSETTS BAY AS MEASURED DURING MAY 1992 CRUISE



Salinity PSU (5/20/92)

Refer to Figure 2 for Transect Location

FIGURE 12
TEMPERATURE (^{o}C) PROFILE OF MASSACHUSETTS BAY, AS MEASURED DURING OCTOBER 1992 CRUISE

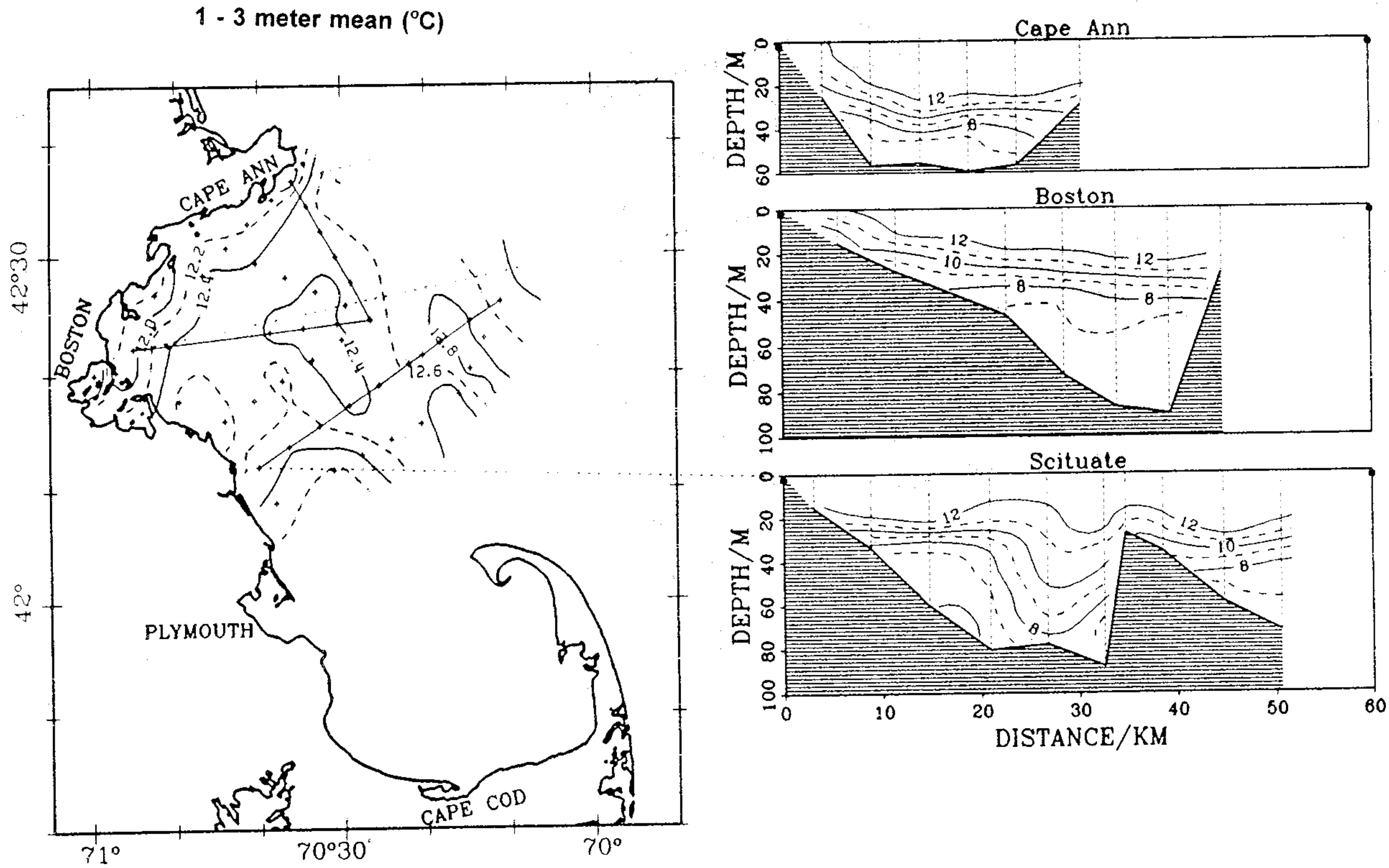
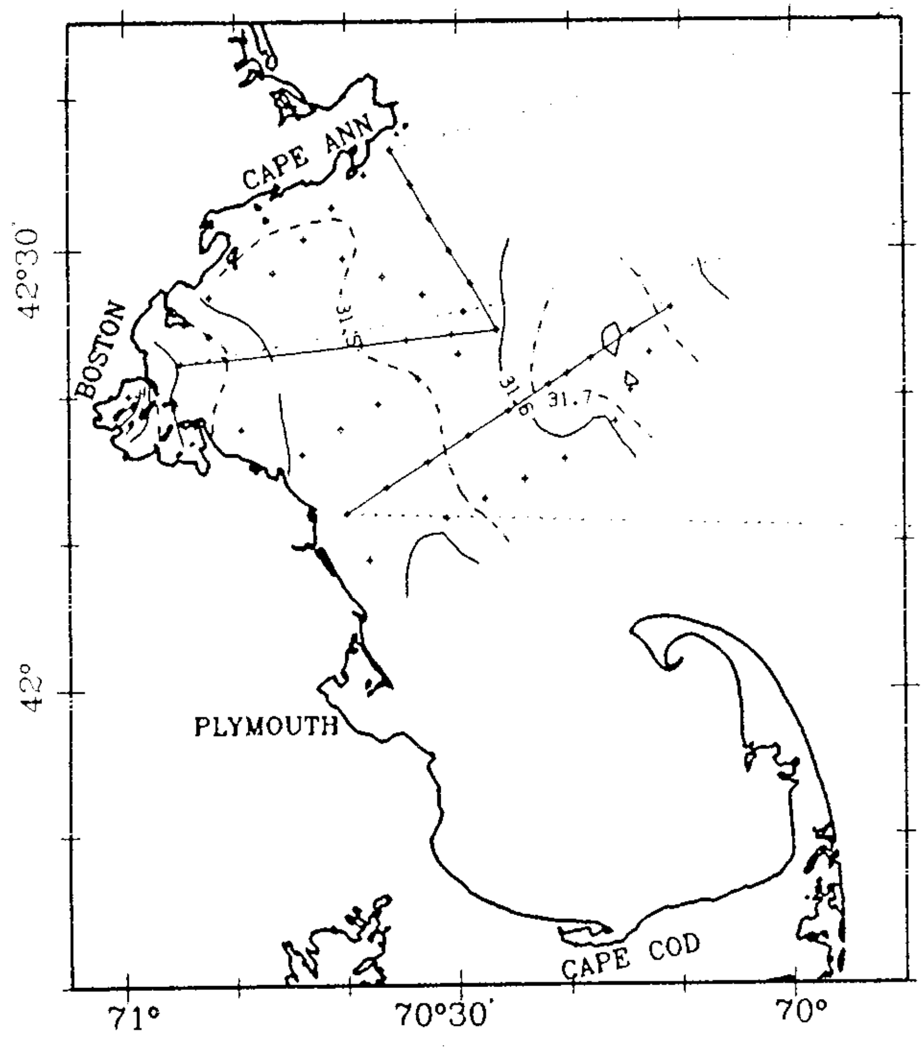


FIGURE 13
SALINITY PROFILE OF MASSACHUSETTS BAY, AS MEASURED DURING OCTOBER 1992 CRUISE

1 - 3 meter mean (PSU)



