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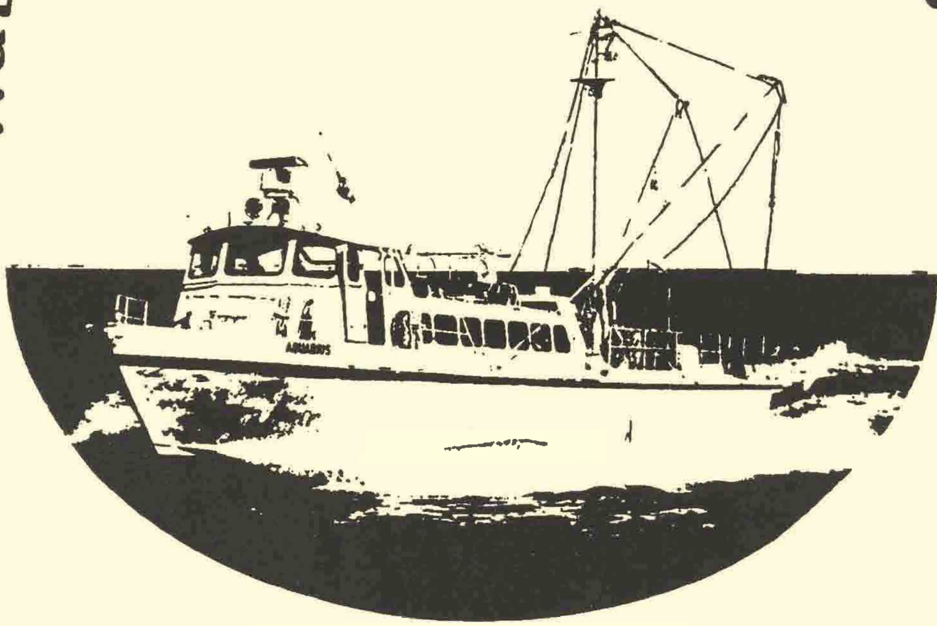
Chesapeake Bay

Water lity Monitoring Program

ECOSYSTEMS PROCESSES COMPONENT (EPC)



LEVEL ONE REPORT #9
Part 1: Interpretive Report

A Program Supported by the
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MARYLAND DEPARTMENT OF THE ENVIRONMENT

MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYSTEM PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT NO. 9

PART 1: INTERPRETIVE REPORT

(July 1984 - December 1991)

PREPARED FOR:

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(July - August 1991)

PREFACE

This report is submitted in accordance with the Schedule of Deliverables set out in Contract 20-C-MDE91 between the Maryland Department of the Environment (MDE), Chesapeake Bay and Special Projects Program and the University of Maryland System, Center for Environmental and Estuarine Studies (CEES).

Part I of this report outlines sampling and data management procedures used by the Ecosystems Processes Component (EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program to collect and analyze data. The remainder of the text describes the temporal and spatial behavior of all the variables measured.

SONE and VFX data for all previous years, August 1984 through December 1989, were submitted in two volumes with the Level 1, No. 7 Interpretive Report Part II: Data Tables [UMCEES]CBL Ref. No. 90-062 (Boynton *et al.*, 1990). Change pages, with correction bars in the right margin indicating corrected data values, will be ssued with future reports for insertion into data volumes as errors are encountered.

Two additional volumes, Part II: Data Tables Volume III and IV, accompany this report. Part II: Volume III - Appendix B (Continued) contains hard copy listings of SONE data (cruises 24 - 36) collected by the EPC during 1990 (February through October), 1991 (February through October) and 1992 (May and June). Part II: Volume IV contains VFX data [Appendix C (Continued)] for the years 1990, 1991 and 1992. The VFX program was terminated on 3rd June, 1992 when the sediment traps were finally retrieved. The VFX data set is now complete. Two additional sections Appendices D and E have been included at the end of Part II: Volume III. Appendix D, contains data collected in association with a larger investigation of physical, chemical and biological characteristics of the deep channel region (deep trough) of the bay immediately south of the Bay Bridge at Annapolis, while Appendix E, contains data collected at an additional monitoring station in the upper bay near Pooles Island, in order to develop sediment-water flux characteristics prior to dredging activities in this area.

Variable names, used in data tables, together with a description of the units presently used in these programs, and the matching variable used in the public information data base of the Chesapeake Bay Program called CHESSEE are listed in Appendix A, Table A-1, Level 1 No. 7 Interpretive Report Part II: Data Tables (Boynton *et. al.*, 1990), and in the EPC Data Dictionary (Boynton and Rohland, 1990). Entries are arranged alphabetically using the MDE/EPC table names. A copy of the Ecosystem Processes Component Data Dictionary is available on request from Dr. R. Eskin (Maryland Department of the Environment) or from Dr. F.M. Rohland (Chesapeake Biological Laboratory). Any specific questions concerning changes in file or variable names should be directed to: Dr. F.M. Rohland: Tel. (410) 326-7215.

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Complete data set, 1984 to 1986, is found in Volume I No additional data has subsequently been collected.

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ABSTRACT

The objectives of the Ecosystem Processes Component (EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program are to: (1) characterize the present state of the bay relative to sediment-water nutrient and oxygen exchanges and the deposition rate of particulate materials to deep waters, (2) determine the long-term trends that develop in sediment-water exchanges and deposition rates in response to pollution control programs, and (3) integrate the information collected in this program with other elements of the monitoring program. Measurements of sediment-water nutrient and oxygen exchanges were made six times between May and October, 1991 at a total of nine mainstem bay and tributary river stations. Deposition rates were monitored almost continuously during spring, summer and fall periods at one mainstem bay location. This program was initiated in July 1984, and the basic data collection scheme has been followed through December 1991. This report includes data collected during the entire monitoring program but specifically evaluates data collected during the 1991 monitoring period.

Sediment trap data collected during 1991 indicate a well developed spring deposition period beginning in early March, reaching a peak in late April and early May and then declining very sharply. The highest rate of total chlorophyll-a deposition in 1991 was 12 mg m^{-2} d^{-1}. In contrast, total chlorophyll-a deposition rates reached 36.6 mg m^{-2} d^{-1} during spring 1990. Summer deposition rates were erratic during 1991, ranging from 2.0 mg m^{-2} d^{-1} immediately following the termination of the spring bloom to 18 mg m^{-2} d^{-1} following an algal bloom in surface waters in late June. There was also a clear indication of a fall deposition event in early October (14-23 mg m^{-2} d^{-1}) which represented the largest deposition event of 1991. The seasonal pattern of deposition was similar to other years, except 1989, when the spring deposition period was very limited. Average deposition rates of total chlorophyll-a during the spring bloom were highest in 1990, lowest 1989 (6.5 mg m^{-2} d^{-1}) and intermediate (9-12 mg m^{-2} d^{-1}) in the remaining years, including 1991.

Sediment-water fluxes of oxygen were similar to those observed in previous years except in the Patuxent and Choptank Rivers where fluxes were larger. Ammonium (NH_4^+) fluxes in the upper Patuxent River remained slightly elevated (as in 1990) and fluxes were distinctly lower in the mid-mainstem bay (R-64) and in the lower Potomac River (Ragged Point [RGPT]). Nitrate plus nitrite (NO_2^- + NO_3^-) fluxes from sediments to water have become progressively rarer over the years and this trend continued during 1991. Nitrate plus nitrite fluxes were more negative in the upper Patuxent and lower Choptank Rivers and in the mid-bay region (R-64). During 1991, inorganic phosphate (DIP) fluxes were similar to ammonium fluxes. Silicate fluxes (Si) were often higher than in previous years, particularly in the upper Patuxent River. Fluxes of ammonium and dissolved inorganic phosphorus measured in the vicinity of Pooles Island were low compared to rates measured in other enriched areas of the bay (*e.g.* R-64, and Ragged Point [RGPT]), but higher than rates observed at more northerly locations in the upper bay.

Efforts to detect relationships between nutrient loading rates and selected environmental variables were continued using 1991 data and the following preliminary conclusions emerged:

(1) All sediment fluxes except Si were found to be correlated with nitrogen (N) loading but not with phosphorus (P) loading rates. Fluxes of Si did not vary appreciably among stations. The mechanism relating N but not P loading rates to N and P sediment fluxes appears to operate as follows: organic matter production is regulated primarily by N supply rates, in turn

hypoxic and anoxic conditions strongly increase P sediment fluxes while the enhancement of N sediment fluxes is smaller.

(2) Summer season (June through August) sediment fluxes were very strongly correlated with winter-spring surficial sediment concentrations of total chloropyhll-a. Strong correlations were also found between sediment fluxes and sediment particulate nitrogen (PN) concentrations but were less strongly correlated with sediment particulate carbon (PC) concentrations and not at all with sediment particulate phosphorus (PP) concentrations.

(3) Spring deposition rates measured at one location in the mainstem bay, particularly an estimate that was corrected for resuspension effects, were correlated with nutrient loading rates. Other indices of deposition also indicated positive trends relative to nutrient loading rates but were not as strong.

(4) Examination of several small data sets containing high frequency measurements of sediment fluxes indicated a strong linkage between the magnitude of fluxes and deposition. Furthermore, lag times between deposition and sediment flux responses were small, ranging from days in summer to several weeks in early spring.

(5) Rates of oxygen decline in deep waters of the mainstem bay were also well correlated with spring deposition rates but not with measured particulate material concentrations in the water column.

2. INTRODUCTION

During the past decade much has been learned about the effects of both natural and anthropogenic nutrient inputs (*e.g.*, nitrogen, phosphorus, silica) on such important estuarine features as phytoplankton production, algal biomass, seagrass abundance and oxygen conditions in deep waters (Nixon, 1981, 1988; Kemp *et al.*, 1983 ; D'Elia *et al.*, 1983; Malone, 1992; and Kemp and Boynton, 1992). While our understanding is not complete, important pathways regulating these processes have been identified and related to water quality issues. Of particular importance here, it has been determined that (1) algal primary production and biomass levels in many estuaries (including Chesapeake Bay) are responsive to nutrient loading rates, (2) high rates of algal production are sustained through summer and fall periods by benthic recycling of essential nutrients and (3) deposition of organic matter from surface to deep waters links these processes of production and consumption (Boynton *et al.*, 1982a ; Garber *et al.*, 1989).

2.1 The Role of Sediments and Depositional Processes in Determining Chesapeake Bay Water Quality Conditions

Research conducted in Chesapeake Bay and other estuaries indicates that estuarine sediments can act as both important storages and sources of nutrients as well as sites of intense organic matter and oxygen consumption (Kemp and Boynton, 1984). For example, during summer periods in the Choptank and Patuxent estuaries, 40-70% of the total oxygen utilization was associated with sediments and 25-70% of algal nitrogen demand was supplied from estuarine sediments (Boynton *et al.*, 1982b). Processes of this magnitude have a pronounced effect on estuarine water quality and habitat conditions. Sediments in much of Chesapeake Bay, especially the upper bay and tributary rivers, contain significant amounts of carbon, nitrogen, phosphorus and other compounds (Boynton *et al.*, 1992a). A large percentage of this material appears to reach sediments following the termination of the spring bloom and again after the fall bloom. A portion of this material is available to regenerative processes and once transformed into inorganic nutrients becomes available for algal utilization. Nutrients and other materials deposited or buried in sediments represent the potential "water quality memory" of the bay.

2.2. Conceptual Model of Estuarine Nutrient and Water Quality Processes in Chesapeake Bay

Nutrients and organic matter enter the bay from a variety of sources, including sewage treatment plant effluents, fluvial inputs, local non-point drainage and direct rainfall on bay waters. These dissolved nutrients are rapidly incorporated into particulate matter via biological, chemical and physical mechanisms. Much of this particulate material then sinks to the bottom and is potentially available for remineralization. Essential nutrients released during the decomposition of organic matter may then again be utilized by algal communities. A portion of this newly produced organic matter sinks to the bottom, contributing to the development of anoxic conditions and loss of habitat for important infaunal, shellfish and demersal fish communities. The regenerative capacities and the potentially large nutrient storages in bottom sediments ensure a large return flux of nutrients from sediments to the water column and thus sustains continued phytoplankton growth. Continued growth supports deposition of organics to deep waters, creating anoxic conditions typically associated with eutrophication of estuarine systems.

To a considerable extent, it is the magnitude of these processes which determines nutrient and oxygen water quality conditions in many zones of the bay. Ultimately, these processes are driven by inputs of organic matter and nutrients from both natural and anthropogenic sources. If water quality management programs are instituted and loadings decrease, changes in the magnitude of the processes monitored in this program will serve as a guide in determining the effectiveness of strategies aimed at improving bay water quality and habitat conditions.

Within the context of this model a monitoring study of deposition, sediment oxygen demand and sediment nutrient regeneration has been initiated. The working hypothesis is that if nutrient and organic matter loading to the bay decreases then the cycle of deposition to sediments, sediment oxygen demand, release of nutrients and continued high algal production will also decrease. Since benthic processes exert important influences on water quality conditions, changes in these processes will serve as important indications of the effectiveness of nutrient control actions.

2.3 Objectives of the Water Quality Monitoring Program

The objectives of the Ecosystem Processes Component (EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program are to:

1) Characterize the present state of the bay (including spatial and seasonal variation) relative to sediment-water nutrient exchanges and oxygen consumption and the rate at which organic and inorganic particulate materials reach deep waters and the sediment surface.

2) Determine the long-term trends that develop in sediment-water exchanges and deposition rates in response to pollution control programs.

3) Integrate the information collected in this program with other elements of the monitoring program to gain a better understanding of the processes affecting Chesapeake Bay water quality and its impact on living resources.

2.4 Status of the Ecosystem Processes Component of the Maryland Chesapeake Bay Water Quality Monitoring Program

The Chesapeake Bay Water Quality Monitoring Program was initiated to provide guidelines for restoration, protection and future use of the mainstem estuary and tributaries and to provide evaluations of implemented management actions directed towards alleviating some critical pollution problems. In order to achieve these goals, the monitoring program design was composed of the three phases mentioned above. In addition to the EPC portion, the monitoring program also has components which measure: (1) nutrient and pollutant input rates, (2) chemical and physical properties of the water column, (3) toxicant levels in sediments and organisms, (4) phytoplankton and zooplankton populations and (5) benthic community characteristics. A complete description of the monitoring program is provided in Magnien *et al.* (1987).

The first phase of the study was undertaken over a period of four years (1984 through 1987) and had as its goal the characterization of the existing state of the bay, including spatial and seasonal variation, and to better identify problem areas. The EPC determined sediment-water oxygen and nutrient exchange rates and rates at which organic and inorganic particulate materials reached deep waters and the sediment surface. Sediment-water exchanges and depositional processes are major features of estuarine nutrient cycles and play an important role in determining water quality and habitat conditions. The results of EPC monitoring have been summarized in a series of interpretive reports (Boynton *et al.*, 1985, 1986, 1987, 1988, 1990 and 1991). The results of the characterization effort have largely confirmed the importance of deposition and sediment processes in determining water quality and habitat conditions.

The second phase of the monitoring effort, completed during 1988-1990, identified interrelationships and trends in key processes monitored during the initial phase of the program. The EPC was able to identify trends in sediment-water exchanges and deposition rates. Important factors regulating these processes have also been identified and related to water quality conditions (Kemp and Boynton, 1992; Boynton *et al.*, 1991).

In 1991 the program entered its third phase. During this phase the long-term 40% nutrient reduction strategy for the bay was reevaluated. In this phase of the process, the monitoring program will be used to assess the appropriateness of targeted nutrient load reductions as well as provide indications of water quality patterns which will likely result from such management actions.

The preliminary reevaluation report (Progress Report of the Baywide Nutrient Reduction Reevaluation, 1992) included the following conclusions: nonpoint sources of nutrients contributed approximately 77% of the nitrogen and 66% of the phosphorus entering the bay; agricultural sources are dominant followed by forest and urban sources; the "controllable" fraction of nutrient loads is about 47% for nitrogen and 70% for phosphorus; point source reductions are ahead of schedule and diffuse source reductions are close to projected reductions; further efforts are needed to reduce diffuse sources; significant reductions in phosphorus concentrations and slight increases in nitrogen concentrations have been observed in some areas of the bay; areas of low dissolved oxygen have been quantified and living resource water quality goals established; simulation model projections indicate significant reductions in low dissolved oxygen conditions associated with a 40% reduction of controllable nutrient loads.