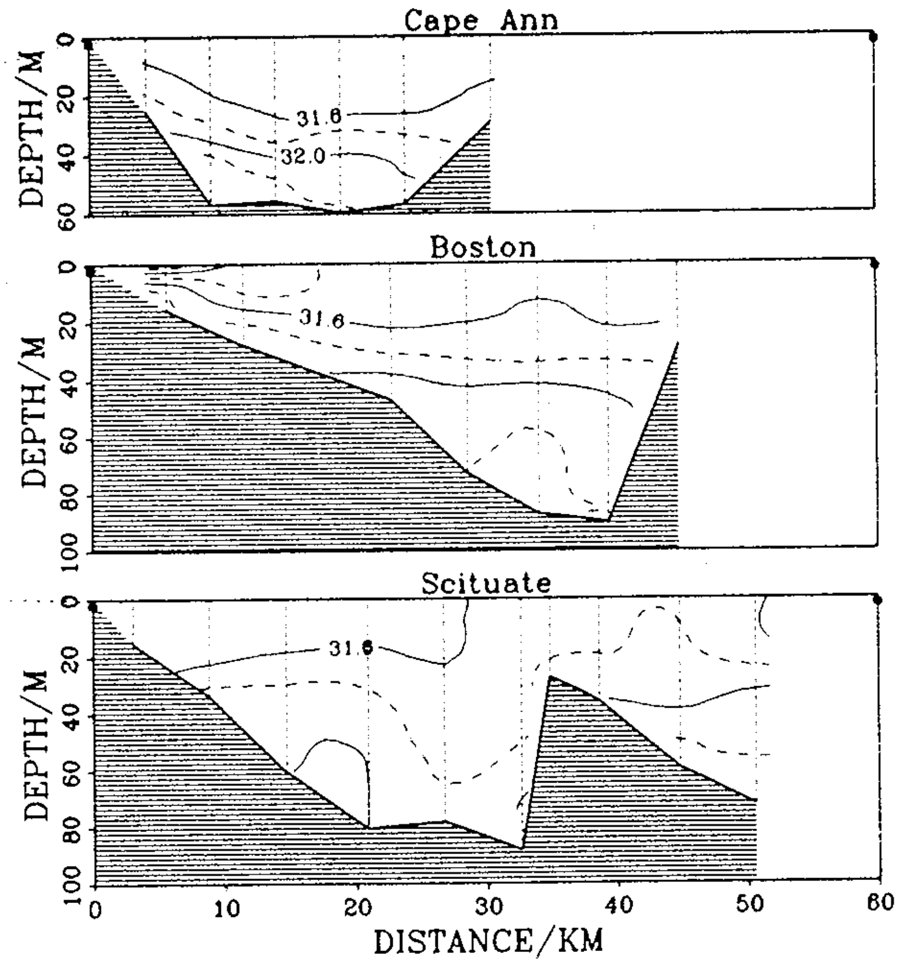
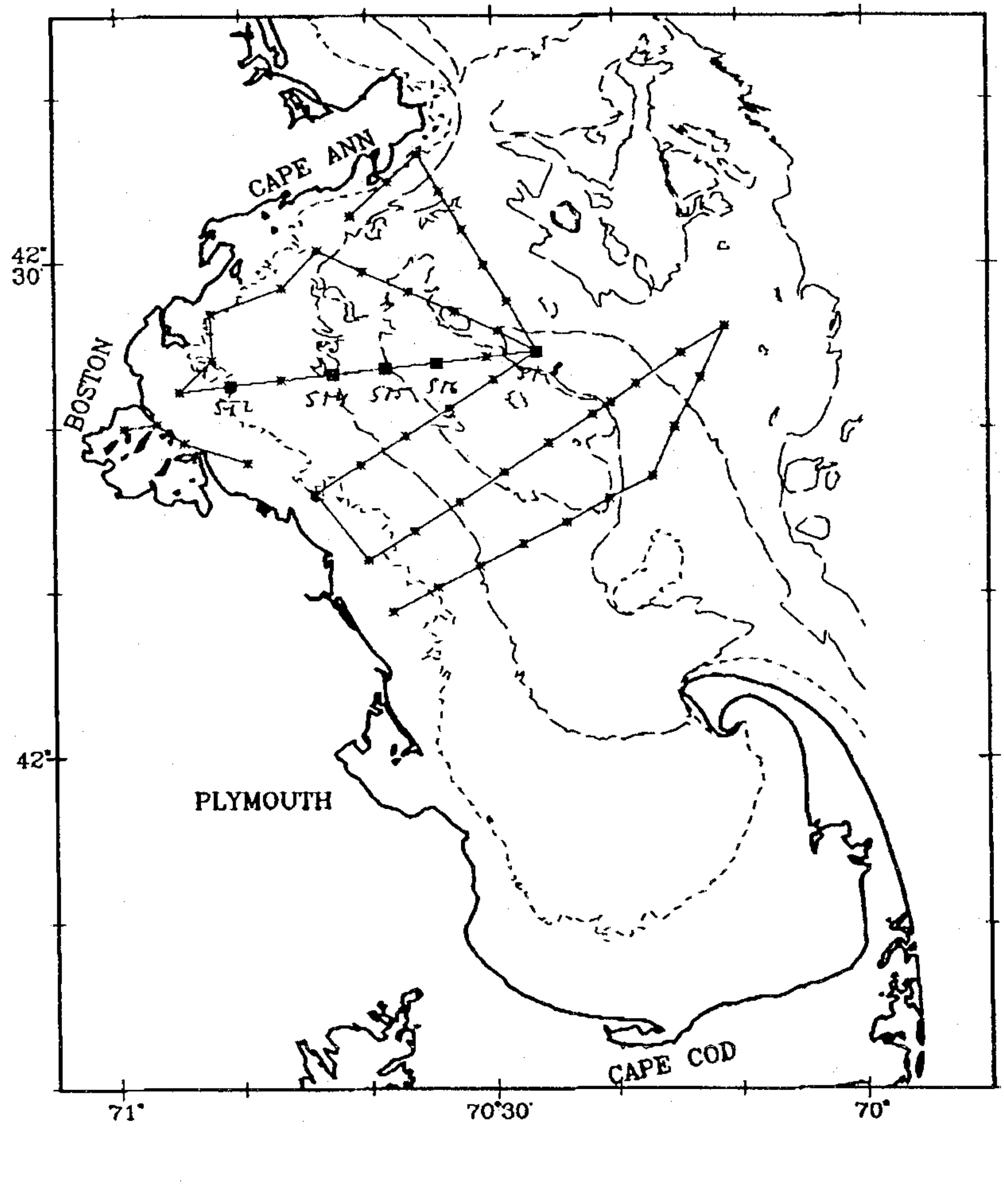
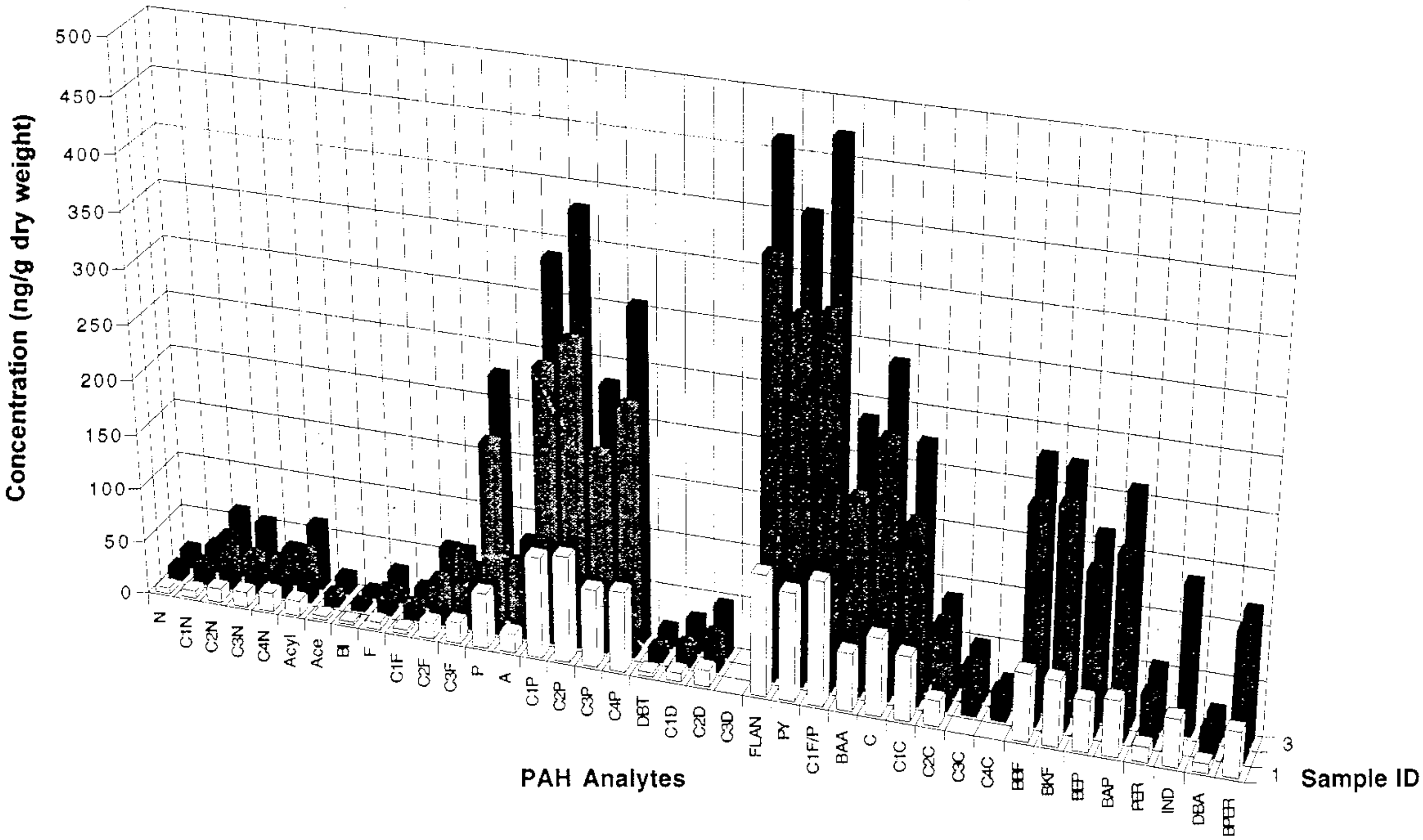


FIGURE 2
MASSACHUSETTS BAY CRUISE TRACKS AND SAMPLING STATIONS



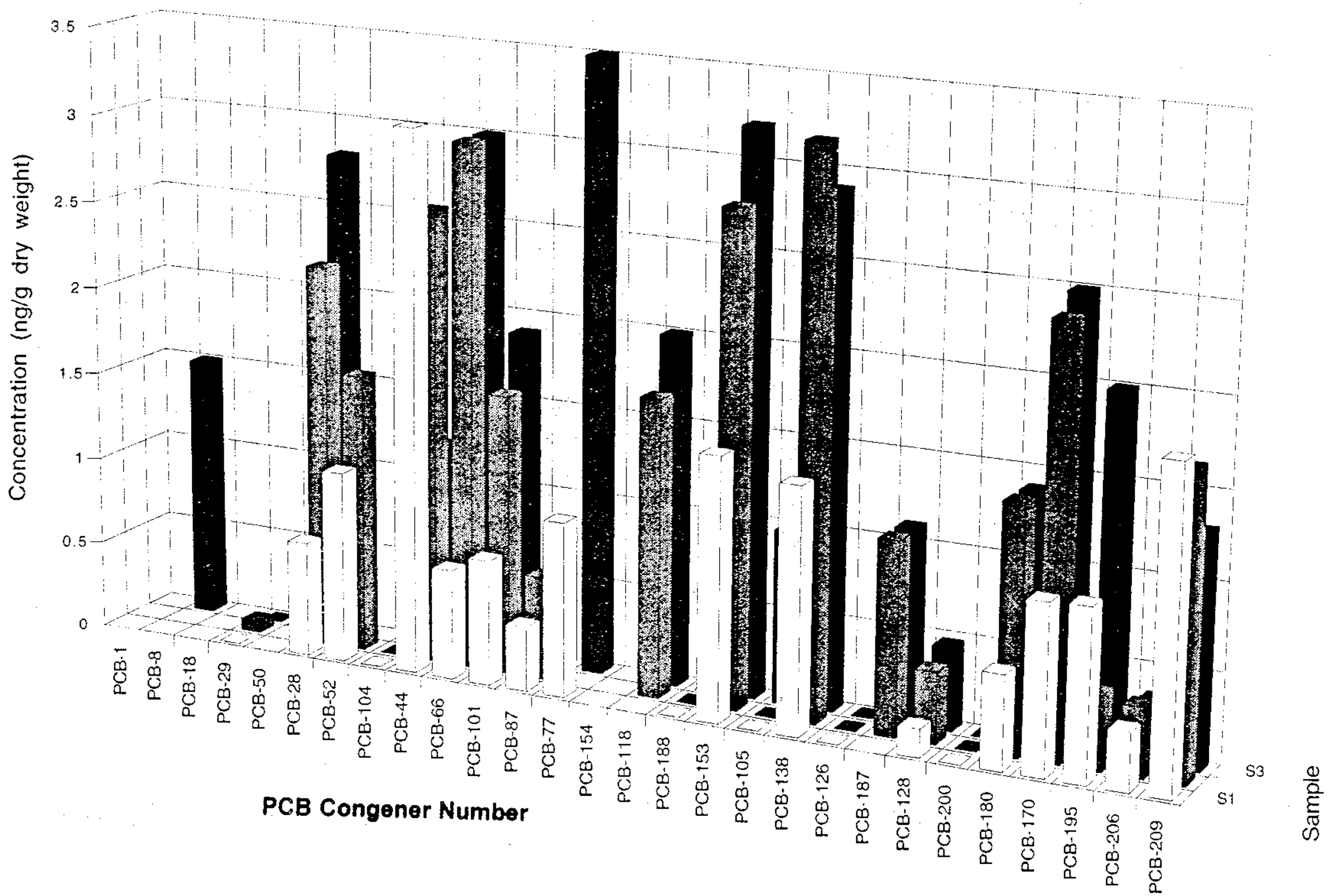
The transect labeled "Boston" was surveyed during the May 1992 survey; water column particulate samples were collected from each of the labeled stations during this cruise. An additional sample from St6 was collected during the October 1992 survey, conducted in conjunction with a larger Bay-wide survey, supported by the MIT Sea Grant Program.