Ecosystem Processes Component (EPC) program data collected during 1991 are presented in this report and examined for trends in sediment-water exchanges and deposition rates in response to inter-annual changes in nutrient loading rates and other environmental conditions. In addition, a thorough review of sediment-water nutrient and oxygen exchange measurements made in the upper bay is included.

3. PROJECT DESCRIPTION

Measurements of sediment-water oxygen and nutrient exchanges were made six times during 1991 at nine locations in the mainstem bay and in each of three major tributary rivers (Patuxent, Choptank, and Potomac). One additional station was monitored in the upper bay near Pooles Island in order to develop sediment-water flux characteristics prior to and following dredging activities in this area. Deposition measurements are made almost continuously during the spring, summer and fall periods, but less frequently during the winter. Activities in this program have been coordinated with other components of the Maryland Chesapeake Bay Water Quality Monitoring Program in terms of station locations, sampling frequency, methodologies, data storage and transmission, reporting schedules and data synthesis. This program was initiated in July 1984 and the basic data collection scheme has been followed through December 1991.

Figure 3-1. shows both current and previously monitored sampling locations of sediment oxygen and nutrient exchange (SONE) and the vertical flux monitoring (VFX) programs, also the recently added Pooles Island Dredge Survey (PIDS) station. A comprehensive listing of all SONE, Pooles Island and VFX stations, providing the station code names, associated latitude and longitude, basin and station location description and references to the nearest MDE station are outlined in Tables 3-1.1., 3-1.2. and 3-1.3. and in the Ecosystem Processes Component (EPC) Data Dictionary (Tables B-5.1., B-5.2. and B-5.3.; Boynton and Rohland, 1990). In 1991, two of the nine stations sampled as part of the SONE study are located in the mainstem bay adjacent to Point No Point (north of the mouth of the Potomac River) and Buoy R-64 (south of the Choptank River mouth). Four stations are located in the Patuxent River estuary and one each in the lower mesohaline regions of the Choptank and Potomac Rivers. The G-Central (GCNT) station is located in oligo-mesohaline, shallow water in the vicinity of Pooles Island (Figure 3-2.). The VFX station is located in the mainstem of the bay in the central anoxic region (Figure 3-1.). The salinity characteristics of each station and the four salinity codes are listed in Table 3-2. (also in EPC Data Dictionary, Table B-7.; Boynton and Rohland, 1990).

3.1 Justification of Station Locations

3.1.1 Sediment Oxygen and Nutrient Exchanges (SONE) Stations

Locations of Sediment Nutrient and Oxygen Exchanges (SONE) stations (Figure 3-1. and Tables 3-1.1., 3-1.2. and 3-1.3.; EPC Data Dictionary Figure B-6. and Tables B-5.2. and B-5.3.) were selected based on prior knowledge of the general patterns of sediment-water nutrient and oxygen exchanges in Chesapeake Bay. Several earlier studies (Boynton *et al.*, 1980, 1985 and Boynton and Kemp, 1985) reported the following:

1) Along the mainstem of the Maryland portion of the bay, fluxes were moderate in the upper bay, large in the mid-bay and minimal in the lower bay.

2) Fluxes in the transition zone of tributaries were larger than those observed in the downstream higher salinity portions of tributaries.

Hence, a series of stations were located along the mainstem from Still Pond Neck in the upper bay to Point No Point near the mouth of the Potomac River. A pair of stations were established in each of the three tributaries (Potomac, Patuxent, and Choptank Rivers), one in the transition zone and one in the lower estuary. In all cases, station locations were selected to have depths and sediment characteristics representative of the estuarine zone being monitored.

In a few instances (Patuxent stations and Choptank station at Horn Point [HNPT]) SONE stations are not located exactly at the same site as other Maryland Chesapeake Bay Water Quality Monitoring Program stations, although they are close (< 10 km). The prime reason for including these stations was the considerable amount of benthic flux data available from the SONE sites selected in the Patuxent and Choptank Rivers that could be used by the monitoring program. In all cases our stations and the MDE stations are in the same estuarine zone. Benthic fluxes are reasonably similar over small spatial scales (10-20 km) within estuarine zones of similar salinity, sediment type and depth; therefore, this program retains a high degree of comparability with other program components (Boynton *et al.*, 1982b).

Beginning July 1989 the number and location of SONE sampling stations was revised. Prior to July 1989, four of the ten stations sampled were located along the salinity gradient in the mainstem bay between Point No Point (north of the mouth of the Potomac River) and Still Pond Neck (20 km south of the Susquehanna River mouth). Two stations were located in each of three tributary rivers (Patuxent River: Buena Vista [BUVA] and St. Leonard Creek [STLC], Choptank River: Windy Hill [WDHL] and Horn Point [HNPT] and Potomac River: Maryland Point [MDPT] and Ragged Point [RGPT]), one in the turbidity maximum or salinity transition zone and one in the lower mesohaline region. After July 1, 1989 sampling at all of the upper tributaries (except in the Patuxent River) and sampling at the two upper mainstem stations was discontinued and two stations (Marsh Point [MRPT] and Broomes Island [BRIS]) were added in the Patuxent River (Figure 3-1.). These modifications were made in response to budget constraints, but also to improve spatial resolution in the Patuxent River which is a focal point of management activities.

3.1.2 Pooles Island Dredge Survey (PIDS) Stations

Data collected between 1980 and 1991 from five different programs conducted in the upper bay are reviewed in this report. Figure 3-2. shows the location of five upper bay stations monitored during these programs. Station names, station abbreviations, associated latitude and longitude, sampling dates and sponsor information is given in Table 3-3. The earliest of these programs (Boynton and Kemp, 1985) included two stations in this region at Worton Creek (WNCK) and Hart-Miller Island (HMIS). Measurements of sediment-water nutrient and oxygen exchanges were made at Still Pond (SLPD) the only station monitored in the upper bay during the SONE program. Data from this station included in this review covers a five year period, beginning in May, 1985 and ending in June, 1989. During April, August and November 1988 and February, 1989, sediment-water exchanges were measured at Still Pond (SLPD) and Pooles Island (GCNT) as part of a shorter program, Benthic Exchanges and Sediment Transformations Program (BEST)(Garber *et al.*, 1989). The same measurements were taken at Still Pond (SLPD) from April, 1989 through November, 1991 as part of the Land Margin Ecosystem Research Program (LMER)(Boynton W.R., Watts J.L. and D.A. Jasinski, *pers. observations*).

Since July 1991 sediment-water nutrient exchanges are measured at G-Central (GCNT) in the vicinity of Pooles Island (Figures 3-1. and 3-2.).

3.1.3 Vertical Flux (VFX) Stations

The use of sediment trap methodology to determine the net vertical flux of particulate material is restricted to the deeper portions of the bay. In shallower areas local resuspension of bottom sediments is sufficiently large to mask the downward flux of "new" material. Hence, sediment traps are not useful tools in either the upper reaches of the mainstem bay or in many tributary areas. The sediment trap array, positioned near the center of the region experiencing seasonal anoxia (Figure 3-1.), monitors the vertical flux of particulate organics reaching deeper waters. This location is close to MDE station 4.3.C. Since sediment traps are moored pieces of gear and therefore exposed to damage or loss by commercial boat traffic, the location was selected to be out of main traffic lanes, but still close to the MDE station.

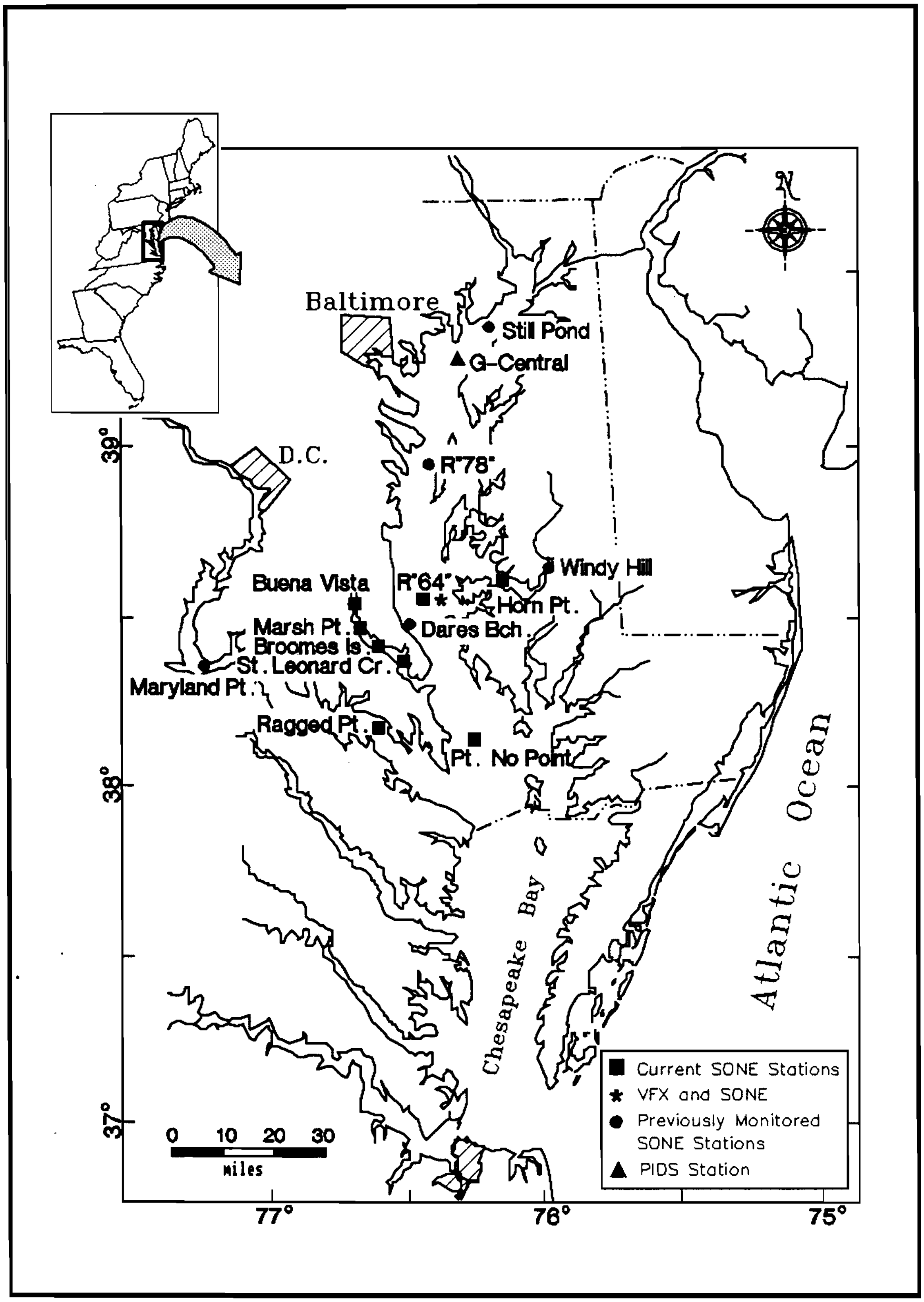


Figure 3-1. Location of current and previous SONE and VFX Monitoring Stations and PIDS Station in the Maryland Portion of Chesapeake Bay

Table 3-1.1. Station Name, ID and Sampling Order

REGION	STATION NAME	STATION CODE NAME	SAMPLING ORDER[3] A	B
Patuxent River	St. Leonard Creek	STLC	1	1
	Broomes Island	BRIS		2
	Marsh Point	MRPT		3
	Buena Vista	BUVA	2	4
Choptank River	Horn Point	HNPT	3	5
	Windy Hill	WDHL	4	
Potomac River	Ragged Point	RGPT	5	6
	Maryland Point	MDPT	6	
Chesapeake Mainstream	Point No Point	PNPT	7	7
	Buoy R-64[1]	R-64	8	8
	Dares Beach	DRBH	x	
	Thomas Point	TMPT	*	
	Buoy R-78[2]	R-78	9	
	G-Central[4]	GCNT		9
	Still Pond	SLPD	10	

NOTES:

A = Station sampled in SONE 1 - 21, August 1984 - June 1989. Numerical ranking indicates the order in which they appear in the data tables.
B = Station sampled beginning with SONE 22 and future samples. Numerical ranking indicates the order in which they appear in the data tables.
* = Thomas Point was sampled July - August 1984. Thomas Point was replaced by Station R-78.
x = Dares Beach was a VFX station sampled from 11 July 1985 to 14 November 1986.
1 = This is the only current VFX station.
2 = This was also a VFX station which was sampled from 17 September 1984 to 27 June 1985.
3 = Prior to July 1, 1989, measurements at SONE stations were made four times per year (April or May, June August and October or November). After this date, measurements were made five times per year (May, June, July, August and October)
4 = An additional Pooles Island station was added in 1991.

Table 3-1.2. Station Code, Grid Location and Nearest MDE Station

STATION CODE NAME	LATITUDE DEG MIN	LONGITUDE DEG MIN	STATION DEPTH	MDE STATION	BAY SEGMENT
Patuxent River					
STLC	38° 22.88'	76° 30.06'	7.0	XDE2792	LE1
BRIS	38° 23.64'	76° 33.17'	15.0	XDE2792	LE1
MRPT	38° 26.81'	76° 30.06'	5.2	XDE5339	LE1
BUVA	38° 31.12'	76° 39.82'	5.8	XDE9401	RET1
Choptank River					
HNPT	38° 37.18'	76° 08.09'	8.2	MET5.2	ET5
WDHL	38° 41.45'	77° 11.49'	3.8	NONE	ET5
Potomac River					
RGPT	38° 09.86'	76° 15.13'	16.5	XBE9541	LE2
MDPT	38° 21.37'	76° 26.63'	10.2	XDA1177	LE2
Chesapeake Mainstream					
PNPT	38° 07.99'	76° 15.13'	14.2	MCB5.2	CB5
R-64	38° 33.59'	76° 26.63'	16.8	MCB4.3C	CB4
DRBH	38° 33.50'	76° 29.30'	10.7	MCB4.3C	CB4
TMPT	38° 54.08'	76° 24.46'	52.0	MCB4.1W	CB4
R-78	38° 57.81'	76° 23.62'	15.8	MCB3.3C	CB4
GCNT	39° 16.53'	76° 15.62'	6.0	NE*	CB3
SLPD	39° 20.87'	76° 10.87'	10.4	MCB2.2	CB2

NOTES:

* = No equivalent MDE station because of dredging activity in this region of the Bay.

Table 3-1.3. Station Code and Description

STATION CODE NAME	DESCRIPTION
Patuxent River	
STLC	7.5 nautical miles upstream of Patuxent River mouth. (R km = 12.1)
BRIS	10 nautical miles upstream of Patuxent River mouth. (R km = 16.1)
MRPT	14.5 nautical miles upstream of Patuxent River mouth. (R km = 23.4)
BUVA	0.75 nautical miles north of Route 231 Bridge at Benedict, MD. (R km = 31.5)
Choptank River	
HNPT	4.0 nautical miles downstream of Route 50 Bridge at Cambridge, MD. (R km = 18.6)
WDHL	10.0 nautical miles upstream from Route 50 Bridge at Cambridge, MD. (R km = 39.5)
Potomac River	
RGPT	1.5 nautical miles WNW of Buoy 51-B. (R km = 29.8)
MDPT	1250 yards SE of Buoy R-18. (R km = 71.0)
Chesapeake Mainstream	
PNPT	3.2 nautical miles East of Point No Point. (R km = 129.0)
R-64	300 yards North East of channel Buoy R-64.* (R km = 177.4)
DRBH	West of channel Buoy R-64.* (R km = 177.4)
TMPT	4.03 nautical miles south of channel Buoy R-78.* (R km = 219.3)
R-78	200 yards NNW of channel Buoy R-78.* (R km = 225.8)
GCNT	(R km[1] = 261.8)
SLPD	700 yards West of channel marker 41.* (R km = 258.1)

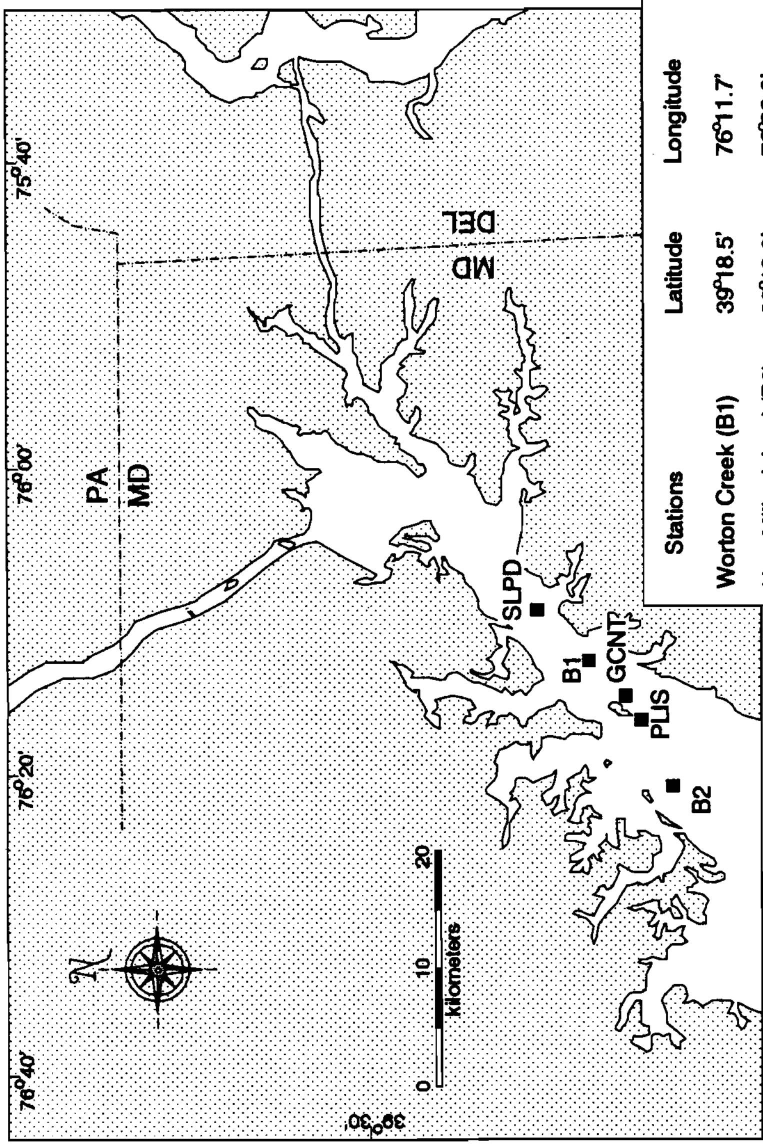
NOTE:
* Marked buoy numbers correspond to numbering system prior to USCG renumbering.
[1] River kilometers (R km) are measured from the mouth of the river or Chesapeake Bay.

Table 3-2. Station Salinity

STATION CODE	SALINITY CODE
Patuxent River	
STLC	M
BRIS	M
MRPT	M
BUVA	O
Choptank River	
HNPT	M
WDHL	O
Potomac River	
RGPT	M
MDPT	O
Chesapeake Mainstream	
PNPT	M
R-64	M
TMPT	M
R-78	M
GCNT	O/M
SLPD	O

The Salinity Zone layer codes are as follows:

SALINITY CODE	DESCRIPTION
F	Freshwater
O	Oligohaline 0.5 - 5.0 ppt
M	Mesohaline 5.0 - 18.0 ppt
P	Polyhaline 18.0 - 32.0 ppt



Stations	Latitude	Longitude	Dates
Worton Creek (B1)	39°18.5'	76°11.7'	Aug 80 - May 81
Hart-Miller Island (B2)	39°12.0'	76°22.0'	Aug 80 - May 81
SONE (SLPD)	39°20.87'	76°18.87'	May 85 - Jun 89
BEST (SLPD)	39°20.87'	76°18.87'	Dec 88 - Feb 89
BEST (PLIS)	39°16.28'	76°17.42'	Apr 88 - Nov 88
LMER (SLPD)	39°20.87'	76°18.87'	Mar 89 - Nov 91
G-Central (GCNT)	39°16.53'	76°15.62'	Jul 91 - Aug 91

Figure 3-2. Location of Monitoring Stations at which Sediment-water Oxygen and Nutrient Exchange Measurements have been made in upper Chesapeake Bay

Table 3-3. Station Names, Sampling Order and Associated Programs in upper Chesapeake Bay

Station Name	Station Abbrev.	Latitude	Longitude	Data Sampled	Sponsor of Program
EPA PROGRAM 1 STATIONS					
Worton Creek	WNCK	39° 18.50'	76° 11.70'	August 1980 May 1981	Chesapeake Bay Program
Hart-Miller Island	HTMR	39° 12.00'	76° 22.00'	August 1980 May 1981	Chesapeake Bay Program
SONE Station					
Still Pond	SLPD	39° 16.35'	76° 18.87'	1984 - SONE 1,2 1985 - SONE 3,4,5,6 1986 - SONE 7,8,9,10 1987 - SONE 11,12,13,14 1988 - SONE 15,16,17,18 1989 - SONE 19,20	Maryland Department of the Environment
BEST STATION					
Still Pond	SLPD	39° 20.87'	76° 10.87'	April 1988 August 1988 November 1988 February 1989	US Environmental Protection Agency
Pooles Island	PLIS	39° 16.28'	76° 17.42'	February 1989	US Environmental Protection Agency
LMER STATION					
Still Pond	SLPD	39° 20.87'	76° 18.87'	April 1989 May 1989 June 1989 July 1989 August 1989 September 1989 November 1989 April 1990 June 1990 July 1990 November 1990 May 1991 June 1991 July 1991 September 1991 November 1991	National Science Foundation
POOLES ISLAND STATION					
G-Central	GCNT	39° 16.53'	76° 15.62'	July 1991 - SONE 31 August 1991 - SONE 32	Maryland Department of the Environment

3.2 Sampling Frequency

3.2.1 Sediment Oxygen and Nutrient Exchanges (SONE) Stations

The sampling frequency for the SONE portion of this program is based on the seasonal patterns of sediment water exchanges observed in previous studies conducted in the Chesapeake Bay region (Kemp and Boynton, 1980; Kemp and Boynton, 1981; Boynton *et al.*, 1982b; and Boynton and Kemp, 1985). These studies indicated several distinct periods over an annual cycle including:

> 1) A period characterized by the presence of a large macrofaunal community, high concentrations of nitrite in surface waters and the development and deposition of the spring phytoplankton bloom (April - June).
>
> 2) A period during which macrofaunal biomass is low but water temperature and water column metabolic activity high with anoxia prevalent in deeper waters (July - September).
>
> 3) A period in the fall when anoxia is not present and macrofaunal community abundance is low but re-establishing (October - November).
>
> 4) A winter period when fluxes are very low and vary only slightly, during which the data collected would not add appreciably to our understanding of water quality conditions. No samples are collected during this period (December - March).

Previous studies also indicate that short-term temporal (day-month) variation in these exchanges is small; however, considerable differences in the magnitude and characteristics of fluxes appear among distinctively different estuarine zones (*i.e.* tidal fresh vs. mesohaline regions). In light of these results, the monitoring design adopted for the SONE study involves six monthly measurements made between May and October, 1991. A complete listing giving the sampling dates of all SONE cruises together with alpha-numeric cruise identification codes can be found in Table 3-3.1.

3.2.2 Pooles Island Dredge Survey (PIDS) Station

One station, G-Central (GCNT), was sampled during July and August, 1991. This station will be monitored in June, 1992.

3.2.2 Vertical Flux (VFX) Stations

The selection of sampling frequency for the VFX (organic deposition) monitoring program, although compatible with SONE sampling frequencies, is governed by different constraints. Net deposition rates appear largest during the warm seasons of the year (April - October) and are lower during winter periods (November - March). Deposition of sediments and organics in one tributary of the bay (Patuxent River) followed a similar pattern (Boynton *et al.*, 1982b; Kemp and Boynton, 1984). However, some variability occurs in warm season deposition rates, probably due to algal blooms of short duration (days - week), variation in zooplankton grazing rates (week - month) and other less well described features of the bay. Given the importance of obtaining inter-annual estimates of organic matter deposition rates to deep waters of the bay, sampling is almost continuous from spring to fall (March - November) and only occasional during the winter (December - February). Direct measurements of organic deposition to bay sediments were monitored 19 to 31 times per year (30 times in 1991). To coordinate vertical deposition rate measurements with SONE measurements, sediment-water exchanges are monitored at the end of each intensive VFX deployment period. VFX measurements also coincide with other monitoring program sampling activities. The sampling schedule for this component of the monitoring program 1984-1986 is shown in Figure 3-3.1., for 1987-1989 in Figure 3-3.2. and for 1990-1991 in Figure 3-3.3.(also EPC Data Dictionary Figures B-3., B-4. and B-5.; Boynton and Rohland, 1990). Tables 3-4.1., 3-4.2., 3-4.3. and 3-4.4. (also EPC Data Dictionary Tables B-2.1., B-2.2., B-2.3. and B-2.4.; Boynton and Rohland, 1990) provide detailed cruise information including date, cruise number and research vessel.