FIGURE 3
CONCENTRATIONS OF
PAH COMPOUNDS DETECTED IN MERRIMACK RIVER SEDIMENT SAMPLES



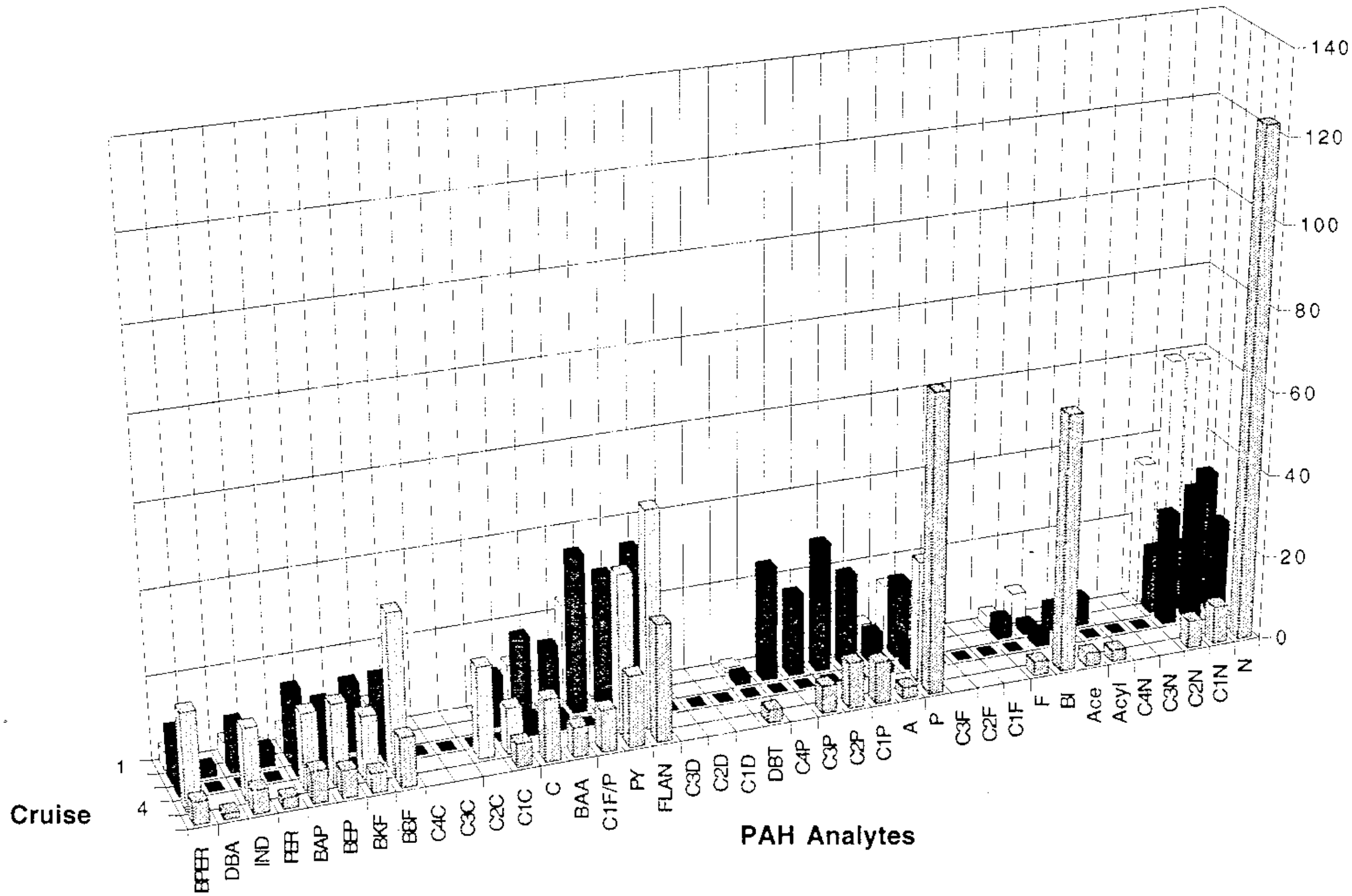
Refer to Figure 1 for sample locations.
PAH identifiers are listed in the front of Appendix A.

FIGURE 4
CONCENTRATIONS OF PCB CONGENERS DETECTED IN MERRIMACK RIVER SEDIMENT SAMPLES



Refer to Figure 1 for sample locations.
PCB congeners are listed in the front of Appendix A.

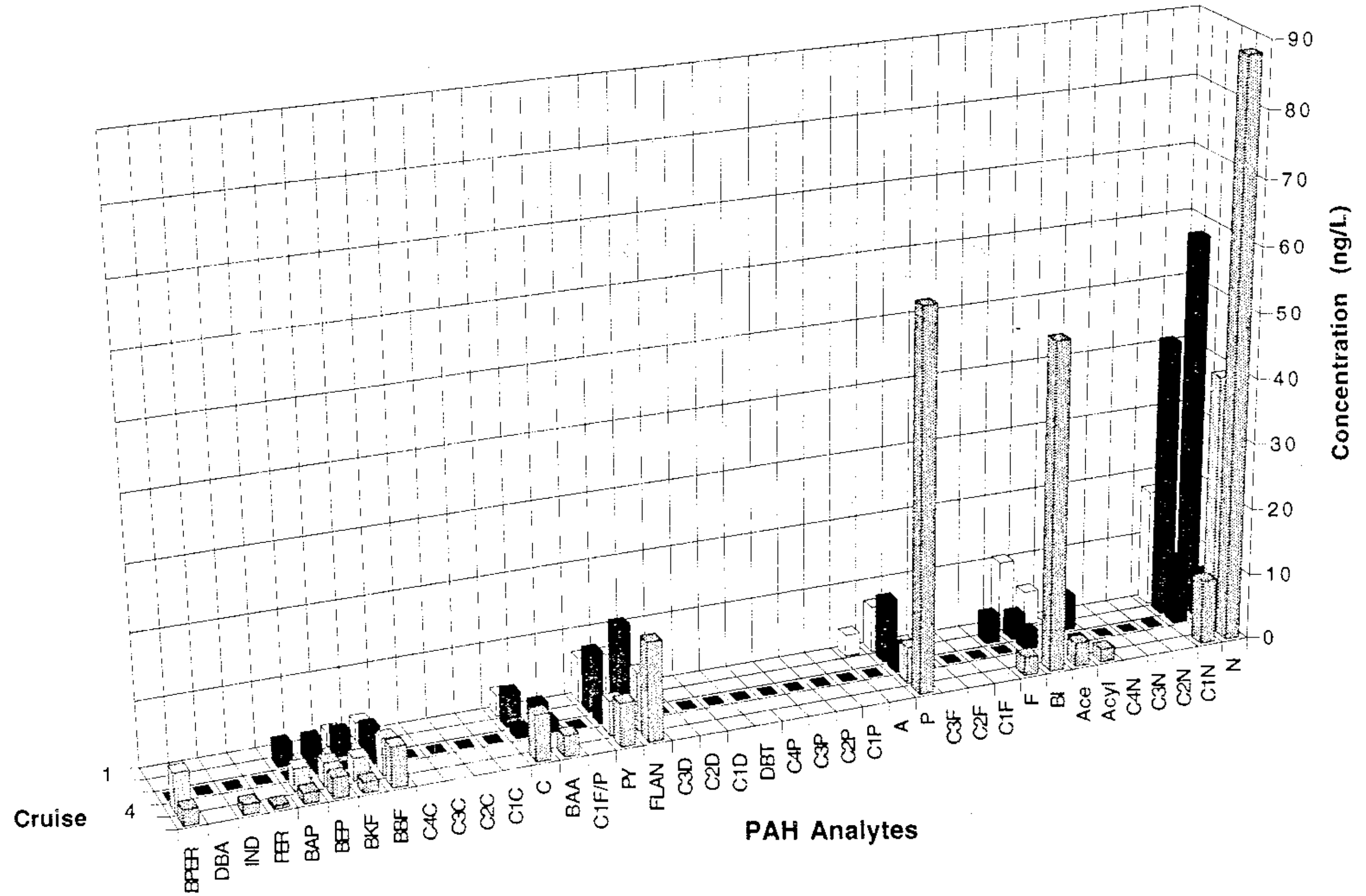
FIGURE 5
CONCENTRATIONS OF PAH COMPOUNDS DETECTED IN WHOLE FRESH WATER, WELL-MIXED WATER COLUMN SAMPLES AT LOW TIDE, NEAR NEWBURYPORT (STATION 3)



Cruise Dates
1 4/29/92
2 5/9/92
3 10/10/92
4 1/8/93
5 5/1/93

PAH Identifiers are listed in the front of Appendix A

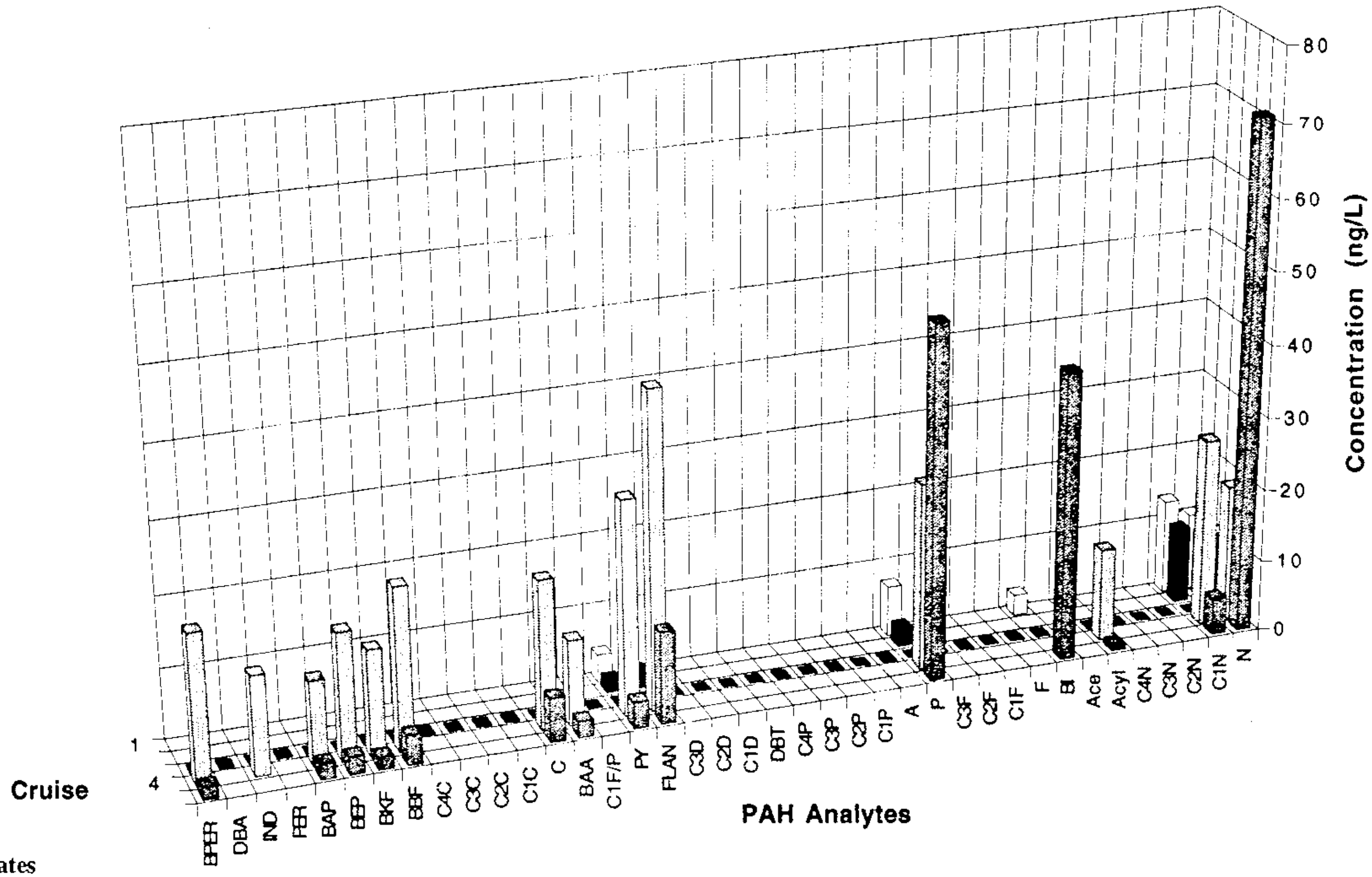
FIGURE 6
CONCENTRATIONS OF PAH COMPOUNDS DETECTED IN WHOLE WATER SAMPLES FROM THE SURFACE FRESH WATER LAYER AT HIGH TIDE, SOUTH OF BUOY 13 (STATION 1)