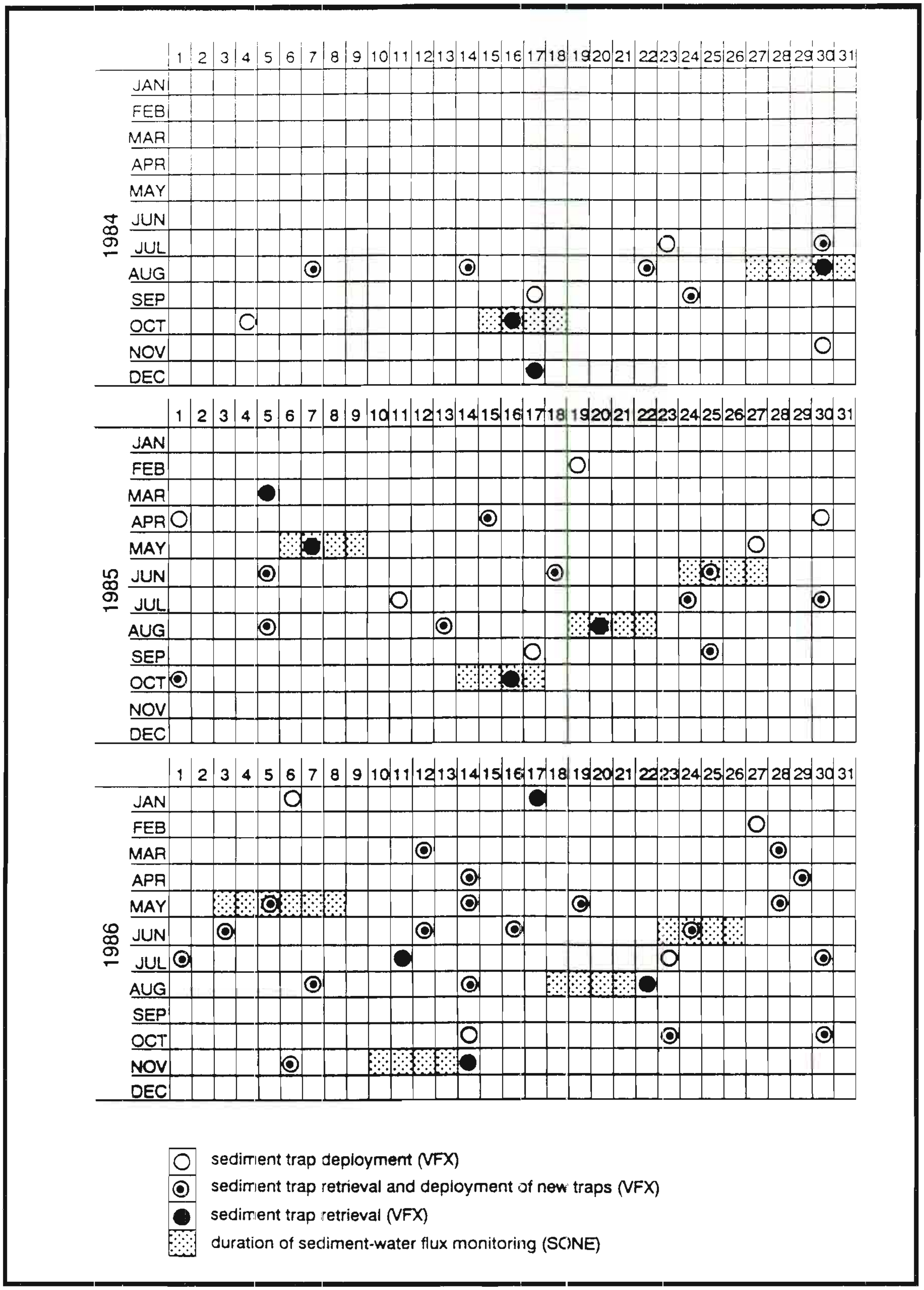


Figure 3-3.1. SONE and VFX Sampling Schedule for 1984-1986

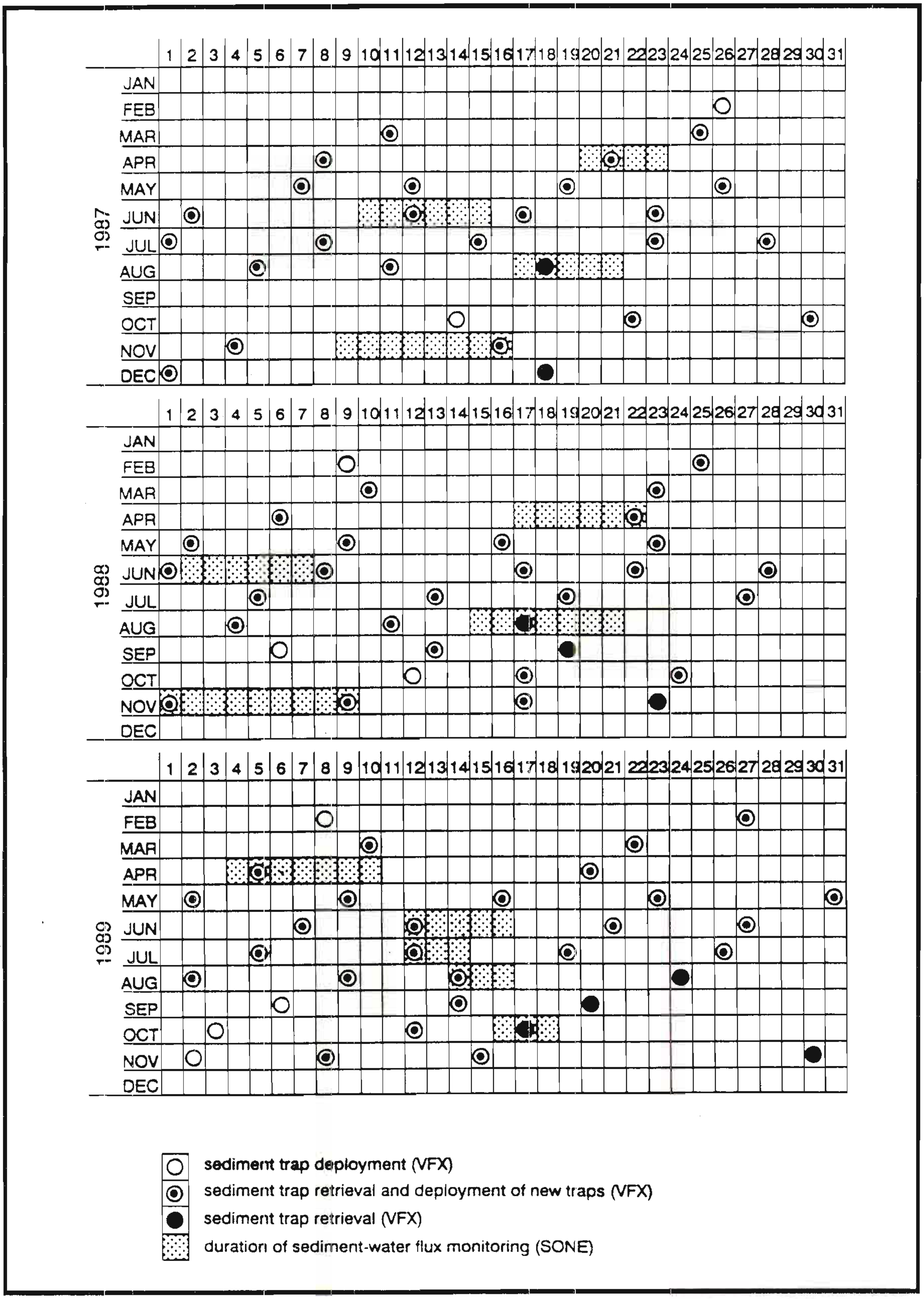


Figure 3-3.2. SONE and VFX Sampling Schedule for 1987 - 1989

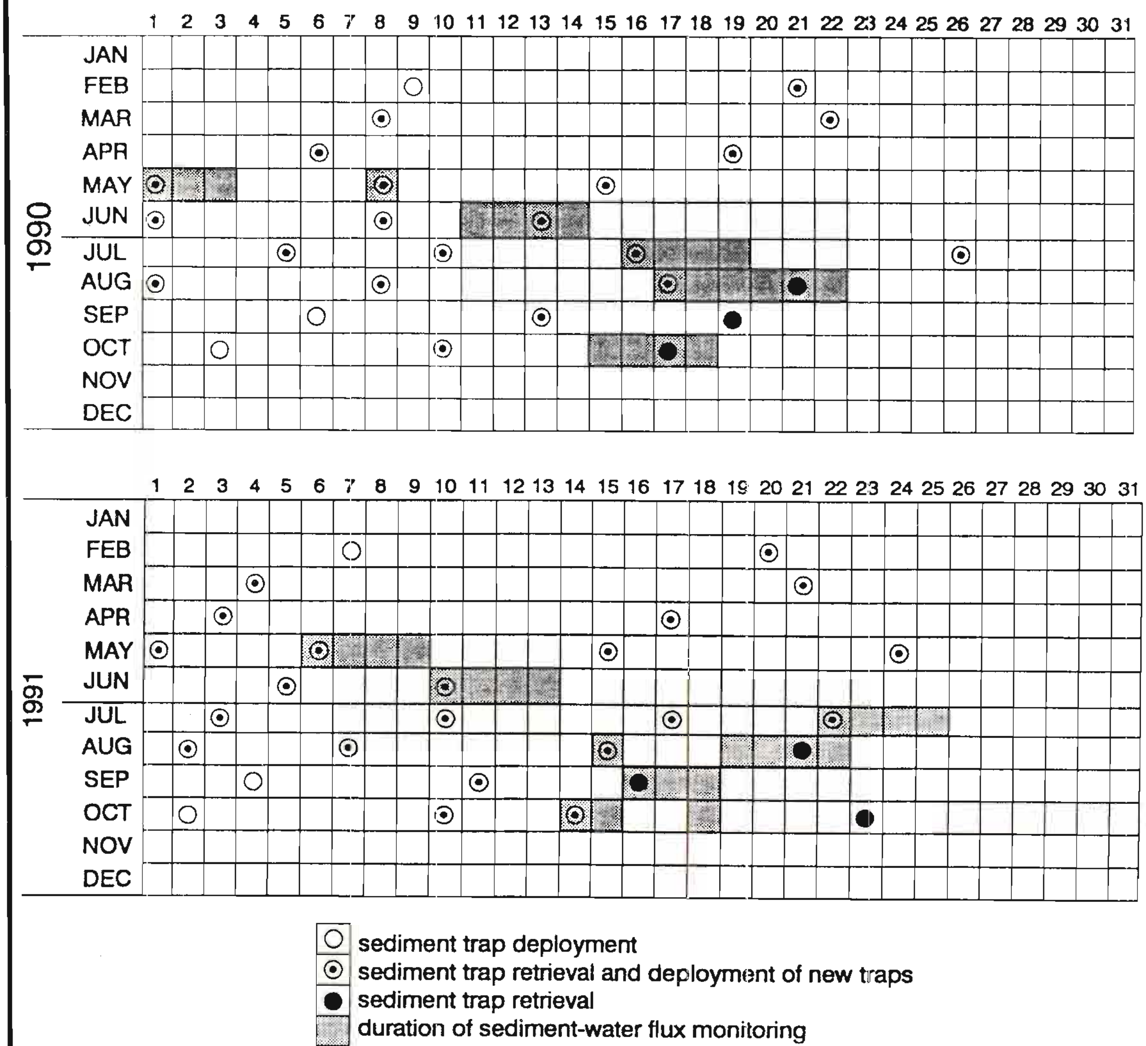


Figure 3-3.3. SONE and VFX Sampling Schedule for 1990 - 1991

Table 3-4.1. SONE Cruise Identifier

CRUISE	DATE	BEGIN DATE	END DATE	RESEARCH VESSEL
SONE 01	AUG 1984	27 AUG	30 AUG	Aquarius
SONE 02	OCT 1984	15 OCT	18 OCT	Aquarius
SONE 03	MAY 1985	06 MAY	09 MAY	Aquarius
SONE 04	JUN 1985	24 JUN	27 JUN	Aquarius
SONE 05	AUG 1985	19 AUG	22 AUG	Aquarius
SONE 06	OCT 1985	14 OCT	17 OCT	Aquarius
SONE 07	MAY 1986	03 MAY	08 MAY	Aquarius
SONE 08	JUN 1986	23 JUN	26 JUN	Aquarius
SONE 09	AUG 1986	18 AUG	22 AUG	Orion
SONE 10	NOV 1986	10 NOV	13 NOV	Aquarius
SONE 11	APR 1987	20 APR	23 APR	Aquarius
SONE 12	JUN 1987	10 JUN	15 JUN	Aquarius
SONE 13	AUG 1987	17 AUG	20 AUG	Aquarius
SONE 14	NOV 1987	09 NOV	16 NOV	Aquarius
SONE 15	APR 1988	17 APR	22 APR	Aquarius
SONE 16	JUN 1988	01 JUN	07 JUN	Aquarius
SONE 17	AUG 1988	15 AUG	21 AUG	Aquarius
SONE 18	NOV 1988	01 NOV	09 NOV	Aquarius
SONE 19	APR 1989	04 APR	10 APR	Aquarius
SONE 20	JUN 1989	12 JUN	16 JUN	Aquarius
SONE 21	JUL 1989	12 JUL	14 JUL	Aquarius
SONE 22	AUG 1989	14 AUG	16 AUG	Aquarius
SONE 23	OCT 1989	16 OCT	18 OCT	Aquarius
SONE 24	MAY 1990	1 MAY	3 MAY	Orion
		8 MAY	8 MAY	Aquarius
SONE 25	JUN 1990	11 JUN	14 JUN	Aquarius
SONE 26	JUL 1990	16 JUL	19 JUL	Aquarius
SONE 27	AUG 1990	17 AUG	22 AUG	Aquarius
SONE 28	OCT 1990	15 OCT	18 OCT	Aquarius
SONE 29	MAY 1991	6 MAY	9 MAY	Aquarius
SONE 30	JUN 1991	10 JUN	13 JUN	Aquarius
SONE 31	JUL 1991	22 JUL*	25 JUN	Aquarius
SONE 32	AUG 1991	15 AUG	15 AUG	Aquarius
		19 AUG*	22 AUG	
SONE 33	SEP 1991	16 SEP	18 SEP	Aquarius
SONE 34	OCT 1991	14 OCT (14, 15, 18 OCT)	18 OCT	Aquarius

NOTES:

* Data was also corrected for the Pooles Island Dredge Survey (PIDS) Program at GCNT.

Table 3-4.2. VFX Cruise Dates (23rd July 1984 to 30th August 1984) for Station Thomas Point (TMPT)

DATE	CRUISE NO.	RESEARCH VESSEL
23 JUL 1984	1042	Orion
30 JUL 1984	1046	Orion
07 AUG 1984	Note 1	Osprey
14 AUG 1984	Note 1	Osprey
22 AUG 1984	Note 1	Osprey
30 AUG 1984	766	Aquarius

NOTE 1: Divers Serviced Traps.

Table 3-4.3. VFX Cruise Dates (17th September 1984 to 27th June 1985) for Station R-78

DATE	CRUISE NO.	RESEARCH VESSEL
17 SEP 1984	774	Aquarius
24 SEP 1984	777	Aquarius
04 OCT 1984	784	Aquarius
16 OCT 1984	790	Aquarius
30 NOV 1984	802	Aquarius
17 DEC 1984	1082	Orion
19 FEB 1985	809	Aquarius
05 MAR 1985	1090	Orion
01 APR 1985	815	Aquarius
15 APR 1985	1097	Orion
27 MAY 1985	1109	Orion
05 JUN 1985	829	Aquarius
18 JUN 1985	1113	Orion
27 JUN 1985	833	Aquarius

Table 3-4.4. VFX Cruise Dates (23rd July 1984 to 23rd October 1991) for Station R-64 and Dares Beach (11th July 1985 to 14th November 1986).[1]

DATE	CRUISE NO.	RESEARCH VESSEL
23 JUL 1984	1042	Orion
30 JUN 1984	1046	Orion
07 AUG 1984	Note 2	Osprey
14 AUG 1984	Note 2	Osprey
22 AUG 1984	Note 2	Osprey
30 AUG 1984	766	Aquarius
17 SEP 1984	774	Aquarius
24 SEP 1984	777	Aquarius
04 OCT 1984	784	Aquarius
16 OCT 1984	790	Aquarius
30 NOV 1984	802	Aquarius
17 DEC 1984	1082	Orion
19 FEB 1985	809	Aquarius
05 MAR 1985	1090	Orion
01 APR 1985	815	Aquarius
15 APR 1985	1097	Orion
30 APR 1985	1101	Orion
08 MAY 1985	825	Aquarius
27 MAY 1985	1109	Orion
05 JUN 1985	829	Aquarius
18 JUN 1985	1113	Orion
25 JUN 1985	833	Aquarius
11 JUL 1985	1119	Orion
24 JUL 1985	1123	Orion
30 JUL 1985	1125	Orion
05 AUG 1985	1128	Orion
13 AUG 1985	1130	Orion
21 AUG 1985	844	Aquarius
17 SEP 1985	1141	Orion
25 SEP 1985	851	Aquarius
01 OCT 1985	1146	Orion
16 OCT 1985	858	Aquarius
06 JAN 1986	1165	Orion
17 JAN 1986	872	Aquarius
27 FEB 1986	884	Aquarius
12 MAR 1986	1170	Orion
28 MAR 1986	888	Aquarius
14 APR 1986	1178	Orion
29 APR 1986	1185	Orion
05 MAY 1986	898	Aquarius
14 MAY 1986	899	Aquarius
19 MAY 1986	1194	Orion

DATE	CRUISE NO.	RESEARCH VESSEL
28 MAY 1986	1197	Orion
03 JUN 1986	1198	Orion
12 JUN 1986	1201	Orion
16 JUN 1986	906	Aquarius
24 JUN 1986	910	Aquarius
01 JUL 1986	912	Aquarius
11 JUL 1986	915	Aquarius
23 JUL 1986	1208	Orion
30 JUL 1986	1212	Orion
07 AUG 1986	1215	Orion
14 AUG 1986	921	Aquarius
22 AUG 1986	1220	Orion
14 OCT 1986	1231	Orion
23 OCT 1986	936	Aquarius
30 OCT 1986	1235	Orion
06 NOV 1986	1237	Orion
14 NOV 1986	941	Aquarius
26 FEB 1987	1247	Orion
11 MAR 1987	1251	Orion
25 MAR 1987	951	Aquarius
08 APR 1987	1256	Orion
21 APR 1987	956	Aquarius
07 MAY 1987	959	Aquarius
12 MAY 1987	1272	Orion
19 MAY 1987	1276	Orion
26 MAY 1987	1279	Orion
02 JUN 1987	1283	Orion
12 JUN 1987	968	Aquarius
17 JUN 1987	969	Aquarius
23 JUN 1987	1288	Orion
01 JUL 1987	1292	Orion
08 JUL 1987	1294	Orion
15 JUL 1987	1297	Orion
23 JUL 1987	976	Aquarius
28 JUL 1987	1301	Orion
05 AUG 1987	1304	Orion
11 AUG 1987	1306	Orion
18 AUG 1987	983	Aquarius
14 OCT 1987	1323	Orion
22 OCT 1987	998	Aquarius
30 OCT 1987	1000	Aquarius
04 NOV 1987	1329	Orion

Table 3-4.4. VFX Cruise Dates (23rd July 1984 to 23rd October 1991) for Station R-64 and Dares Beach (11th July 1985 to 14th November 1986).[1] - Continued

DATE	CRUISE NO.	RESEARCH VESSEL
16 NOV 1987	1003	Aquarius
01 DEC 1987	1005	Aquarius
18 DEC 1987	1335	Orion
09 FEB 1988	1341	Orion
25 FEB 1988	1346	Orion
10 MAR 1988	1352	Orion
23 MAR 1988	1355	Orion
06 APR 1988	1015	Aquarius
22 APR 1988	1017	Aquarius
02 MAY 1988	1366	Orion
09 MAY 1988	1368	Orion
16 MAY 1988	1370	Orion
23 MAY 1988	1372	Orion
01 JUN 1988	1027*	Aquarius
08 JUN 1988	1027*	Aquarius
17 JUN 1988	1376	Orion
22 JUN 1988	1378	Orion
28 JUN 1988	1034	Aquarius
05 JUL 1988	1380	Orion
13 JUL 1988	1038	Aquarius
19 JUL 1988	1039	Aquarius
27 JUL 1988	1385	Orion
04 AUG 1988	1043	Aquarius
11 AUG 1988	1389	Orion
17 AUG 1988	1047	Aquarius
06 SEP 1988	1392	Orion
13 SEP 1988	1050	Aquarius
19 SEP 1988	1395	Orion
12 OCT 1988	1401	Orion
17 OCT 1988	1404	Orion
24 OCT 1988	1066	Aquarius
01 NOV 1988	1067*	Aquarius
09 NOV 1988	1067*	Aquarius
17 NOV 1988	1070	Aquarius
23 NOV 1988	1408	Orion
08 FEB 1989	1082	Aquarius
27 FEB 1989	1084	Aquarius
10 MAR 1989	1087	Aquarius
22 MAR 1989	1089	Aquarius
05 APR 1989	1091	Aquarius

DATE	CRUISE NO.	RESEARCH VESSEL
20 APR 1989	1093	Aquarius
02 MAY 1989	1426	Orion
09 MAY 1989	1098	Aquarius
16 MAY 1989	1429	Orion
23 MAY 1989	1104	Aquarius
31 MAY 1989	1432	Orion
07 JUN 1989	1435	Orion
12 JUN 1989	1110	Aquarius
21 JUN 1989	1441	Orion
27 JUN 1989	1112	Aquarius
05 JUL 1989	1114	Aquarius
12 JUL 1989	1118	Aquarius
19 JUL 1989	1120	Aquarius
26 JUL 1989	1122	Aquarius
02 AUG 1989	1450	Orion
09 AUG 1989	1128	Aquarius
14 AUG 1989	1129	Aquarius
24 AUG 1989	1131	Aquarius
06 SEP 1989	1455	Orion
14 SEP 1989	1457	Orion
20 SEP 1989	1458	Orion
03 OCT 1989	1141	Aquarius
12 OCT 1989	1464	Orion
17 OCT 1989	1146	Aquarius
02 NOV 1989	1469	Orion
08 NOV 1989	1470	Orion
15 NOV 1989	1155	Aquarius
30 NOV 1989	1156	Aquarius
16 JUL 1990	1195	Aquarius
26 JUL 1990	1515	Orion
01 AUG 1990	1198	Aquarius
08 AUG 1990	1522	Orion
17 AUG 1990	1203	Aquarius
21 AUG 1990	1203	Aquarius
05 SEP 1990	1525	Orion
06 SEP 1990	1526	Orion#
13 SEP 1990	1208	Aquarius
19 SEP 1990	1529	Orion
03 OCT 1990	1213	Aquarius
10 OCT 1990	1536	Orion

Table 3-4.4. VFX Cruise Dates (23rd July 1984 to 23rd October 1991) for Station R-64 and Dares Beach (11th July 1985 to 14th November 1986).[1] - Continued

DATE	CRUISE NO.	RESEARCH VESSEL
17 OCT 1990	1216	Aquarius
07 FEB 1991	1546	Orion
20 FEB 1991	1548	Orion
04 MAR 1991	1549	Orion
21 MAR 1991	1551	Orion
03 APR 1991	1553	Orion
17 APR 1991	1556	Orion
01 MAY 1991	1558	Orion
06 MAY 1991	1243	Aquarius
15 MAY 1991	1563	Orion
24 MAY 1991	1247	Aquarius
29 MAY 1991	1564	Orion
05 JUN 1991	1566	Orion
10 JUN 1991	1252	Aquarius
20 JUN 1991	1569	Orion
26 JUN 1991	1257	Aquarius

DATE	CRUISE NO.	RESEARCH VESSEL
03 JUL 1991	1573	Orion
10 JUL 1991	1574	Orion
17 JUL 1991	1575	Orion
22 JUL 1991	1265	Aquarius
02 AUG 1991	1581	Orion
07 AUG 1991	1267	Aquarius
15 AUG 1991	1269*	Aquarius
21 AUG 1991	1269*	Aquarius
04 SEP 1991	1584	Orion
11 SEP 1991	1586	Orion
16 SEP 1991	1273	Aquarius
02 OCT 1991	1276	Aquarius
10 OCT 1991	1279	Aquarius
14 OCT 1991	1282	Aquarius
23 OCT 1991	1285	Aquarius

NOTE 1: Dares Beach was sampled on the same VFX cruises as R-64 from 11 July 1985 to 14 November 1986.
NOTE 2: Divers Serviced Traps.
- * Traps serviced at beginning and end of same SONE cruise.
- x Traps gone.
- # Traps reset.

4. DATA COLLECTION

4.1 Field Methods

Details concerning methodologies are described in the Ecosystem Processes Component (EPC) Study Plan (Garber *et al.*, 1987) and fully documented in the EPC Data Dictionary (Boynton and Rohland, 1990). The following section provides an overview of field activities.

4.1.1 Sediment Oxygen and Nutrient Exchanges (SONE) Study

4.1.1.1 Water Column Profiles

At each of the ten SONE stations (eight stations since July 1989), vertical water column profiles of temperature, salinity and dissolved oxygen are measured at 2 meter intervals from the surface to the bottom immediately after obtaining intact sediment cores for incubation. The turbidity of surface waters is measured using a Secchi disc.

4.1.1.2 Water Column Nutrients

Near-surface (approximately 0.5 meters) and near-bottom (approximately 1 meter) water samples are also collected using a high volume submersible pump system. Samples are filtered, where appropriate, using 0.7 μm GF/F filter pads, and immediately frozen. Samples are analyzed by Nutrient Analytical Services Laboratory (NASL) for the following dissolved nutrients and particulate materials: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$), dissolved inorganic phosphorus corrected for salinity (DIP or PO_4^-), silicious acid ($Si(OH)_4$), particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations and seston content.

Measurements of total dissolved nitrogen (TDN: $NH_4^+ + NO_2^- + NO_3^-$ + DON), and total dissolved phosphorus (TDP: DIP + DOP) were discontinued at the end of the 1987 calendar year due to reduction in finances related to the grant supplied by the funding agency. Near-surface samples were discontinued in November 1991 (SONE cruise 31) as these measurements are not of particular importance in the interpretation of flux data. This was also necessary due to further budget reductions.

4.1.1.3 Sediment Profiles

At each SONE station an intact sediment core is used to measure Eh of sediments at 1 cm intervals to about 10 cm. Additionally, surficial sediments are sampled to a depth of 1 cm (2 mm since 9 August 1989) for particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), and total and active chlorophyll-a concentrations.

4.1.1.4 Sediment Cores

Intact sediment cores are obtained at each SONE station using a modified Bouma box corer. After deployment and retrieval of the box corer, the metal box is removed to reveal the Plexiglass liner containing the sediment core. The core is visually inspected for disturbance. A satisfactory core is placed in a darkened, water-filled holding incubator prior to further processing.

Three intact cores are used to estimate net exchanges of oxygen and dissolved nutrients between sediments and overlying waters (Figure 4-1.). Prior to beginning flux measurements, the overlying water in the core is replaced by fresh bottom water to ensure that water quality conditions in the core closely approximate in-situ conditions. Gentle circulation of water, with no induction of sediment resuspension, is maintained in the cores during the measurement period via the stirring devices attached to the O_2 probes. The cores are placed in a darkened water bath to maintain ambient temperature. Oxygen concentrations are recorded and overlying water samples (35 ml) are extracted from each core every 30 to 60 minutes (depending on the rate of oxygen uptake) over a 2 to 5 hour incubation period. During the incubation period, five overlying water samples are extracted from each core. As a nutrient sample is extracted from a core, an equal amount of ambient bottom water is added. An opaque Plexiglass liner filled with bottom water, incubated and sampled as described above serves as a blank. Overlying water samples are filtered and immediately frozen for later analysis for ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate (NO_2^- + NO_3^-), dissolved inorganic phosphorous (DIP or PO_4^-) and silicious acid ($Si(OH)_4$) concentrations. Oxygen and nutrient fluxes are estimated by calculating the mean rate of change in concentration over the incubation period and converting the volumetric rate to a flux using the volume:area ratio of each core.

It should be noted that at low oxygen concentrations (< 2 mg l^{-1}) SOC rates become proportional to oxygen concentrations as we noted in a previous report (Boynton *et al.*, 1991). Prior to 1989, between five and seven of the SONE stations rarely if ever experienced low bottom water DO concentrations. Since 1989, SONE stations have been modified and only three of eight stations rarely experience low oxygen concentrations. Hypoxic conditions are common at the remaining stations and influence SOC rates. This represents a methodological limitation which is more serious given our current configuration of stations. We are trying to develop a method for measuring total sediment metabolism (dissolved inorganic carbon flux) which is independent of oxygen conditions. During 1990 and 1991 a series of preliminary measurments of sulfate reduction ($SO_4^=$) were made. It now appears that a method is available for measuring anaerobic metabolism (the majority of which is carried out via $SO_4^=$ reduction) which is ameniable to the constraints of the monitoring program. In brief the method involves incubation of intact sediments under anaerobic conditions with sulfate concentration measured during the incubation period using ion chromotography as a detection method. Routine use of this technique is expected to begin in June 1992. A complete description of the method will be included in our next interpretive report and will be inserted into the data dictionary (Boynton and Rohland, 1990).

4.1.2 Pooles Island Dredge Survey (PIDS) Program

Sampling at G-Central (GCNT) station followed the same overall procedure as that initiated at SONE stations and included the general characterization of both water column (see Section 4.1.1.1) and sediment profile (see Section 4.1.1.3), measurement of dissolved water column nutrients and particulates (see Section 4.1.1.2) and sediment-water exchanges of oxygen (DO) and dissolved nutrients (see Section 4.1.1.4): ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate (NO_2^- + NO_3^-), dissolved inorganic phosphorus (PO_4^- or DIP) and silicious acid ($Si(OH)_4$) concentrations.

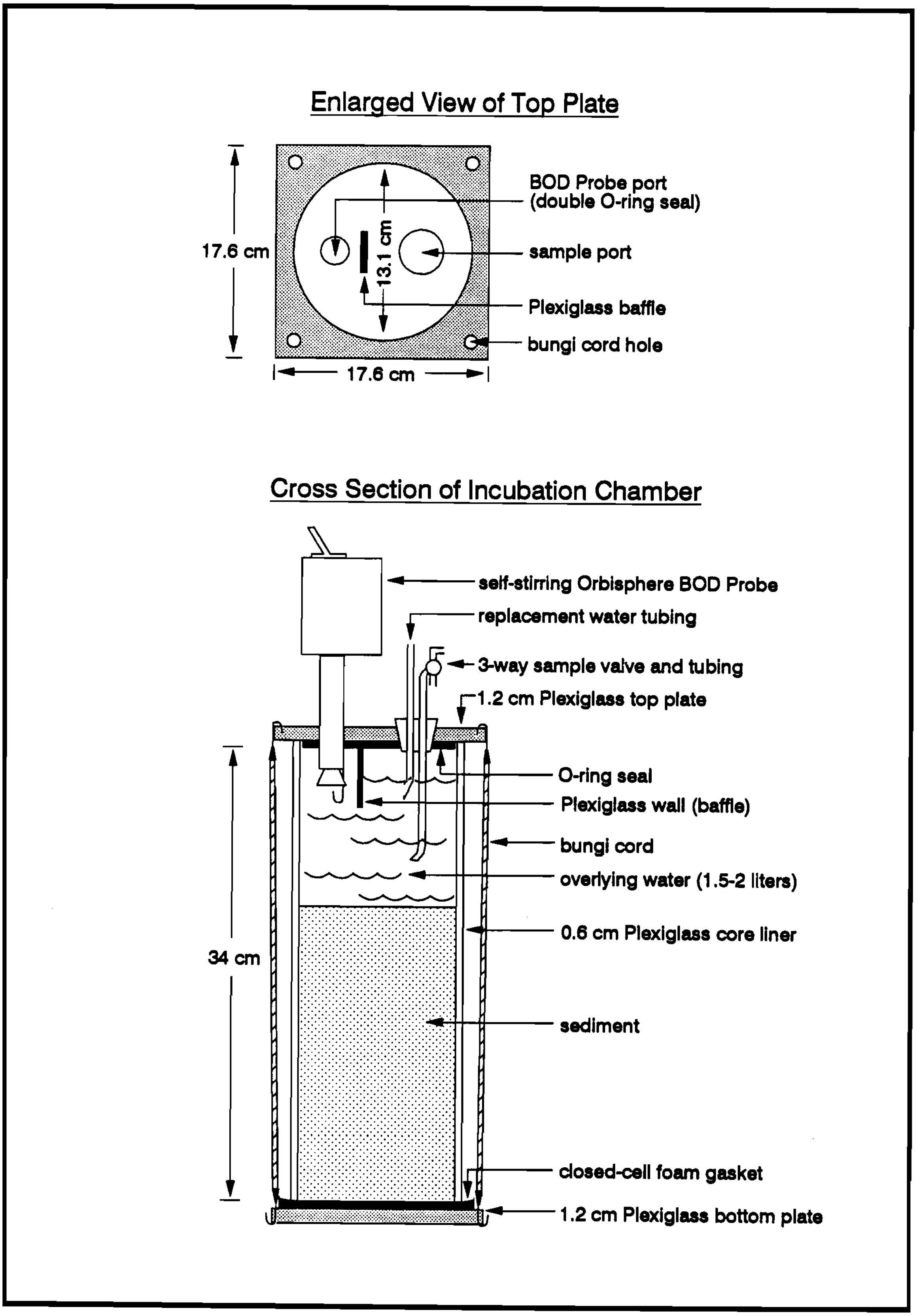


Figure 4-1. Schematic Diagram of the Incubation Chamber

4.1.3 Vertical Flux (VFX) Study

At the Vertical Flux (VFX) station, a water column profile of temperature, salinity and dissolved oxygen is obtained at 2 meter intervals from 0.5 meters to 1 meter off of the bottom to characterize the general physical features of the water column. Turbidity of surface waters is measured using a Secchi disc.

Water samples are also collected at three depths using a submersible pump system. Routinely, a sample is taken from near-bottom and near-surface waters and just above the top of the middle sediment trap. Water samples are analyzed for particulate materials including particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations, biogenic silica and seston content. These data provide descriptions of the particulate matter in the field at the time of sampling and are useful in evaluating results obtained from sediment trap collections.

4.1.3.1 Sediment Sampling

During previous VFX monitoring cruises a surficial sediment sample (surface 1 cm; 2 mm since 9 August, 1989) was obtained using either a Van Veen grab or the Bouma box corer. During this reporting period the Bouma corer was used exclusively because it obtains a better surficial sediment sample. Sediment samples are later analyzed to determine particulate carbon (PC), particulate nitrogen (PN) and particulate phosphorous (PP), total and active chlorophyll-a concentrations.

4.1.3.2 Vertical Flux (VFX) Sampling

The sampling device used to develop estimates of the vertical flux of particulate materials has a surface buoy connected to a lead or concrete anchor-weight (200 kg) by a series of stainless steel cables (0.8 cm diameter, Figure 4-2.). The array is maintained in a vertical position through the water column by two sub-surface buoys (45 cm diameter, 40 kg positive buoyancy and 33 cm diameter, 16 kg positive buoyancy). Collecting frames with cups are attached at about 5 meters and 9 meters beneath the water surface to obtain estimates of vertical flux of particulates from the surface euphotic zone to the pycnocline and flux across the pycnocline to deep waters.

The sediment trap string is routinely deployed and retrieved using CEES research vessels with normal sampling periods lasting one to two weeks depending upon fouling rates. At the end of a sampling period, collecting cups are retrieved by hoisting the entire array to shipboard. Cups are not capped prior to retrieval. After fouling organisms are removed from the frames, new cups are attached and the array lowered back into the water.

The contents of a collecting cup are removed and aliquots taken for determination of particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations and seston content. Until the end of the 1987 calendar year, an additional 10 ml sample was preserved using a modified Lugol's solution and later examined to determine characteristics of collected particulate material (*e.g.*, algal speciation, zooplankton fecal pellets, etc.).

The VFX program was not supported by the Maryland Department of the Environment during July through October 1991 but was supported financially by other University of Maryland Programs. Particulate phosphorus (PP) samples were not collected or analyzed during this period.

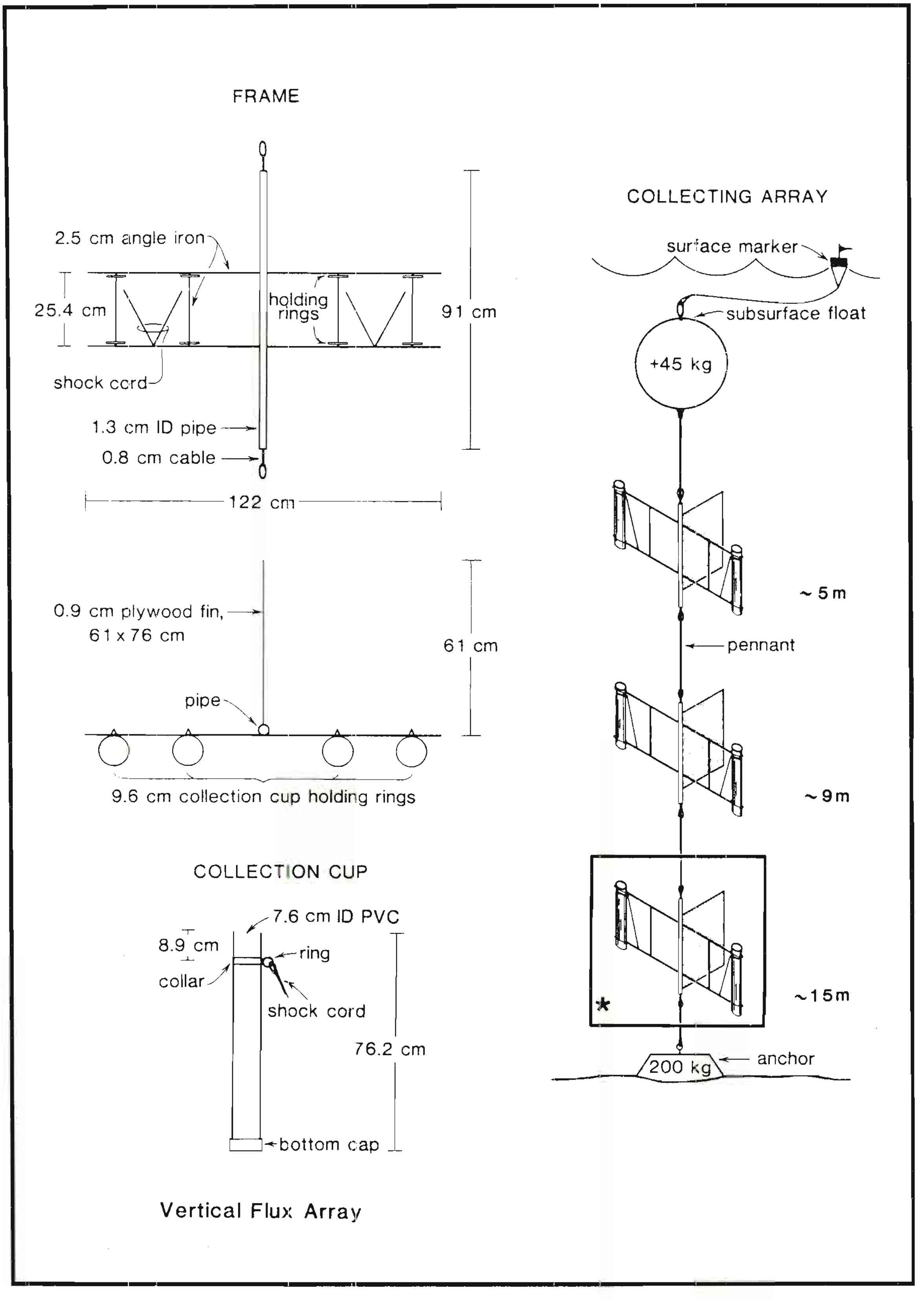


Figure 4-2. Schematic Diagram of the Sediment Trap used in VFX Monitoring
*** Measurements are only made using surface and mid cups.**
Bottom array has not been deployed or retrieved since July 8, 1987.