Cruise Dates
1 4/29/92
2 5/9/92
3 10/10/92
4 1/8/93
5 5/1/93

PAH Identifiers are listed in the front of Appendix A

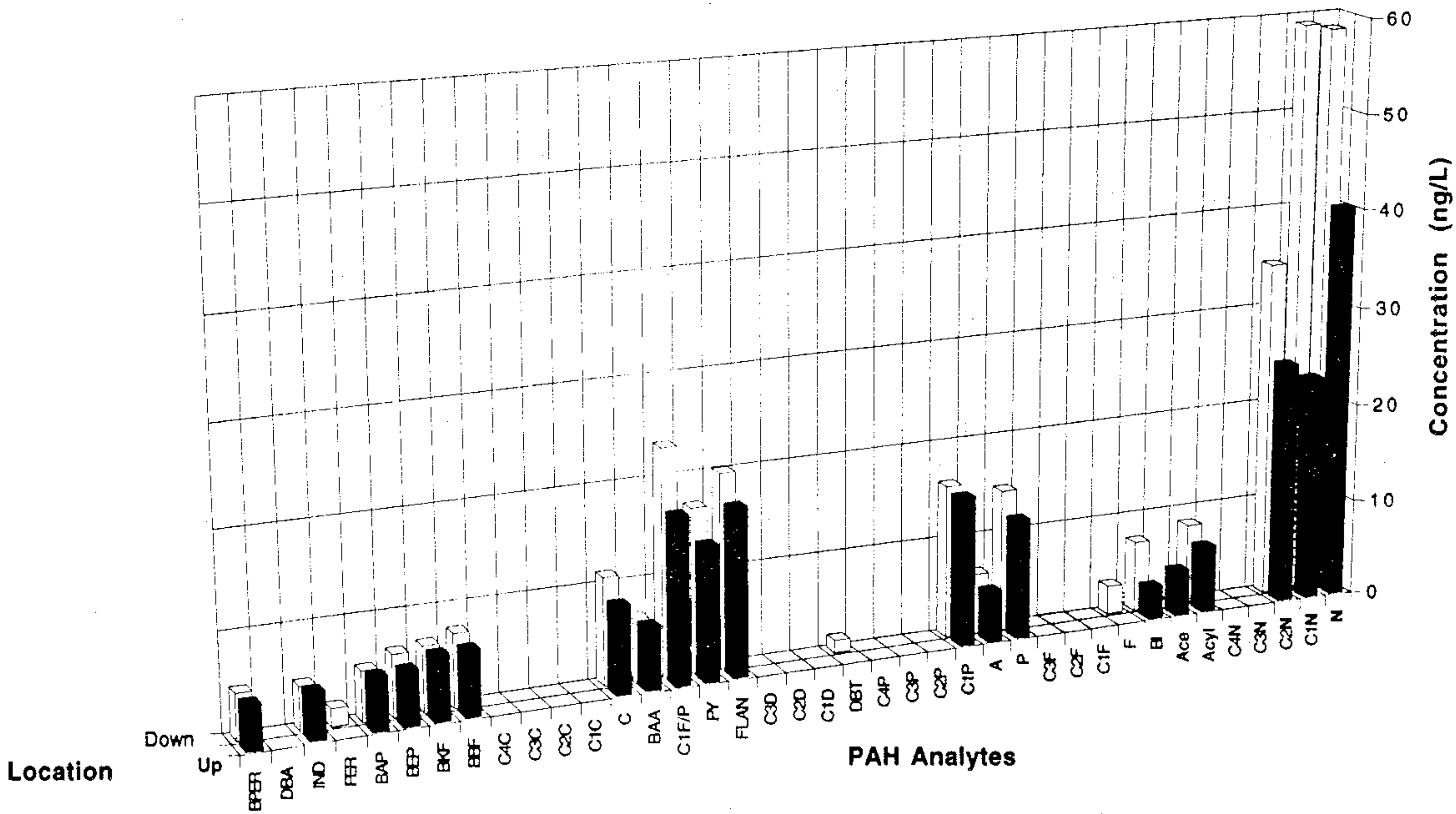
FIGURE 7
CONCENTRATIONS OF PAH COMPOUNDS DETECTED IN WHOLE WATER SAMPLES FROM THE SALT WATER LAYER AT HIGH TIDE, NEAR BUOY 13 (STATION 2)



Cruise Dates
1 4/29/92
2 5/9/92
3 10/10/92
4 1/8/93
5 5/1/93

PAH Identifiers are listed in the front of Appendix A

FIGURE 8
COMPARISON OF CONCENTRATIONS OF PAH COMPOUNDS DETECTED IN WHOLE WATER SAMPLES COLLECTED UPSTREAM (STATION 3) AND DOWNSTREAM (STATION 3A) OF THE NEWBRUYPORT WASTEWATER TREATMENT PLANT, CRUISE 1 (APRIL 29, 1992)



PAH Identifiers are listed in the front of Appendix A

APPENDIX A

WATER COLUMN AND SEDIMENT DATA FOR ORGANIC COMPOUNDS AND CONVENTIONAL WATER QUALITY PARAMETERS, BY STATION AND SAMPLING DATE AND LABORATORY QA DATA

Mass Bays Program
Merrimack River Chemical Data
Compound Names and Codes

PAHs and Related Compounds	**Laboratory Code**	**Code on Figures**
Naphthalene	C0N	N
C1-Naphthalene	C1N	C1N
C2-Naphthalene	C2N	C2N
C3-Naphthalene	C3N	C3N
C4-Naphthalene	C4N	C4N
Acenaphthylene	ACEY	Acyl
Acenaphthene	ACE	ACE
Biphenyl	BIP	BI
Fluorene	C0F	F
C1-Fluorene	C1F	C1F
C2-Fluorene	C2F	C2F
C3-Fluorene	C3F	C3F
Phenanthrene	C0P	P
Anthracene	C0A	A
C1-Phenanthrene/Anthracene	C1P/A	C1P
C2-Phenanthrene/Anthracene	C2P/A	C2P
C3-Phenanthrene/Anthracene	C3P/A	C3P
C4-Phenanthrene/Anthracene	C4P/A	C4P
Dibenzothiophene	C0D	DBT
C1-Dibenzothiophene	C1D	C1D
C2-Dibenzothiophene	C2D	C2D
C3-Dibenzothiophene	C3D	C3D
Fluoranthene	FLANT	FLAN
Pyrene	PYR	PY
C1-Fluoranthene/Pyrene	C1F/P	C1F/P
Benzo(a)anthracene	BAA	BAA
Chrysene	C0C	C
C1-Chrysene	C1C	C1C
C2-Chrysene	C2C	C2C
C3-Chrysene	C3C	C3C
C4-Chrysene	C4C	C4C
Benzo(b)fluoranthene	BBF	BBF
Benzo(k)fluoranthene	BKF	BKF
Benzo(e)pyrene	BEP	BEP
Benzo(a)pyrene	BAP	BAP
Perylene	PER	PER
Indeno(1,2,3-cd)pyrene	IND	IND
Dibenzo(a,h)anthracene	DAH	DBA
Benzo(g,h,i)perylene	BGP	BPER
Total PAHs	TPAH	TPAH
Carcinogenic PAHs	CPAH	CPAH

Total PAHs calculated as the sum of all detected PAH compounds

Carcinogenic PAHs calculated as the sum of the following compounds:
pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthe benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthrancene and benzo(g,h,i)perylene.

PCBs	Code
2-Chloro	PCB1
2,4'--Dichloro	PCB8
2,2',5-Trichloro	PCB18
2,4,5-Trichloro	PCB29
2,2',4,6-Tetrachloro	PCB50
2,4,4'-Trichloro	PCB28
2,2',5,5'-Tetrachloro	PCB52
2,2',4,6,6'-Pentachloro	PCB104
2,2',3,5'-Tetrachloro	PCB44
2,3',4,4'-Tetrachloro	PCB66
2,2',4,5,5'-Pentachloro	PCB101
2,2',3,4,5'-Pentachloro	PCB87
3,3',4,4'-Tetrachloro	PCB77
2,2',4,4',5,6'-Hexachloro	PCB154
2,3',4,4',5-Pentachloro	PCB118
2,2',3,4',5,6,6'-Heptachloro	PCB188
2,2',4,4',5,5'-Hexachloro	PCB153
2,3,3',4,4'-Pentachloro	PCB105
2,2',3,4,4',5'-Hexachloro	PCB138
3,3',4,4',5-Pentachloro	PCB126
2,2',3,4',5,5',6-Heptachloro	PCB187
2,2',3,3',4,4'-Hexachloro	PCB128
2,2',3,3',4,5',6,6'-Octachloro	PCB200
2,2',3,4,4',5,5'-Heptachloro	PCB180
2,2',3,3',4,4',5-Heptachloro	PCB170
2,2',3,3',4,4',5,6-Octachloro	PCB195
2,2',3,3',4,4',5,5',6-Nonachloro	PCB206
Decachloro	PCB209
Total PCBs	TPCBs

Total PCBs calculated as the sum of all detected PCB compounds.

Mass Bays Program
Merrimack River Chemical Data
Compound Names and Codes

Pesticides	Code
HCB	HCB
gamma-BHC	GBHC
Heptachlor	HEPT
Aldrin	ALD
Heptachlor epoxide	HE
2,4'-DDE	2,4'-DDE
cis-Chlordane	CIS
trans-Chlordane	TRANS
Dieldrin	DIEL
4,4'-DDE	4,4'-DDE
2,4'-DDD	2,4'-DDD
4,4'-DDD	4,4'-DDD
2,4'-DDT	2,4'-DDT
4,4'-DDT	4,4'-DDT
Mirex	MIREX
Total Pesticides	TPEST

Total Pesticides calculated as the sum of all detected pesticide compounds.