Particulate material concentrations in the sampling cups are converted to units of vertical flux, at the depth of the collecting cup, using the cross-sectional area of the collecting cup, deployment time, sample and subsample volumes. Further details concerning this monitoring program are provided in Boynton *et al.* (1985), Garber *et al.* (1987) and Boynton and Rohland (1990).

4.1.4 Chemical Analyses

Detailed reference material pertaining to all chemical analyses used is to be found in the EPC Data Dictionary (Boynton and Rohland, 1990). In brief, methods for the determinations of dissolved and particulate nutrients are: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate (NO_2^- + NO_3^-), and dissolved inorganic phosphorus (DIP or PO_4^-) are measured using the automated method of EPA (1979); silicious acid ($Si(OH)_4$) is determined using the Technicon Industrial System (1977) method; particulate carbon (PC) and particulate nitrogen (PN) samples are analyzed using a model 240B Perkin-Elmer Elemental Analyzer; particulate phosphorus (PP) concentration is obtained by acid digestion of muffled-dry samples (Aspila *et al.*, 1976); methods of Strickland and Parsons (1972) and Shoaf and Lium (1976) are followed for chlorophyll-a analysis; biogenic silica is measured using the method of Paasche (1973); total suspended solids (seston) are determined by the gravimetric technique of EPA (1979).

4.2. Analytical methods Quality Assurance/Quality Control (QA/QC)

The Nutrient Analytical Services Laboratory (NASL) at the Chesapeake Biological Laboratory provides nutrient analyses to university, State and federal agencies. As part of the laboratory's QA/QC program, NASL participates in cross calibration exercises with other institutions and agencies whenever possible. Some examples include:

- Particulate carbon and nitrogen cross calibration with Woods Hole Oceanographic Institution and Horn Point Environmental Laboratory.

- ICES inorganic nutrient round-robin communication. This will result in an international inter-comparison report to be issued in the near future.

- Dissolved nutrients in comparison with Horn Point Environmental Laboratory, Bigelow Laboratory, the University of Delaware and the University of New Hampshire.

- Cross calibration exercises with Virginia Institute of Marine Science (VIMS) and Old Dominion University (ODU). The most recent inter-comparison (March 1990) confirmed all parameters routinely analyzed by these laboratories as part of the Chesapeake Bay Monitoring Program. Samples from various salinities and nutrient regimes were analyzed under this exercise.

- Environmental Protection Agency (EPA) unknown audits for various nutrients have been conducted.

- EPA audits of known nutrients were analyzed using samples in different salinity water while looking for possible matrix effects.

NASL has analyzed National Institute of Standards and Technology (NIST) and National Research Board of Canada reference materials, primarily estuarine sediment, as a check for their particulate and sediment carbon, nitrogen and phosphorus methods.

As part of the Chesapeake Bay Mainstem Monitoring Program, the laboratory analyzes approximately ten percent of the total sample load for QA/QC checks. These samples include laboratory duplicates and spike analyses.

Specific EPC procedures include inorganic nutrients (ammonium [NH_4^+], nitrite [NO_2^-], nitrite plus nitrate [NO_2^- + NO_3^-], dissolved inorganic phosphorus [DIP or PO_4^-] and silicious acid [$Si(OH)_4$]) for which a standard curve usually comprising five concentrations encompassing the expected range for that particular sample set, are analyzed at the beginning of each new run. A standard which is treated as a sample, is analyzed at least every 20 samples. Baseline corrections are determined either manually or automatically, depending on the instrument providing the analysis. Data needed to calculate concentrations are recorded along with the sample concentration in laboratory notebooks, a carbon copy of which is provided to the EPC group. This procedure is also carried out for other parameters performed by the laboratory in support for the EPC effort. Precision and limits of detection for the variables measured by the EPC program are provided in the EPC Data Dictionary (Boynton and Rohland, 1990).

5. DATA MANAGEMENT

Hard copy data table listings of every variable measured during SONE and VFX monitoring programs for August 1984 through December 1989, were submitted in two volumes with the Level 1, No 7 Interpretive Report Part II: Data Tables [UMCEES]CBL Ref. No. 90-062 (Boynton *et al.*, 1990). A third volume contains data for 1990 and data collected in future years will be added to it. Part II: Data Tables of this interpretive report includes tabular listings of SONE, VFX and Pooles Island Dredge Survey Program data for 1991. Data files are given unique names which are a combination of an alpha code reflecting the type of data set and a numeric descriptor which indicates the number of the SONE cruise or sampling year in the case of Pooles Island and VFX files (EPC Data Dictionary; Boynton and Rohland, 1990).

5.1 Sediment Oxygen and Nutrient Exchanges (SONE) Study

The data collected at each SONE station are organized into six data sets:

WATER COLUMN PROFILES (Filename: **H2OPRFxx,** Table B-1) contain temperature, salinity and dissolved oxygen data measured at two meter intervals.

WATER COLUMN NUTRIENTS (Filename: **H2ONUTxx**, Table B-2) report surface and bottom water dissolved nutrient concentrations.

SEDIMENT PROFILES (Filename: **SEDPRFxx**, Table B-3) include redox potential and selected sediment measurements of particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations.

CORE PROFILES (Filename: **CORPRFxx**, Table B-4) lists percentage water, particulates and pore water nutrient measurements at SONE stations. Data are available only for SONE Cruise Numbers 2, 6 and 10.

CORE DATA (Filename: **CORDATxx**, Table B-5) lists dissolved oxygen and nutrient measurements in SONE sediment-water flux chambers.

SEDIMENT-WATER FLUX (Filename: **SWFLUXxx**, Table B-6) is a summary table providing oxygen and nutrient flux data.

5.2 Pooles Island Dredge Survey (PIDS) Program

Data was collected at one station, G-Central (GCNT) in July and August, 1991 and are organized into five data sets:

WATER COLUMN PROFILES (Filename: **HPPIDSxx,** Table E-1) contain temperature, salinity and dissolved oxygen data measured at two meter intervals.

WATER COLUMN NUTRIENTS (Filename: **NTPIDSxx**, Table E-2) report surface and bottom water dissolved nutrient concentrations.

SEDIMENT PROFILES (Filename: **SPPIDSxx**, Table E-3) include redox potential and selected sediment measurements of particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations.

CORE DATA (Filename: **CDPIDSxx**, Table E-4) lists dissolved oxygen and nutrient measurements in SONE sediment-water flux chambers.

SEDIMENT-WATER FLUX (Filename: **FLPIDSxx**, Table E-5) is a summary table providing oxygen and nutrient flux data.

5.3 Vertical Flux (VFX) Study

Vertical Flux (VFX) data, currently collected only at one station, R-64, are organized into three data sets:

WATER COLUMN PROFILES (Filename: **VFXPssxx**, Table C-1) contain temperature, salinity and dissolved oxygen data measured at two meter intervals.

SURFICIAL SEDIMENT PARTICULATES (Filename: **VFXSssxx**, Table C-2) lists particulate material concentration data including particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations.

VERTICAL FLUX OF PARTICULATES (Filename: **VFXDssxx**, Table C-3) which includes rate of deposition of particulate materials to collection cup depth for particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), active and total chlorophyll-a concentrations, and a biogenic silica and seston measurement.

5.4 Incorporation of Error Codes in Data Tables

In order to eliminate blank spaces in the data tables a one or two letter alpha code (Table 5-1) is used to describe the problems associated with questionable parameter values. Valid entries from the Sediment Data Management Plan (EPA, 1989) are used and where necessary additional codes which are related to the SONE, VFX studies or PIDS program have been added.

Table 5-1. Analysis Problem Codes

ANALYSIS PROBLEM CODE	DESCRIPTION
A	Laboratory accident
B	Interference
C	Mechanical/materials failure
D	Insufficient sample
N	Sample lost
P	Lost results
R	Sample contaminated
S	Sample container broken during analysis
V	Sample results rejected due to QA/QC criteria
W	Duplicate results for all parameters
X	Sample not preserved properly
AA	Sample thawed when received
BB	Torn filter paper
CC	Pad unfolded in foil pouch
EE	Foil pouch very wet when received from field, therefore poor replication between pads, mean reported.
FF	Poor replication between pads; mean reported
HH	Sample not taken
JJ	Amount filtered not recorded (calculation could not be done)
LL	Mislabeled
NI	Data for this variable are considered to be non-interpretable
NN	Particulates found in filtered sample
PP	Assumed sample volume (pouch volume differs from data sheet volume; pouch volume used)
QQ	Although value exceeds a theoretically equivalent or greater value (e.g., PO4F>TDP), the excess is within precision of analytical techniques and therefore not statistically significant
RR	No sample received
SS	Sample contaminated in field
TF	Dissolved oxygen probe failure
TS	Dissolved oxygen probe not stabilized
TT	Instrument failure on board research vessel
UU	Analysis discontinued
WW	Station was not sampled due to bad weather conditions, research vessel mechanical failure, VFX array lost or failure of state highway bridges to open or close
XX	Sampling for this variable was not included in the monitoring program at this time or was not monitored during a specific cruise
YY	Data not recorded.

5.5 Data Tables Quality Assurance/Quality Control (QA/QC)

Data recorded by instruments in the field are entered directly onto specially prepared data sheets. Data from samples analyzed by Nutrient Analytical Services Laboratory (NASL) are returned in written format. Data are keyed into Lotus using the standard format developed during the continuing effort begun in August 1989 to standardize all EPC data files. Hard copies of the files are manually checked for errors. Data files are corrected, a second printout produced which is re-verified by a different staff member.

5.6 Statistical Analysis System (SAS) Files and Statistical Analyses

The schedule of deliverables (an attachment to the EPC contract) indicates that after verification data are to be transferred into Statistical Analysis System (SAS) format and submitted with labels and file structures supplied by the EPA Chesapeake Bay Liaison Office (EPA/CBLO) and be readable on the VAX 8650. Lotus files, which are only acceptable as an interim submission to EPA, are stripped of headings and converted into ASCII files. Final editing is completed using a word processing program.

The first SAS data set, Water Column Profile H2OPRF (SONE), was successfully loaded during January, 1992. During February, March and April, 1992 four additional SONE SAS data sets and two VFX SAS data sets were created and loaded to the VAX 8650. This comprises about 90% of the available data. The two remaining data sets will be loaded by the end of December, 1992. SAS reference files are being compiled for each data set containing detailed station and variable information as well as other important information related to missing data.

The final step in this processes will involve rigorous data checking prior to requesting the formal sign off of each data set. All data sets will be available in SAS format by the end of December, 1992.

Sediment-water fluxes are being examined for temporal and spatial trends with the assistance of Professor Larry Douglass, Research Statistician at the University of Maryland, College Park. These analyses are performed on the SAS sediment-water flux data set and the results will be described in a special report to be completed by the end of February, 1993.

SEDIMENT OXYGEN AND NUTRIENT EXCHANGES (SONE) RESULTS AND DISCUSSION

6.1 Inter-annual Patterns of River Flow and Nutrient Loading

6.1.1 Overview

One of the continuing objectives of the Ecosystem Processes Component (EPC) Program is to explore monitoring program data, as well as other data sources, for relationships between nutrient loading (e.g. point, non-point and atmospheric data) and responses of sediment and deposition processes. Particulate material deposition, sediment oxygen consumption and sediment nutrient exchanges have been shown to have strong influences on water quality conditions (Boynton *et al.*, 1990) and are ultimately believed to be regulated by rates of external nutrient supplies. River flow has been shown to be a good first approximation of nutrient loading rates for many areas of Chesapeake Bay. Since loading rates will be referred to throughout this report, a summary of these (as indicated by river flow) are provided here. Actual nutrient loading rates for the period 1978 through 1988 have been reported in a previous EPC report (Boynton *et al.*, 1991) and a detailed treatment of these variables is given in Summers (1989). River flow is used here because it is available for the period of time evaluated in this report.

6.1.2 Average Annual River Flows

Annual average river flows for the period 1978 through 1991 are shown in Figure 6-1.1. Additionally, average flows to each system during this period are indicated by horizontal lines on this figure (James *et al.*, 1990; J. Hornlein, *pers. comm.*). Despite the fact that these basins are distinctly different, and in some cases separated in space by large distances, there are strong similarities in inter-annual flows among systems. Flows in all systems were above average in 1978 and 1979, below average from 1980 to 1982, higher during 1983 and 1984, generally lower from 1985 through 1988 and above average in 1989 (except in the Potomac River in 1989). Flows during 1990 and 1991 were progressively lower than during 1989 in all systems except the Susquehanna which was characterized by above normal flow in 1990 and very low flow in 1991. Flows from the Potomac River during 1985 through 1991, the period for which EPC Program data are available, were below average as they were in the Susquehanna except in 1989 and 1990 when flows were average and above average, respectively. Flows in the Choptank and Patuxent Rivers were well below average except in 1989 when flows were above normal. In 1990 and 1991 flows in both of these rivers were again below average. In general, river flows have been average to below average during the EPC monitoring period with a few exceptions. As a result of this, water column stratification might be expected to be less intense than usual and diffuse source nutrient loads to be lower than normal.

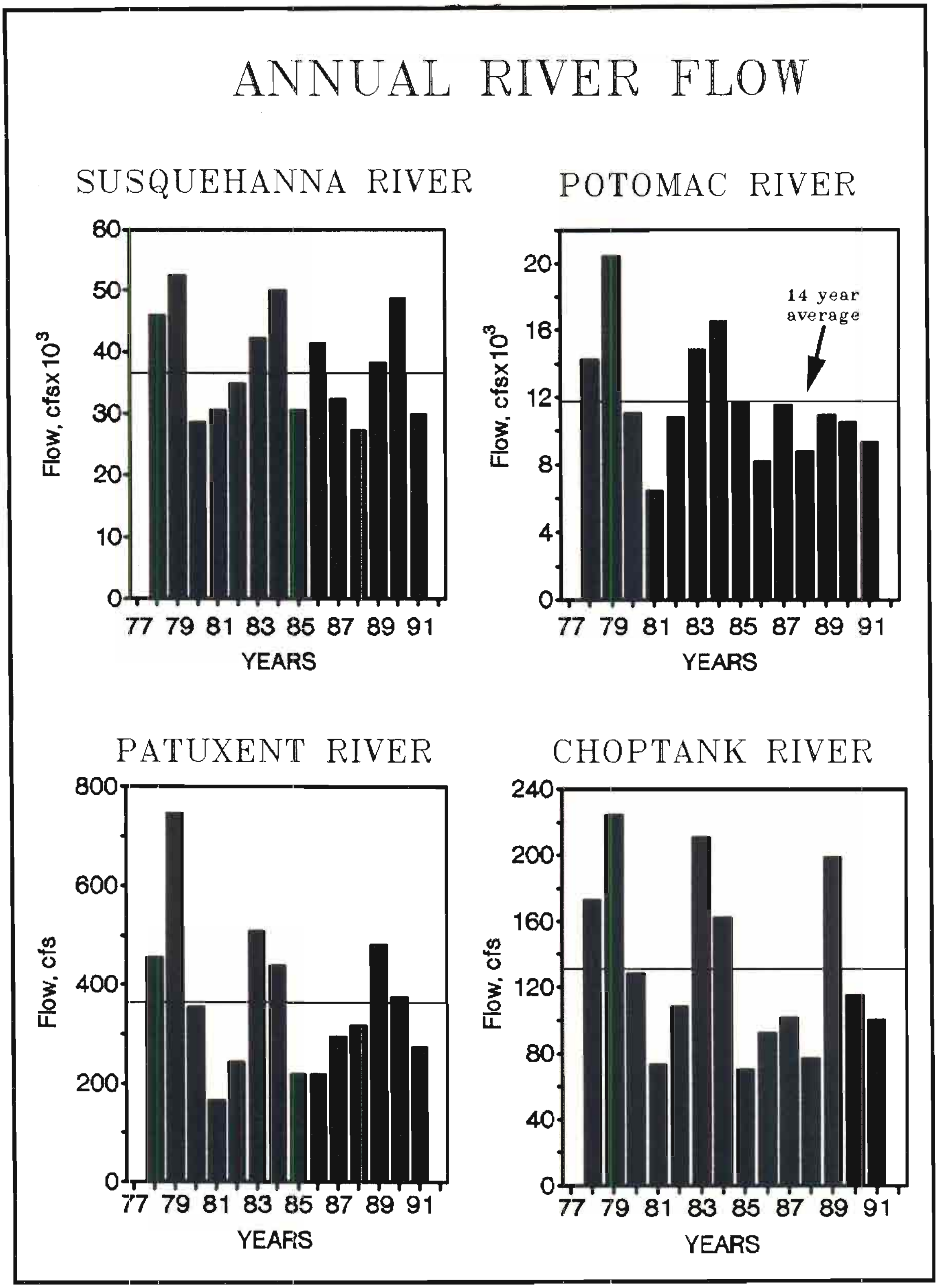


Figure 6-1.1. Bar graphs of average annual river flow from the Susquehanna, Potomac, Patuxent and Choptank Rivers for the period 1978 through 1991 (James *et al.*, 1990; J. Horlein, *pers. comm.*).
Flows were measured at Conowingo, MD; Washington, D.C.; Bowie, MD and Greensboro, MD for the four systems, respectively.