Conventional Pollutants	Code
Total Suspended Solids	TSS
Oil & Grease Analytical Results	O&G
Total Organic Carbon	TOC

Mass Bays Program	1st River Cruise	1st River Cruise	2nd River Cruise
Merrimack River Data	No. of Buoy 13	So. of Buoy 13	So. of Buoy 13
Station Designation	SED-1	SED-2	SED-3
Matrix	Sediment	Sediment	Sediment
Organics Sample ID	MESED-1	MESED-2	M3HT-SED
Sample Collection Date	04/29/92	04/29/92	05/09/92
PAH Analytical Results	07/26/92	07/26/92	07/26/92
Units	ng/g	ng/g	ng/g
Naphthalene	5.67	13.22	16.78
C1-Naphthalene	6.91	20.23	24.9
C2-Naphthalene	12.91	49.56	60.88
C3-Naphthalene	13.96	35.59	54.38
C4-Naphthalene	17.49	35.61	33.91
Acenaphthylene	14.24	47.63	61.11
Acenaphthene	3.59	11.05	15.78
Biphenyl	2.72	6.38	5.9
Fluorene	6.74	23.59	29.15
C1-Fluorene	4.02	13.59	17.65
C2-Fluorene	15.01	42.88	60.16
C3-Fluorene	19.28	72.93	45.09
Phenanthrene	51.46	177.82	226.73
Anthracene	17.34	70.99	79
C1-Phenanthrene/Anthracene	93.89	252.22	336.9
C2-Phenanthrene/Anthracene	98.95	279.5	381.7
C3-Phenanthrene/Anthracene	71.91	183.19	232.83
C4-Phenanthrene/Anthracene	74.2	230.3	306.46
Dibenzothiophene	3.92	12.56	17.09
C1-Dibenzothiophene	8.08	19.16	30.18
C2-Dibenzothiophene	15.18	33.69	47.11
C3-Dibenzothiophene			
Fluoranthene	112.43	378.52	463.5
Pyrene	99.59	329.81	404.62
C1-Fluoranthene/Pyrene	114.57	335.98	472.55
Benzo(a)anthracene	52.57	180.9	236.54
Chrysene	71.35	236.46	288.67
C1-Chrysene	59.2	166.05	224.33
C2-Chrysene	23.31	79.37	87.61
C3-Chrysene		44.97	49.11
C4-Chrysene		26.48	21.44
Benzo(b)fluoranthene	61.82	198.14	228.14
Benzo(k)fluoranthene	60.07	202.24	224.61
Benzo(e)pyrene	46.72	147.75	167.57
Benzo(a)pyrene	51.01	167.82	210.81
Perylene	13.74	46.29	55.28
Indeno(1,2,3-cd)pyrene	43.56		137.02
Dibenzo(a,h)anthracene	8.35	24.3	25.16
Benzo(g,h,i)perylene	41.21	115.22	120.31
Total PAHs	**1,417**	**4,312**	**5,501**
Carcinogenic PAHs	**490**	**1,455**	**1,876**

Blank spaces indicate non-detect.

Mass Bays Program Merrimack River Data Station Designation	1st Bay Cruise Massachusetts Bay Station 2	1st Bay Cruise Massachusetts Bay Station 4	1st Bay Cruise Massachusetts Bay Station 5	1st Bay Cruise Massachusetts Bay Station 6
Matrix	**100L Seawater Particulate**	**100L Seawater Particulate**	**100L Seawater Particulate**	**100L Seawater Particulate**
Organics Sample ID	**B02-5-21-92**	**B04-5-21-92**	**B05-5-21-92**	**B06 5-21-92**
Sample Collection Date	**05/21/92**	**05/21/92**	**05/21/92**	**05/21/92**
PAH Analytical Results	**07/27/92**	**07/27/92**	**07/27/92**	**07/29/92**
Units	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Naphthalene	0.32	0.35	0.39	0.43
C1-Naphthalene	0.31	0.3	0.28	0.24
C2-Naphthalene	1.13	0.57	0.45	
C3-Naphthalene	0.23			
C4-Naphthalene				
Acenaphthylene	0.06			
Acenaphthene				
Biphenyl			0.07	0.1
Fluorene				
C1-Fluorene				
C2-Fluorene				
C3-Fluorene				
Phenanthrene	0.24	0.07		0.075
Anthracene	0.2			
C1-Phenanthrene/Anthracene				0.18
C2-Phenanthrene/Anthracene				
C3-Phenanthrene/Anthracene				
C4-Phenanthrene/Anthracene				
Dibenzothiophene			0.07	
C1-Dibenzothiophene			0.26	
C2-Dibenzothiophene				
C3-Dibenzothiophene				
Fluoranthene	0.33	0.06	0.07	0.048
Pyrene	0.23	0.05	0.05	0.03
C1-Fluoranthene/Pyrene	0.49			
Benzo(a)anthracene	0.21	0.17	0.11	0.07
Chrysene	0.19	0.05	0.06	0.032
C1-Chrysene	0.2			
C2-Chrysene				
C3-Chrysene				
C4-Chrysene				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Benzo(k)fluoranthene	0.14	0.04	0.04	0.028
Benzo(e)pyrene	0.11			
Benzo(a)pyrene	0.15			
Perylene				
Indeno(1,2,3-cd)pyrene	0.13	0.04	0.05	
Dibenzo(a,h)anthracene				
Benzo(g,h,i)perylene	0.13			0
Total PAHs	**4.95**	**1.75**	**1.95**	**1.27**
Carcinogenic PAHs	**1.33**	**0.40**	**0.36**	**0.20**

Blank spaces indicate non-detect.

Mass Bays Program	1st Bay Cruise	2nd Bay Cruise
Merrimack River Data	Massachusetts	Massachusetts
Station Designation	Bay Station 8	Bay Station 6
	100L Seawater	300L Seawater
Matrix	Particulate	Particulate
Organics Sample ID	B08-5-21-92	BO-6-10-15-92
Sample Collection Date	05/21/92	10/15/92
PAH Analytical Results	**07/27/92**	**2/24/93**
Units	ng/L	ng/L
Naphthalene	0.31	0.13
C1-Naphthalene	0.17	0.079
C2-Naphthalene	0.45	0.039
C3-Naphthalene		
C4-Naphthalene		
Acenaphthylene		
Acenaphthene		
Biphenyl	0.07	0.021
Fluorene		
C1-Fluorene		
C2-Fluorene		
C3-Fluorene		
Phenanthrene		0.049
Anthracene		
C1-Phenanthrene/Anthracene		
C2-Phenanthrene/Anthracene	0.37	0.024
C3-Phenanthrene/Anthracene		
C4-Phenanthrene/Anthracene		
Dibenzothiophene		0.028
C1-Dibenzothiophene		
C2-Dibenzothiophene		
C3-Dibenzothiophene		
Fluoranthene	0.05	
Pyrene	0.04	0.036
C1-Fluoranthene/Pyrene		0.025
Benzo(a)anthracene	0.13	0.024
Chrysene	0.03	0.035
C1-Chrysene		
C2-Chrysene		
C3-Chrysene		
C4-Chrysene		
Benzo(b)fluoranthene	0.03	0.03
Benzo(k)fluoranthene	0.03	0.013
Benzo(e)pyrene		0.016
Benzo(a)pyrene		0.025
Perylene		
Indeno(1,2,3-cd)pyrene		0.022
Dibenzo(a,h)anthracene		0.008
Benzo(g,h,i)perylene		0.026
Total PAHs	**1.68**	**0.63**
Carcinogenic PAHs	**0.26**	**0.22**

Blank spaces indicate non-detect.

Mass Bays Program Merrimack River Data Station Designation	1st River Cruise So. of Buoy 13 River Station 1 Fresh Layer High Tide	1st River Cruise Near Buoy 13 River Station 2 Salt Layer High Tide	1st River Cruise Upstream River Station 3A Fresh Layer Low Tide	1st River Cruise Upstream River Station 3 Fresh Layer Low Tide
Matrix	**River Water**	**River Water**	**River Water**	**River Water**
Organics Sample ID	**ME3HT**	**ME7HT**	**ME12LT**	**ME16LT**
Sample Collection Date	**04/29/92**	**04/29/92**	**04/29/92**	**04/29/92**
PAH Analytical Results	**07/29/92**	**07/30/92**	**07/30/92**	**07/29/92**
Units	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Naphthalene	28.75	10.65	58.51	40.21
C1-Naphthalene	17.59	13.11	59.12	23.06
C2-Naphthalene			34.39	24.79
C3-Naphthalene				
C4-Naphthalene				
Acenaphthylene			8.46	6.96
Acenaphthene	5.17			4.78
Biphenyl	10.49	2.91	7.4	3.42
Fluorene			3.07	
C1-Fluorene				
C2-Fluorene				
C3-Fluorene				
Phenanthrene	6.98	7.11	14.7	12.47
Anthracene	3.18		6.29	5.34
C1-Phenanthrene/Anthracene			15.87	15.51
C2-Phenanthrene/Anthracene				
C3-Phenanthrene/Anthracene				
C4-Phenanthrene/Anthracene				
Dibenzothiophene			1.26	
C1-Dibenzothiophene				
C2-Dibenzothiophene				
C3-Dibenzothiophene				
Fluoranthene	6.54	5.81	20.06	17.49
Pyrene	6.63	3.89	17.01	13.99
C1-Fluoranthene/Pyrene			23.3	17.37
Benzo(a)anthracene			6.41	6.5
Chrysene	3.24		11.11	9.07
C1-Chrysene				
C2-Chrysene				
C3-Chrysene				
C4-Chrysene				
Benzo(b)fluoranthene	2.75		7.45	6.69
Benzo(k)fluoranthene	1.99		6.63	6.6
Benzo(e)pyrene			6.23	5.49
Benzo(a)pyrene			5	5.3
Perylene			1.77	
Indeno(1,2,3-cd)pyrene			4.38	4.71
Dibenzo(a,h)anthracene				
Benzo(g,h,i)perylene			4.58	4.43
Total PAHs	**93.31**	**43.48**	**323**	**234**
Carcinogenic PAHs	**14.61**	**3.89**	**62.57**	**57.29**

Blank spaces indicate non-detect.