6.1.3 Average Monthly River Flows

One of the more obvious characteristics of estuarine systems is the time and space variability associated with many variables as is the case for river flow (and diffuse source nutrient loading). Monthly average river flows for all of the main Maryland tributary rivers are shown as a series of bar graphs for 1990 (Figure 6-1.2.) and 1991 (Figure 6-1.3.). In these figures the vertical bars represent average monthly flows while the bold dots represent average monthly flows calculated over longer time periods (1977-1991 [14 years] for the Susquehanna, Potomac and Patuxent Rivers and 1948-1991 [43 years] for the Choptank River). In 1990 (Figure 6-1.2.) only flows in the Patuxent River were reasonably close to the long-term monthly average flows. The remaining systems exhibited large departures from mean conditions for at least part of the year, *e.g.* the Susquehanna and Potomac River flows were below average in spring and higher than normal in fall (Figure 6-1.2.). During 1991 flows were generally below normal in all of these systems except for portions of the winter season (Figure 6-1.3.).

These data are presented to emphasize the need for careful consideration of temporal relationships between variables such as river flow or nutrient loading and ecosystem processes such as deposition and sediment-water nutrient and oxygen exchanges. In cases where a rapid response is expected (weeks to months) examination of intra-annual data will be necessary. In those cases where effects of inputs such as river flow or nutrient loading are expected to appear over longer periods of time (months to years) consideration of inter-annual data will be necessary. It is becoming apparent that both time scales are important features governing relationships between nutrient loading rates and sediment-water nutrient and oxygen exchange rates in Chesapeake Bay.

6.2 Inter-annual Characteristics of Sediment-Water Oxygen and Nutrient Exchanges

6.2.1. Overview

In this section monthly sediment-water fluxes are summarized in the form of bar graphs for five variables: sediment oxygen consumption (SOC), ammonium (NH_4^+), nitrite plus nitrate ($NO_2^- + NO_3^-$), phosphate (PO_4^-), and silicate ($Si(OH)_4$). In each of these graphs (Figures 6-2.1a. to 6-2.5b.) all data for each variable collected from May, 1985 through October, 1991 are displayed as a function of the time during which the variable is measured. Data collected at each of the eight stations routinely monitored during SONE cruises are used to draw these graphs. Each bar represents the mean flux value (based on triplicate measurements) for a particular month and the vertical line shown on each bar indicates the standard deviation from this mean. Data have only recently been collected at two stations in the Patuxent River (Broomes Island [BRIS] and Marsh Point [MRPT]) and so the period of record for these stations is very limited.

Sediment oxygen consumption (SOC), rates are plotted as positive values (following the convention of the oceanographic literature) but indicate a flux of oxygen from overlying waters to sediments. In all remaining fluxes, a positive value indicates a flux from sediments to overlying waters while conversely a negative flux represents a flux from overlying waters to sediments.

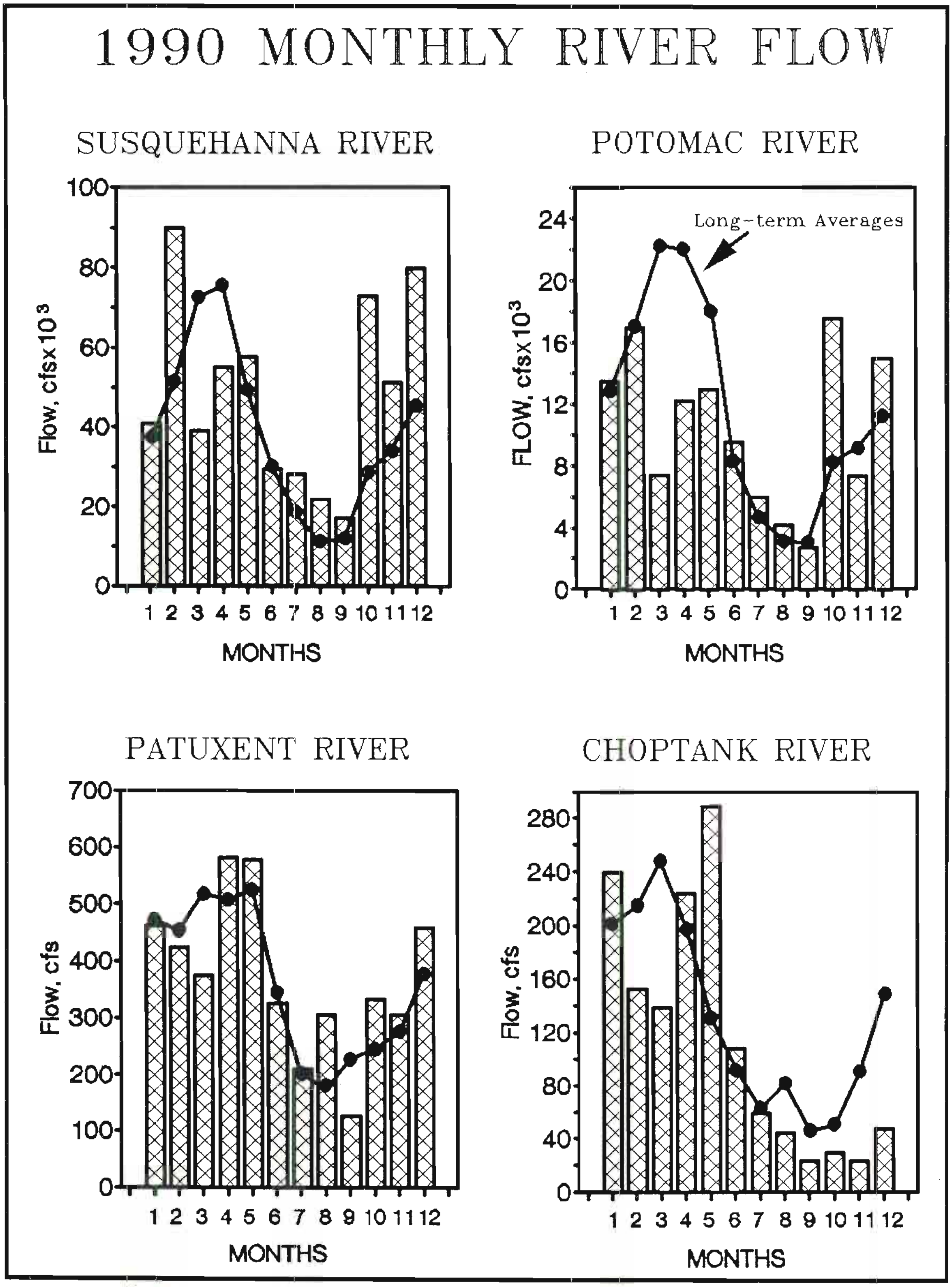


Figure 6-1.2. Bar graphs of average monthly river flow from the Susquehanna, Potomac, Patuxent and Choptank Rivers for 1990. The bold dots indicate long term average monthly flows calculated for the period 1978 through 1991.
Flows were measured at Conowingo, MD; Washington, D.C.; Bowie, MD and Greensboro, MD for the four systems, respectively.

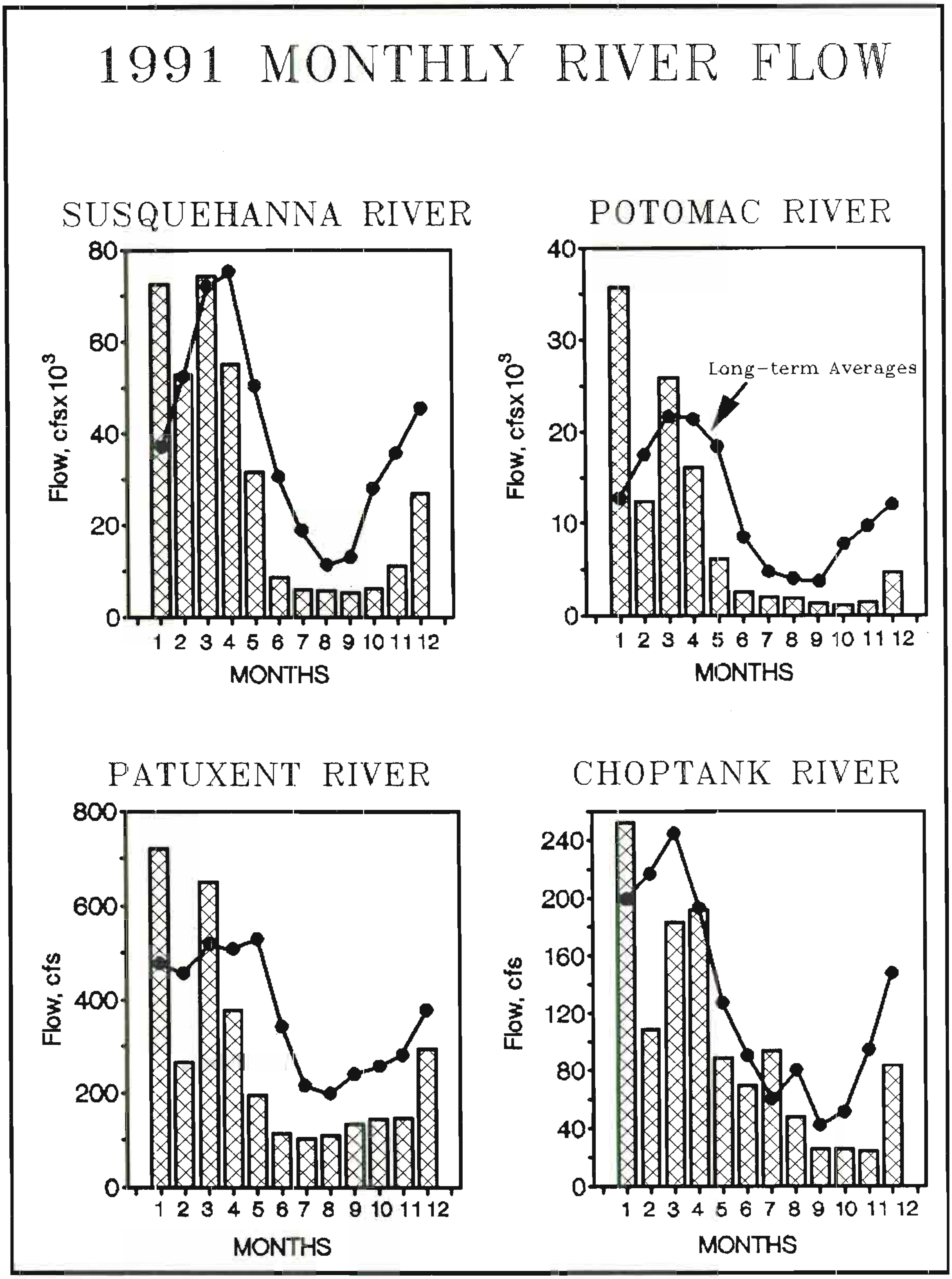


Figure 6-1.3. Bar graphs of average monthly river flow from the Susquehanna, Potomac, Patuxent and Choptank Rivers for 1991. The bold dots indicate long term average monthly flows calculated for the period 1978 through 1991. Flow data for gauges in the Susquehanna, Potomac and Patuxent Rivers began in 1977 and in 1948 in the Coptank River.
Flows were measured at Conowingo, MD; Washington, D.C.; Bowie, MD and Greensboro, MD for the four systems, respectively.

6.2.2 Sediment Oxygen Consumption (SOC)

Mean monthly sediment oxygen consumption (SOC) fluxes measured at eight SONE stations between May, 1985 and October, 1991 ranged from almost zero (0.0) to about 4.3 g O_2 m^{-2} d^{-1} and were generally higher in the Patuxent and Choptank Rivers than at the other sites (Figure 6-2.1a. and 6-2.1b.). In almost all cases a seasonal pattern was evident with increased rates of SOC in the springtime (May through June), depressed values in the summer (July through August) and increased rates in the fall (October through November). The largest fluxes were generally recorded in May and June, with a secondary peak recorded in October. High SOC fluxes in the Choptank and Patuxent Rivers may be caused by the generally higher bottom water oxygen conditions experienced at these sites as opposed to deep areas of the mainstem and the Potomac River.

The 1991 data followed the same pattern as previous years but provides a more detailed picture of seasonal flux pattern because there are six sampling periods in 1991. During 1991, fluxes at the two long-term stations (St. Leonard Creek [STLC] and Buena Vista [BUVA]) in the Patuxent River were higher than during the 1987 and 1988 period and similar to rates observed during 1985 and 1986. Sediment oxygen consumption rates at the down river station (St. Leonard Creek [STLC]) exhibited this pattern more clearly than did the up river station (Buena Vista [BUVA]). Fluxes at the mid-river stations (Broomes Island [BRIS] and Marsh Point [MRPT]) were generally lower than at the upper and lower river stations because of low bottom water dissolved concentrations during summer periods. Fluxes at the Horn Point station (HNPT) in the lower Choptank River were slightly higher than the seven year mean in 1991, but were lower than rates observed in 1990. To a large extent SOC rates in the lower Choptank River followed a long-term pattern similar to that observed in the Patuxent River where rates were highest in recent years and during the 1985-1986 period and lower during 1987-1989. Rates at the remaining three stations (Ragged Point [RGPT], Point No Point [PNPT] and R-64) were relatively low (approximately 0.0 - 1.0 g O_2 m^{-2} day^{-1}).

Spring and fall SOC rates at most stations are of sufficient magnitude to constitute a substantial direct dissolved oxygen loss (W.M. Kemp, *pers. observation*). However, as indicated in an earlier report (Boynton *et al.*, 1990) SOC is not an adequate measure of sediment metabolism during summer periods if low oxygen conditions occur. The SOC rates reported here during periods of low oxygen concentrations grossly underestimate sediment metabolism and oxygen demand exerted via oxidation of reduced sulphur compounds (Roden, 1990). The EPC program is attempting to add a routine measurement of anaerobic sediment metabolism to better estimate total sediment oxygen demand.