Mass Bays Program	2nd River Cruise	2nd River Cruise	2nd River Cruise	2nd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3A	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	M3HT	M4HT	M1LT	M2LT
Sample Collection Date	05/09/92	05/09/92	05/09/92	05/09/92
PAH Analytical Results	**07/26/92**	**07/26/92**	**07/26/92**	**07/26/92**
Units	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Naphthalene	58.05	9.28	32.46	31.26
C1-Naphthalene	42.24	10.6	15.47	15.37
C2-Naphthalene			15.46	
C3-Naphthalene				
C4-Naphthalene				
Acenaphthylene	5.21		6.9	5.92
Acenaphthene			5.76	5.92
Biphenyl	3.76		2.32	3.15
Fluorene	4.35		4.98	3.43
C1-Fluorene				
C2-Fluorene				
C3-Fluorene				
Phenanthrene	9.41	2.76	18.43	15.55
Anthracene			6.91	5.99
C1-Phenanthrene/Anthracene			22.09	17.99
C2-Phenanthrene/Anthracene			30.66	
C3-Phenanthrene/Anthracene			19.58	
C4-Phenanthrene/Anthracene			27.18	21.46
Dibenzothiophene			1.89	1.69
C1-Dibenzothiophene				
C2-Dibenzothiophene				
C3-Dibenzothiophene				
Fluoranthene	12.54	2.41	36.96	25.59
Pyrene	9.08	1.86	31.75	21.39
C1-Fluoranthene/Pyrene			37.6	24.66
Benzo(a)anthracene	2.67		16.91	9.04
Chrysene	5.13		20.25	12.69
C1-Chrysene			12.35	8.51
C2-Chrysene				
C3-Chrysene				
C4-Chrysene				
Benzo(b)fluoranthene	3.68		16.42	10.97
Benzo(k)fluoranthene	3.72		16.21	10.2
Benzo(e)pyrene	3.39		12.88	8.38
Benzo(a)pyrene	3.42		17.19	9.97
Perylene			4.36	2.8
Indeno(1,2,3-cd)pyrene			11.8	7.67
Dibenzo(a,h)anthracene			2.29	2.16
Benzo(g,h,i)perylene			12.35	8.49
Total PAHs	**167**	**26.91**	**459**	**290**
Carcinogenic PAHs	**27.70**	**1.86**	**145**	**92.58**

Blank spaces indicate non-detect.

Mass Bays Program	3rd River Cruise	3rd River Cruise	3rd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	01HT-PAH	02HT-PAH	03LT-PAH
Sample Collection Date	10/10/92	10/10/92	10/10/92
PAH Analytical Results	11/11/93	11/11/93	11/11/93
Units	ng/L	ng/L	ng/L
Naphthalene	7.1	9.8	23
C1-Naphthalene	9.9		32
C2-Naphthalene			27
C3-Naphthalene			
C4-Naphthalene			
Acenaphthylene			
Acenaphthene			
Biphenyl	2.9		3.1
Fluorene			
C1-Fluorene			
C2-Fluorene			
C3-Fluorene			
Phenanthrene	3.7		5.3
Anthracene			1.4
C1-Phenanthrene/Anthracene			
C2-Phenanthrene/Anthracene			
C3-Phenanthrene/Anthracene			
C4-Phenanthrene/Anthracene			
Dibenzothiophene			
C1-Dibenzothiophene			
C2-Dibenzothiophene			
C3-Dibenzothiophene			
Fluoranthene	4.5		7.6
Pyrene	3.1		5.7
C1-Fluoranthene/Pyrene			
Benzo(a)anthracene	1.8		3.4
Chrysene	1.4		4
C1-Chrysene			
C2-Chrysene			
C3-Chrysene			
C4-Chrysene			
Benzo(b)fluoranthene	1.4		3.1
Benzo(k)fluoranthene			
Benzo(e)pyrene	0.97		1.9
Benzo(a)pyrene			2.3
Perylene			
Indeno(1,2,3-cd)pyrene			
Dibenzo(a,h)anthracene			
Benzo(g,h,i)perylene			1.7
Total PAHs	36.77	9.8	122
Carcinogenic PAHs	7.70	0.0	20.2

Blank spaces indicate non-detect.

Mass Bays Program	4th River Cruise	4th River Cruise	4th River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	2J-HT-PAH	1J-HT-PAH	3J-LT-PAH
Sample Collection Date	1/8/93	1/8/93	1/8/93
PAH Analytical Results	05/08/93	05/08/93	05/08/93
Units	ng/L	ng/L	ng/L
Naphthalene	39	19	
C1-Naphthalene		26	
C2-Naphthalene			
C3-Naphthalene			
C4-Naphthalene			
Acenaphthylene		13	
Acenaphthene			
Biphenyl			
Fluorene			
C1-Fluorene			
C2-Fluorene			
C3-Fluorene			
Phenanthrene	5.5	26	29
Anthracene			
C1-Phenanthrene/Anthracene			
C2-Phenanthrene/Anthracene			
C3-Phenanthrene/Anthracene			
C4-Phenanthrene/Anthracene			
Dibenzothiophene			
C1-Dibenzothiophene			
C2-Dibenzothiophene			
C3-Dibenzothiophene			
Fluoranthene	8.8	44	52
Pyrene	5.2	30	38
C1-Fluoranthene/Pyrene			
Benzo(a)anthracene		12	
Chrysene		21	
C1-Chrysene			11
C2-Chrysene			22
C3-Chrysene			
C4-Chrysene			
Benzo(b)fluoranthene	5.6	23	38
Benzo(k)fluoranthene	3.4	15	15
Benzo(e)pyrene	3.5	18	19
Benzo(a)pyrene	3.4	12	18
Perylene			
Indeno(1,2,3-cd)pyrene		14	17
Dibenzo(a,h)anthracene			
Benzo(g,h,i)perylene	5.9	21	23
Total PAHs	**80.3**	**294**	**282**
Carcinogenic PAHs	**23.5**	**148**	**149**

Blank spaces indicate non-detect.

Mass Bays Program	5th River Cruise	5th River Cruise	5th River Cruise	5th River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	SB13-PAH	B13MA-PAH	CA-PAH-1	Duplicate
Sample Collection Date	5/1/93	5/1/93	5/1/93	5/1/93
PAH Analytical Results	05/29/93	05/29/93	05/29/93	Not Analyzed
Units	ng/L	ng/L	ng/L	
Naphthalene	88	71	123	
C1-Naphthalene	9.8	5.2	8.9	
C2-Naphthalene			6.5	
C3-Naphthalene				
C4-Naphthalene				
Acenaphthylene	1.9	0.93	2.8	
Acenaphthene	3.6		3.2	
Biphenyl	50	40	62	
Fluorene	2.8		3.3	
C1-Fluorene				
C2-Fluorene				
C3-Fluorene				
Phenanthrene	58	49	72	
Anthracene			2.7	
C1-Phenanthrene/Anthracene			10	
C2-Phenanthrene/Anthracene			11	
C3-Phenanthrene/Anthracene			6.5	
C4-Phenanthrene/Anthracene				
Dibenzothiophene			3.1	
C1-Dibenzothiophene				
C2-Dibenzothiophene				
C3-Dibenzothiophene				
Fluoranthene	15	13	28	
Pyrene	6.6	3.7	17	
C1-Fluoranthene/Pyrene			10	
Benzo(a)anthracene	3.2	2.3	7.1	
Chrysene	7.1	6.2	15	
C1-Chrysene			5.7	
C2-Chrysene				
C3-Chrysene				
C4-Chrysene				
Benzo(b)fluoranthene	6.1	4.2	12	
Benzo(k)fluoranthene	1.6	1.8	4.7	
Benzo(e)pyrene	3.1	2.5	6.5	
Benzo(a)pyrene	1.6	2.2	7.6	
Perylene	0.49		2.5	
Indeno(1,2,3-cd)pyrene	1.5		5.6	
Dibenzo(a,h)anthracene			1.5	
Benzo(g,h,i)perylene	2.3	1.7	5.4	
Total PAHs	**263**	**204**	**444**	**0**
Carcinogenic PAHs	**30.00**	**22.10**	**75.9**	**0**

Blank spaces indicate non-detect.

Mass Bays Program	1st River Cruise	1st River Cruise	2nd River Cruise
Merrimack River Data	No. of Buoy 13	So. of Buoy 13	So. of Buoy 13
Station Designation	SED-1	SED-2	SED-3
Matrix	Sediment	Sediment	Sediment
Organics Sample ID	MESED-1	MESED-2	M3HT-SED
Sample Collection Date	04/29/92	04/29/92	05/09/92
PCB/Pesticide Analytical Results	**6/4/92**	**6/4/92**	**6/4/92**
Blank spaces indicate non-detect.			
Units	**ng/g**	**ng/g**	**ng/g**
PCBs			
2-Chloro			
2,4'-Dichloro			1.5
2,2',5-Trichloro			
2,4,5-Trichloro		0.068	
2,2',4,6-Tetrachloro			
2,4,4'-Trichloro	0.66	2.2	2.8
2,2',5,5'-Tetrachloro	1.1	1.6	
2,2',4,6,6'-Pentachloro			
2,2',3,5'-Tetrachloro	3.1	2.6	1.2
2,3',4,4'-Tetrachloro	0.63	3	3
2,2',4,5,5'-Pentachloro	0.72	1.6	1.9
2,2',3,4,5'-Pentachloro	0.37	0.59	0.76
3,3',4,4'-Tetrachloro	1		3.5
2,2',4,4',5,6'-Hexachloro			
2,3',4,4',5-Pentachloro		1.7	2
2,2',3,4',5,6,6'-Heptachloro			
2,2',4,4',5,5'-Hexachloro	1.5	2.8	3.2
2,3,3',4,4'-Pentachloro			0.99
2,2',3,4,4',5'-Hexachloro	1.4	3.2	2.9
3,3',4,4',5-Pentachloro			
2,2',3,4',5,5',6-Heptachloro		1.1	1.1
2,2',3,3',4,4'-Hexachloro	0.16	0.4	0.47
2,2',3,3',4,5',6,6'-Octachloro			
2,2',3,4,4',5,5'-Heptachloro	0.53	1.4	1.4
2,2',3,3',4,4',5-Heptachloro	0.96	2.4	2.5
2,2',3,3',4,4',5,6-Octachloro	0.97	0.42	2
2,2',3,3',4,4',5,5',6-Nonachloro	0.33	0.39	0.35
Decachloro	1.8	1.7	1.3
Total PCBs	**15**	**27**	**33**
Pesticides	**6/4/92**	**6/4/92**	**6/4/92**
HCB	1.2	3.6	12
gamma-BHC		4.1	
Heptachlor			
Aldrin			
Heptachlor epoxide			
2,4'-DDE			
cis-Chlordane	0.38	0.87	1
trans-Chlordane	0.37	1.2	1.5
Dieldrin			
4,4'-DDE		1.5	1.7
2,4'-DDD	0.095	0.41	0.78
4,4'-DDD	1.1	2.1	2.9
2,4'-DDT			
4,4'-DDT			
Mirex			
Total Pesticides	**3.1**	**14**	**20**

Mass Bays Program Merrimack River Data Station Designation	1st Bay Cruise Massachusetts Bay Station 2	1st Bay Cruise Massachusetts Bay Station 4	1st Bay Cruise Massachusetts Bay Station 5	1st Bay Cruise Massachusetts Bay Station 6
Matrix	100L Seawater Particulate	100L Seawater Particulate	100L Seawater Particulate	100L Seawater Particulate
Organics Sample ID	B02-5-21-92	B04-5-21-92	B05-5-21-92	B06 5-21-92
Sample Collection Date	05/21/92	05/21/92	05/21/92	05/21/92
PCB/Pesticide Analytical Results	6/26/92	6/26/92	6/26/92	6/26/92
Blank spaces indicate non-detect				
Units	ng/l	ng/l	ng/l	ng/l
PCBs				
2-Chloro				
2,4'--Dichloro	0.12			
2,2',5-Trichloro				
2,4,5-Trichloro				
2,2',4,6-Tetrachloro				
2,4,4'-Trichloro				
2,2',5,5'-Tetrachloro				
2,2',4,6,6'-Pentachloro				
2,2',3,5'-Tetrachloro				
2,3',4,4'-Tetrachloro				
2,2',4,5,5'-Pentachloro				
2,2',3,4,5'-Pentachloro				
3,3',4,4'-Tetrachloro				
2,2',4,4',5,6'-Hexachloro				
2,3',4,4',5-Pentachloro				
2,2',3,4',5,6,6'-Heptachloro				
2,2',4,4',5,5'-Hexachloro				
2,3,3',4,4'-Pentachloro				
2,2',3,4,4',5'-Hexachloro				
3,3',4,4',5-Pentachloro				
2,2',3,4',5,5',6-Heptachloro				
2,2',3,3',4,4'-Hexachloro				
2,2',3,3',4,5',6,6'-Octachloro				
2,2',3,4,4',5,5'-Heptachloro				
2,2',3,3',4,4',5-Heptachloro				
2,2',3,3',4,4',5,6-Octachloro				
2,2',3,3',4,4',5,5',6-Nonachloro				
Decachloro		0.56	0.039	0.33
Total PCBs	**0.12**	**0.56**	**0.039**	**0.33**
Pesticides	6/26/92	6/26/92	6/26/92	6/26/92
HCB				
gamma-BHC				
Heptachlor				
Aldrin				
Heptachlor epoxide				
2,4'-DDE				
cis-Chlordane				
trans-Chlordane				
Dieldrin				
4,4'-DDE				
2,4'-DDD				
4,4'-DDD				
2,4'-DDT				
4,4'-DDT				
Mirex				
Total Pesticides	**0.0**	**0.0**	**0.0**	**0.0**

Mass Bays Program	1st Bay Cruise	2nd Bay Cruise
Merrimack River Data	Massachusetts	Massachusetts
Station Designation	Bay Station 8	Bay Station 6
	100L Seawater	300L Seawater
Matrix	Particulate	Particulate
Organics Sample ID	B08-5-21-92	BO-6-10-15-92
Sample Collection Date	05/21/92	10/15/92
PCB/Pesticide Analytical Results	6/26/92	04/09/93
Blank spaces indicate non-detect.		
Units	ng/l	ng/l
PCBs		
2-Chloro		
2,4'-Dichloro		0.078
2,2',5-Trichloro		
2,4,5-Trichloro		
2,2',4,6-Tetrachloro		
2,4,4'-Trichloro		
2,2',5,5'-Tetrachloro		
2,2',4,6,6'-Pentachloro		
2,2',3,5'-Tetrachloro		
2,3',4,4'-Tetrachloro		
2,2',4,5,5'-Pentachloro		
2,2',3,4,5'-Pentachloro		0.0037
3,3',4,4'-Tetrachloro		
2,2',4,4',5,6'-Hexachloro		
2,3',4,4',5-Pentachloro		
2,2',3,4',5,6,6'-Heptachloro		
2,2',4,4',5,5'-Hexachloro		
2,3,3',4,4'-Pentachloro		
2,2',3,4,4',5'-Hexachloro		0.013
3,3',4,4',5-Pentachloro		
2,2',3,4',5,5',6-Heptachloro		
2,2',3,3',4,4'-Hexachloro		
2,2',3,3',4,5',6,6'-Octachloro		
2,2',3,4,4',5,5'-Heptachloro		0.017
2,2',3,3',4,4',5-Heptachloro		
2,2',3,3',4,4',5,6-Octachloro		0.023
2,2',3,3',4,4',5,5',6-Nonachloro		
Decachloro	0.0066	
Total PCBs	**0.0066**	**0.13**
Pesticides	6/26/92	04/09/93
HCB		
gamma-BHC		
Heptachlor		0.0010
Aldrin		
Heptachlor epoxide		
2,4'-DDE		
cis-Chlordane		
trans-Chlordane		
Dieldrin		
4,4'-DDE		
2,4'-DDD		
4,4'-DDD		
2,4'-DDT		
4,4'-DDT		
Mirex		
Total Pesticides	**0.0**	**0.0010**

Mass Bays Program	1st River Cruise	1st River Cruise	1st River Cruise	1st River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3A	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	ME3HT	ME7HT	ME12LT	ME16LT
Sample Collection Date	04/29/92	04/29/92	04/29/92	04/29/92
PCB/Pesticide Analytical Results	6/25/92	6/25/92	6/26/92	6/26/92
Blank spaces indicate non-detect				
Units	ng/L	ng/L	ng/L	ng/L
PCBs				
2-Chloro				
2,4'-Dichloro				
2,2',5-Trichloro				2.3
2,4,5-Trichloro				
2,2',4,6-Tetrachloro				
2,4,4'-Trichloro				
2,2',5,5'-Tetrachloro				
2,2',4,6,6'-Pentachloro				
2,2',3,5'-Tetrachloro				
2,3',4,4'-Tetrachloro				
2,2',4,5,5'-Pentachloro				
2,2',3,4,5'-Pentachloro				
3,3',4,4'-Tetrachloro				
2,2',4,4',5,6'-Hexachloro				
2,3',4,4',5-Pentachloro				
2,2',3,4',5,6,6'-Heptachloro				
2,2',4,4',5,5'-Hexachloro				
2,3,3',4,4'-Pentachloro				
2,2',3,4,4',5'-Hexachloro				
3,3',4,4',5-Pentachloro				
2,2',3,4',5,5',6-Heptachloro				
2,2',3,3',4,4'-Hexachloro				
2,2',3,3',4,5',6,6'-Octachloro				
2,2',3,4,4',5,5'-Heptachloro				
2,2',3,3',4,4',5-Heptachloro				
2,2',3,3',4,4',5,6-Octachloro				
2,2',3,3',4,4',5,5',6-Nonachloro				
Decachloro	5.7	18	11	4.2
Total PCBs	5.7	18	11	6.5
Pesticides	6/25/92	6/25/92	6/26/92	6/26/92
HCB				
gamma-BHC				
Heptachlor				
Aldrin				
Heptachlor epoxide				
2,4'-DDE				
cis-Chlordane				
trans-Chlordane				
Dieldrin				
4,4'-DDE				
2,4'-DDD				
4,4'-DDD				
2,4'-DDT				
4,4'-DDT				
Mirex				
Total Pesticides	0.0	0.0	0.0	0.0

Mass Bays Program	2nd River Cruise	2nd River Cruise	2nd River Cruise	2nd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3A	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	M3HT	M4HT	M1LT	M2LT
Sample Collection Date	05/09/92	05/09/92	05/09/92	05/09/92
PCB/Pesticide Analytical Results	6/25/92	6/25/92	6/25/92	6/25/92
Blank spaces indicate non-detect				
Units	ng/L	ng/L	ng/L	ng/L
PCBs				
2-Chloro				
2,4'-Dichloro				
2,2',5-Trichloro				
2,4,5-Trichloro				
2,2',4,6-Tetrachloro				
2,4,4'-Trichloro		0.49		0.76
2,2',5,5'-Tetrachloro				
2,2',4,6,6'-Pentachloro				
2,2',3,5'-Tetrachloro				
2,3',4,4'-Tetrachloro				
2,2',4,5,5'-Pentachloro				
2,2',3,4,5'-Pentachloro				
3,3',4,4'-Tetrachloro				
2,2',4,4',5,6'-Hexachloro				
2,3',4,4',5-Pentachloro				
2,2',3,4',5,6,6'-Heptachloro				
2,2',4,4',5,5'-Hexachloro				
2,3,3',4,4'-Pentachloro				
2,2',3,4,4',5'-Hexachloro				
3,3',4,4',5-Pentachloro				
2,2',3,4',5,5',6-Heptachloro				
2,2',3,3',4,4'-Hexachloro				
2,2',3,3',4,5',6,6'-Octachloro				
2,2',3,4,4',5,5'-Heptachloro				
2,2',3,3',4,4',5-Heptachloro				
2,2',3,3',4,4',5,6-Octachloro				
2,2',3,3',4,4',5,5',6-Nonachloro				
Decachloro				
Total PCBs	**0.0**	**0.49**	**0.0**	**0.76**
Pesticides	**6/25/92**	**6/25/92**	**6/25/92**	**6/25/92**
HCB	0.31			0.26
gamma-BHC				
Heptachlor				
Aldrin				
Heptachlor epoxide				
2,4'-DDE				
cis-Chlordane				
trans-Chlordane				
Dieldrin				
4,4'-DDE				
2,4'-DDD				
4,4'-DDD				
2,4'-DDT				
4,4'-DDT				
Mirex				
Total Pesticides	**0.31**	**0.0**	**0.0**	**0.26**

Mass Bays Program	3rd River Cruise	3rd River Cruise	3rd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	01HT-PAH	02HT-PAH	03LT-PAH
Sample Collection Date	10/10/92	10/10/92	10/10/92
PCB/Pesticide Analytical Results	11/03/92	11/03/92	11/03/92
Blank spaces indicate non-detect			
Units	ng/L	ng/L	ng/L
PCBs			
2-Chloro			
2,4'-Dichloro			
2,2',5-Trichloro			1.3
2,4,5-Trichloro			0.50
2,2',4,6-Tetrachloro			
2,4,4'-Trichloro			
2,2',5,5'-Tetrachloro			
2,2',4,6,6'-Pentachloro			
2,2',3,5'-Tetrachloro			0.78
2,3',4,4'-Tetrachloro			
2,2',4,5,5'-Pentachloro			
2,2',3,4,5'-Pentachloro			
3,3',4,4'-Tetrachloro			
2,2',4,4',5,6'-Hexachloro			
2,3',4,4',5-Pentachloro			
2,2',3,4',5,6,6'-Heptachloro			
2,2',4,4',5,5'-Hexachloro			
2,3,3',4,4'-Pentachloro			
2,2',3,4,4',5'-Hexachloro			
3,3',4,4',5-Pentachloro			
2,2',3,4',5,5',6-Heptachloro			
2,2',3,3',4,4'-Hexachloro			
2,2',3,3',4,5',6,6'-Octachloro			
2,2',3,4,4',5,5'-Heptachloro			
2,2',3,3',4,4',5-Heptachloro			
2,2',3,3',4,4',5,6-Octachloro			
2,2',3,3',4,4',5,5',6-Nonachloro			
Decachloro			
Total PCBs	**0.0**	**0.0**	**2.6**
Pesticides	11/03/92	11/03/92	11/03/92
HCB			
gamma-BHC			1.1
Heptachlor			
Aldrin			
Heptachlor epoxide			
2,4'-DDE			
cis-Chlordane			
trans-Chlordane			
Dieldrin			
4,4'-DDE			
2,4'-DDD			
4,4'-DDD			
2,4'-DDT			
4,4'-DDT			
Mirex			
Total Pesticides	0.0	0.0	1.1

Mass Bays Program	4th River Cruise	4th River Cruise	4th River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	2J-HT-PAH	1J-HT-PAH	3J-LT-PAH
Sample Collection Date	1/8/93	1/8/93	1/8/93
PCB/Pesticide Analytical Results	04/09/93	04/09/93	04/09/93
Blank spaces indicate non-detect.			
Units	ng/L	ng/L	ng/L
PCBs			
2-Chloro			
2,4'-Dichloro		6.90	
2,2',5-Trichloro			
2,4,5-Trichloro			
2,2',4,6-Tetrachloro			
2,4,4'-Trichloro			
2,2',5,5'-Tetrachloro			
2,2',4,6,6'-Pentachloro			
2,2',3,5'-Tetrachloro			
2,3',4,4'-Tetrachloro			
2,2',4,5,5'-Pentachloro			
2,2',3,4,5'-Pentachloro			
3,3',4,4'-Tetrachloro			
2,2',4,4',5,6'-Hexachloro			
2,3',4,4',5-Pentachloro			
2,2',3,4',5,6,6'-Heptachloro			
2,2',4,4',5,5'-Hexachloro			
2,3,3',4,4'-Pentachloro			
2,2',3,4,4',5'-Hexachloro			
3,3',4,4',5-Pentachloro			
2,2',3,4',5,5',6-Heptachloro			
2,2',3,3',4,4'-Hexachloro			
2,2',3,3',4,5',6,6'-Octachloro			
2,2',3,4,4',5,5'-Heptachloro			
2,2',3,3',4,4',5-Heptachloro			
2,2',3,3',4,4',5,6-Octachloro			
2,2',3,3',4,4',5,5',6-Nonachloro			
Decachloro			
Total PCBs	0.0	6.90	0.0
Pesticides	04/09/93	04/09/93	04/09/93
HCB		0.63	
gamma-BHC			
Heptachlor			
Aldrin			
Heptachlor epoxide			
2,4'-DDE			
cis-Chlordane			
trans-Chlordane			
Dieldrin			
4,4'-DDE			
2,4'-DDD			
4,4'-DDD			
2,4'-DDT			
4,4'-DDT			
Mirex			
Total Pesticides	0.0	0.63	0.0

Mass Bays Program	**5th River Cruise**	**5th River Cruise**	**5th River Cruise**	**5th River Cruise**
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3	River Station 3
	Fresh Layer	**Salt Layer**	**Fresh Layer**	**Fresh Layer**
	High Tide	**High Tide**	**Low Tide**	**Low Tide**
Matrix	**River Water**	**River Water**	**River Water**	**River Water**
Organics Sample ID	**SB13-PAH**	**B13MA-PAH**	**CA-PAH-1**	**Duplicate**
Sample Collection Date	**5/1/93**	**5/1/93**	**5/1/93**	**5/1/93**
PCB/Pesticide Analytical Results	**05/29/93**	**05/29/93**	**05/29/93**	**Not Analyzed**
Blank spaces indicate non-detect				
Units	**ng/L**	**ng/L**	**ng/L**	
PCBs				
2-Chloro				
2,4'-Dichloro				
2,2',5-Trichloro				
2,4,5-Trichloro				
2,2',4,6-Tetrachloro				
2,4,4'-Trichloro				
2,2',5,5'-Tetrachloro				
2,2',4,6,6'-Pentachloro				
2,2',3,5'-Tetrachloro				
2,3',4,4'-Tetrachloro				
2,2',4,5,5'-Pentachloro				
2,2',3,4,5'-Pentachloro				
3,3',4,4'-Tetrachloro				
2,2',4,4',5,6'-Hexachloro				
2,3',4,4',5-Pentachloro				
2,2',3,4',5,6,6'-Heptachloro				
2,2',4,4',5,5'-Hexachloro				
2,3,3',4,4'-Pentachloro				
2,2',3,4,4',5'-Hexachloro				
3,3',4,4',5-Pentachloro				
2,2',3,4',5,5',6-Heptachloro				
2,2',3,3',4,4'-Hexachloro				
2,2',3,3',4,5',6,6'-Octachloro				
2,2',3,4,4',5,5'-Heptachloro				
2,2',3,3',4,4',5-Heptachloro				
2,2',3,3',4,4',5,6-Octachloro				
2,2',3,3',4,4',5,5',6-Nonachloro				
Decachloro				
Total PCBs	**0.0**	**0.0**	**0.0**	
Pesticides	**05/29/93**	**05/29/93**	**05/29/93**	**Not Analyzed**
HCB				
gamma-BHC				
Heptachlor				
Aldrin				
Heptachlor epoxide				
2,4'-DDE				
cis-Chlordane				
trans-Chlordane				
Dieldrin				
4,4'-DDE				
2,4'-DDD				
4,4'-DDD				
2,4'-DDT				
4,4'-DDT				
Mirex				
Total Pesticides	0.0	0.0	0.0	

Mass Bays Program	1st River Cruise	1st River Cruise	2nd River Cruise
Merrimack River Data	No. of Buoy 13	So. of Buoy 13	So. of Buoy 13
Station Designation	SED-1	SED-2	SED-3
Matrix	**Sediment**	**Sediment**	**Sediment**
Organics Sample ID	**MESED-1**	**MESED-2**	**M3HT-SED**
Sample Collection Date	**04/29/92**	**04/29/92**	**05/09/92**

TSS Analytical Results

Units

TSS

Oil & Grease Analytical Results

Units

Oil & Grease

TOC Analytical Results

Units

TOC

Mass Bays Program	1st Bay Cruise	1st Bay Cruise	1st Bay Cruise	1st Bay Cruise
Merrimack River Data	Massachusetts	Massachusetts	Massachusetts	Massachusetts
Station Designation	Bay Station 2	Bay Station 4	Bay Station 5	Bay Station 6
Matrix	100L Seawater Particulate	100L Seawater Particulate	100L Seawater Particulate	100L Seawater Particulate
Organics Sample ID	B02-5-21-92	B04-5-21-92	B05-5-21-92	B06 5-21-92
Sample Collection Date	05/21/92	05/21/92	05/21/92	05/21/92

TSS Analytical Results

Units

TSS

Oil & Grease Analytical Results

Units

Oil & Grease

TOC Analytical Results

Units

TOC

Mass Bays Program	1st Bay Cruise	2nd Bay Cruise
Merrimack River Data	Massachusetts	Massachusetts
Station Designation	Bay Station 8	Bay Station 6
	100L Seawater	300L Seawater
Matrix	Particulate	Particulate
Organics Sample ID	B08-5-21-92	BO-6-10-15-92
Sample Collection Date	05/21/92	10/15/92

TSS Analytical Results

Units

TSS

Oil & Grease Analytical Results

Units

Oil & Grease

TOC Analytical Results

Units

TOC

Mass Bays Program	1st River Cruise	1st River Cruise	1st River Cruise	1st River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3A	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	ME3HT	ME7HT	ME12LT	ME16LT
Sample Collection Date	04/29/92	04/29/92	04/29/92	04/29/92
TSS Analytical Results	5/7/92	5/7/92	5/7/92	5/7/92
Units	mg/l	mg/l	mg/l	mg/l
TSS	4.0	2.5	11	11
Oil & Grease Analytical Results	Not Analyzed	Not Analyzed	Not Analyzed	Not Analyzed
Units				
Oil & Grease				
TOC Analytical Results	5/7/92	5/7/92	5/7/92	5/7/92
Units	mg/l	mg/l	mg/l	mg/l
TOC	2.7	<1.0	2.3	2.8

Mass Bays Program	2nd River Cruise	2nd River Cruise	2nd River Cruise	2nd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3A	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	M3HT	M4HT	M1LT	M2LT
Sample Collection Date	05/09/92	05/09/92	05/09/92	05/09/92
TSS Analytical Results	5/21/92	5/21/92	5/21/92	5/21/92
Units	mg/l	mg/l	mg/l	mg/l
TSS	8	5	15	12
Oil & Grease Analytical Results	Not Analyzed	Not Analyzed	Not Analyzed	Not Analyzed
Units				
Oil & Grease				
TOC Analytical Results	5/21/92	5/21/92	5/21/92	5/21/92
Units	mg/l	mg/l	mg/l	mg/l
TOC	2	<1	3	3

Mass Bays Program	3rd River Cruise	3rd River Cruise	3rd River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	01HT-PAH	02HT-PAH	03LT-PAH
Sample Collection Date	10/10/92	10/10/92	10/10/92
TSS Analytical Results	11/2/92	11/2/92	11/2/92
Units	mg/l	mg/l	mg/l
TSS	<5	<5	6
Oil & Grease Analytical Results	11/2/92	11/2/92	11/2/92
Units	mg/l	mg/l	mg/l
Oil & Grease	<2.0	<2.0	<2.0
TOC Analytical Results	11/2/92	11/2/92	11/2/92
Units	mg/l	mg/l	mg/l
TOC	1.7	<1.0	2.8

Mass Bays Program	4th River Cruise	4th River Cruise	4th River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream
Station Designation	River Station 1	River Station 2	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer
	High Tide	High Tide	Low Tide
Matrix	River Water	River Water	River Water
Organics Sample ID	2J-HT-PAH	1J-HT-PAH	3J-LT-PAH
Sample Collection Date	1/8/93	1/8/93	1/8/93
TSS Analytical Results	1/19/93	1/19/93	1/19/93
Units	mg/l	mg/l	mg/l
TSS	10	189	8
Oil & Grease Analytical Results	Not Analyzed	Not Analyzed	Not Analyzed
Units			
Oil & Grease			
TOC Analytical Results	1/19/93	1/19/93	1/19/93
Units	mg/l	mg/l	mg/l
TOC	4	2	4

Mass Bays Program	5th River Cruise	5th River Cruise	5th River Cruise	5th River Cruise
Merrimack River Data	So. of Buoy 13	Near Buoy 13	Upstream	Upstream
Station Designation	River Station 1	River Station 2	River Station 3	River Station 3
	Fresh Layer	Salt Layer	Fresh Layer	Fresh Layer
	High Tide	High Tide	Low Tide	Low Tide
Matrix	River Water	River Water	River Water	River Water
Organics Sample ID	SB13-PAH	B13MA-PAH	CA-PAH-1	Duplicate
Sample Collection Date	5/1/93	5/1/93	5/1/93	5/1/93
TSS Analytical Results	5/13/93	5/13/93	5/13/93	5/13/93
Units	mg/l	mg/l	mg/l	mg/l
TSS	<5	<5	6	6
Oil & Grease Analytical Results	Not Analyzed	Not Analyzed	Not Analyzed	Not Analyzed
Units				
Oil & Grease				
TOC Analytical Results	5/13/93	5/13/93	5/13/93	5/13/93
Units	mg/l	mg/l	mg/l	mg/l
TOC	5	5	5	5