6.2.3 Ammonium Fluxes

Monthly ammonium fluxes (Figures 6-2.2a. and 6-2.2b.) during the entire monitoring period (May, 1985 through October, 1991) ranged from about 1 μMN m^{-2} hr^{-1} at St. Leonard Creek (STLC) to 700 μMN m^{-2} hr^{-1} in the mid-mainstem bay (Station R-64). In most cases highest values were recorded in the summer months July or August. Several interesting spatial patterns were also evident. For example, NH_4^+ fluxes tended to increase from the mouth to the turbidity maximum zone of the Patuxent River. This qualitative pattern reflects the expected trend of deposition rates of organic matter to the sediment surface. In fact, deposition rates measured at six sites along the longitudinal axis of the Patuxent River in the late 1970's indicated a deposition maximum in the area of Buena Vista (BUVA) (Boynton *et al.*, 1982b). Similarly, the exceptionally high rates of NH_4^+ release from sediment at R-64 (mainstem bay) are double those recorded at Point No Point (PNPT) a site farther down the

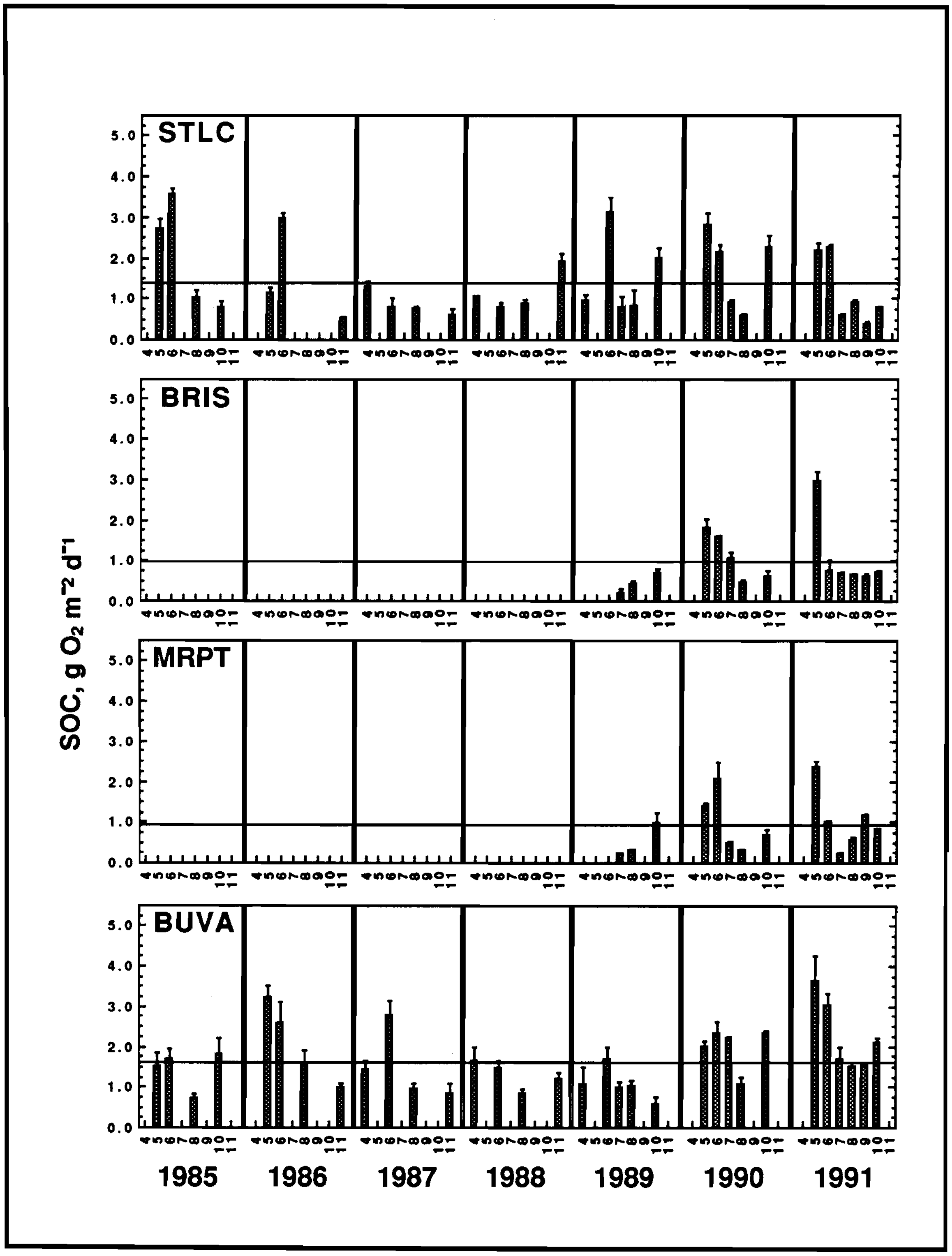


Figure 6-2.1a. Monthly SOC rates (mean and standard deviation of triplicate measurements) at SONE stations located in the Patuxent River for the period May, 1985 - October, 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on 1989 and 1991 data. The horizontal line in each panel indicates the average fluxes for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

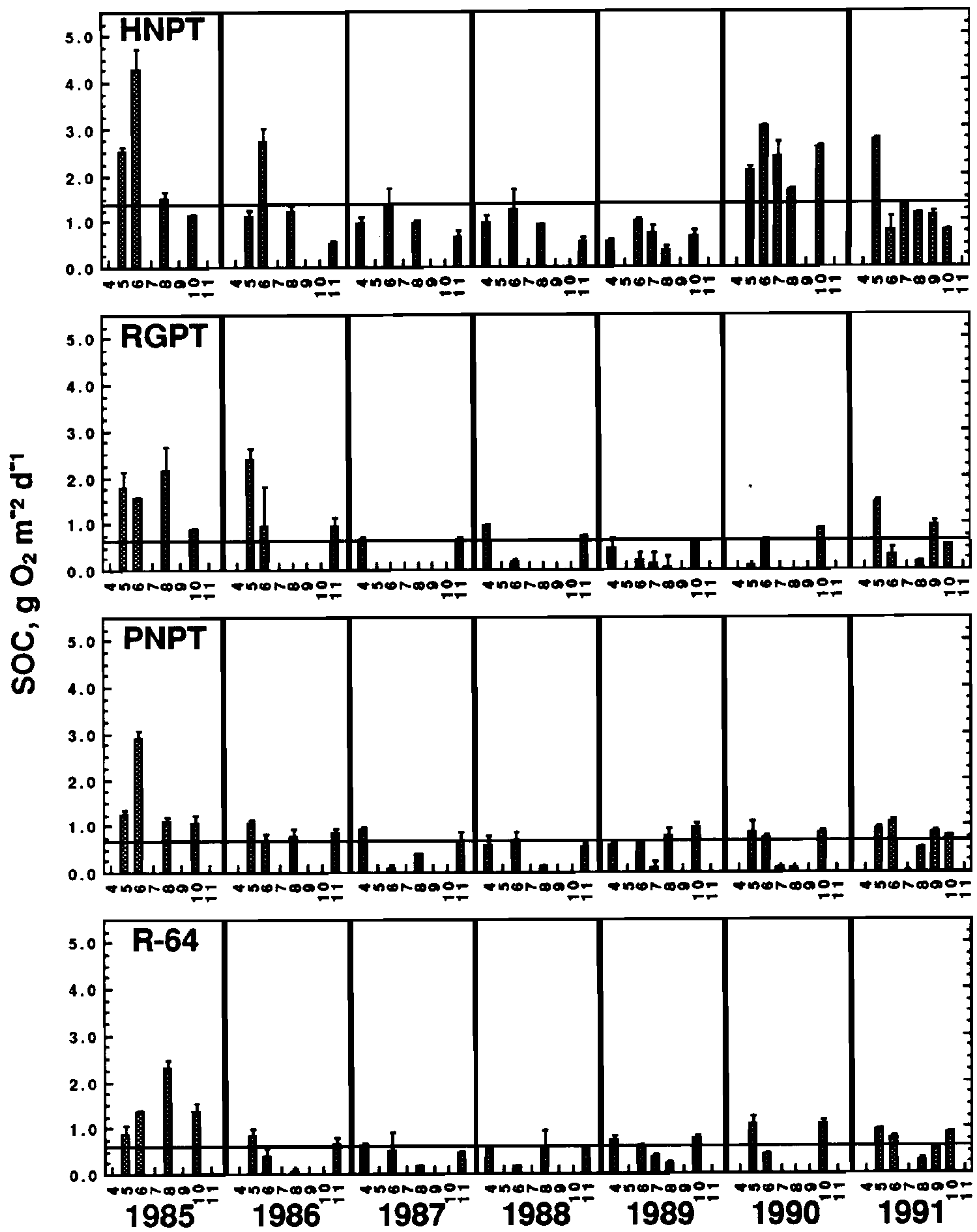


Figure 6-2.1b. Monthly SOC rates (mean and standard deviation of triplicate measurements) at SONE stations located in the lower Choptank (Horn Point, HNPT) and Potomac (Ragged Point, RGPT) Rivers and at two sites in the Maryland mainstem bay (Point No Point, PNPT and R-64) for the period May, 1985 - October, 1991. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

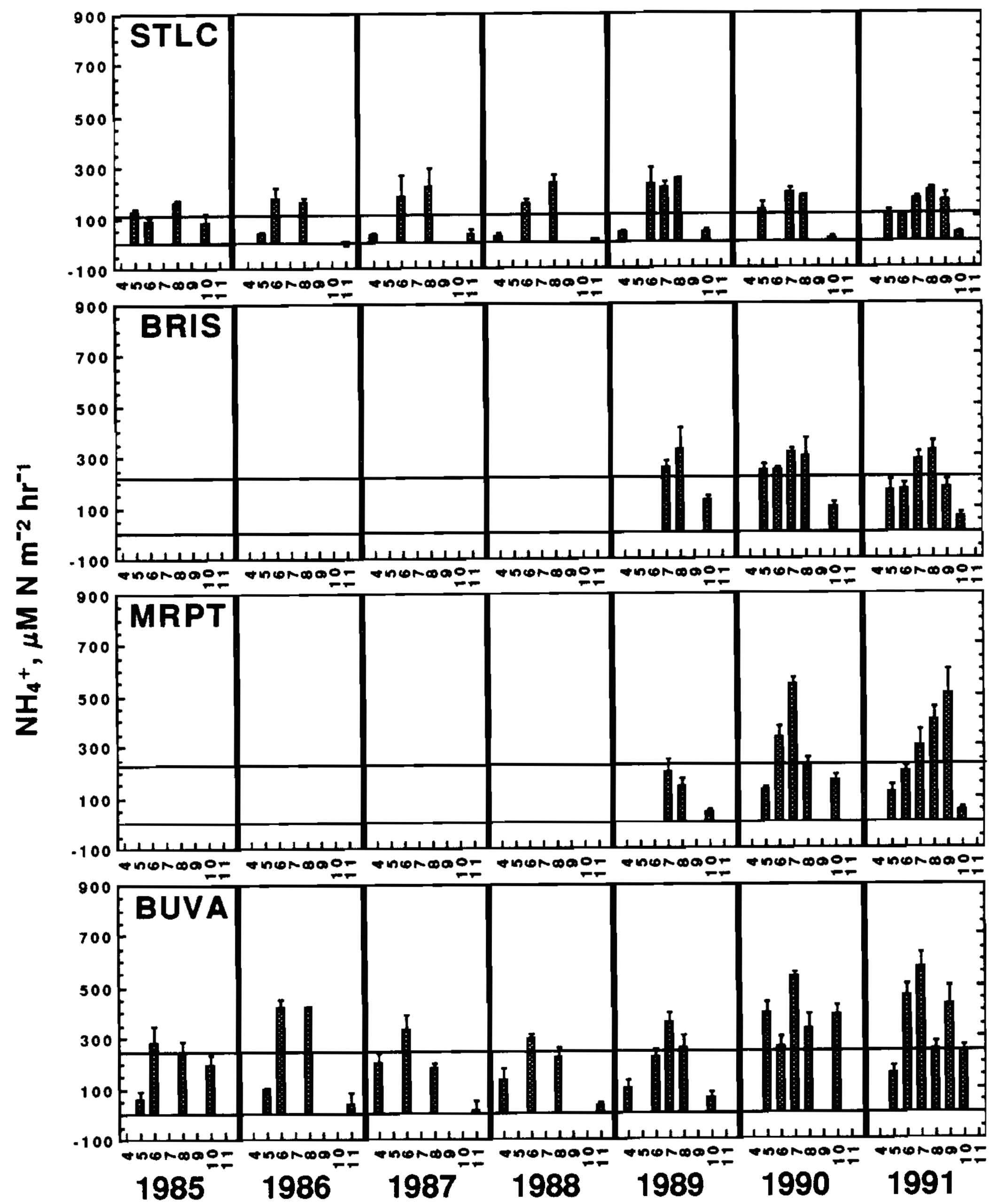


Figure 6-2.2a. Monthly ammonium (NH_4^+) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the Patuxent River for the period May, 1985 - October, 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on 1989 and 1991 data. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

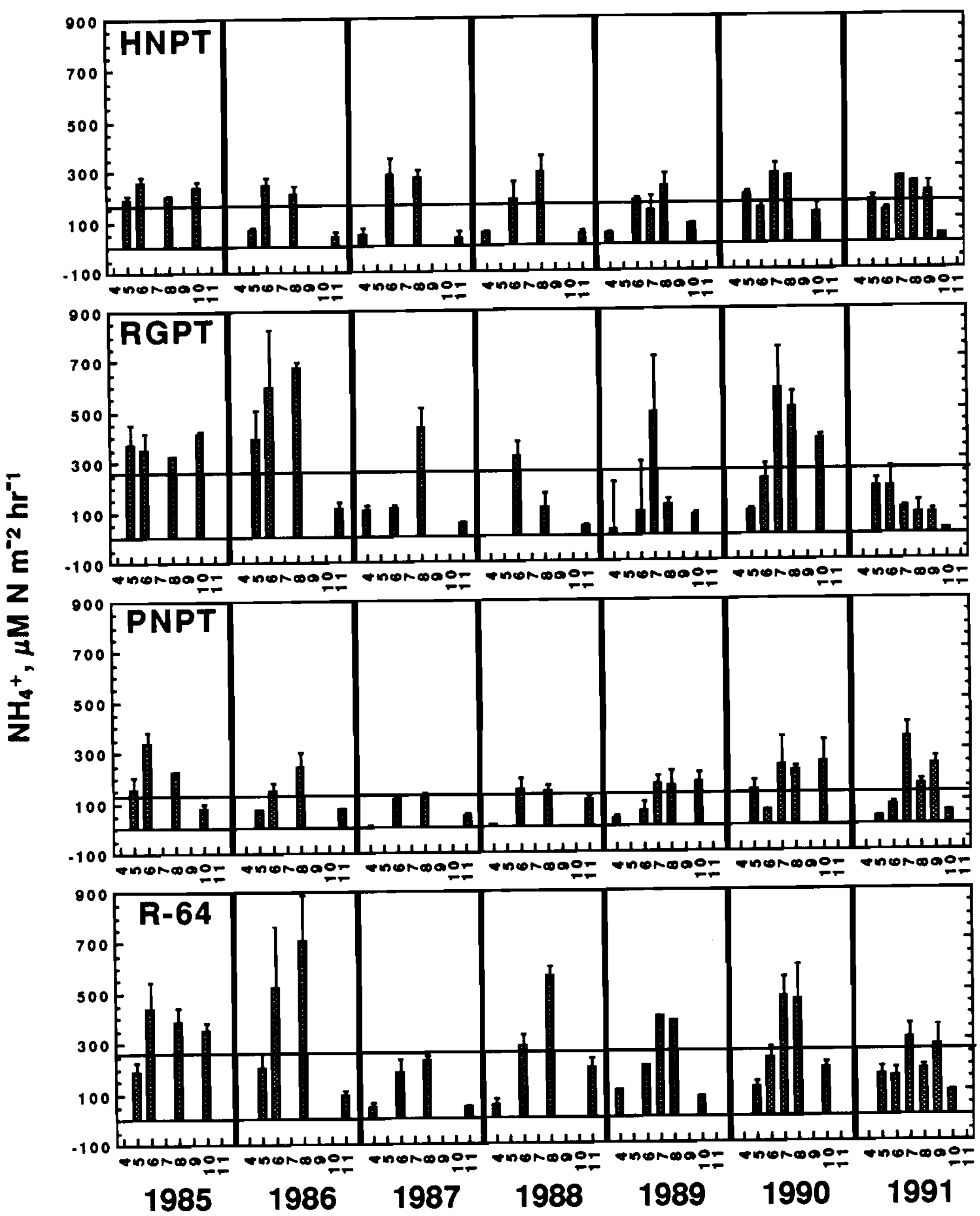


Figure 6-2.2b. Monthly ammonium (NH_4^+) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the lower Choptank (Horn Point, HNPT) and Potomac (Ragged Point, RGPT) Rivers and at two sites in the Maryland mainstem bay (Point No Point, PNPT and R-64) for the period May, 1985 - October, 1991. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

bay in an area where primary production, chlorophyll-a stocks and presumably deposition rates were considerably lower.

In general, the highest ammonium flux rates recorded in 1991 were measured during July and August. However, NH_4^+ fluxes were above mean fluxes in 1991 at two stations in the upper Patuxent River (Marsh Point [MRPT] and Buena Vista [BUVA]). Ammonium fluxes in the lower Choptank River (Horn Point [HNPT]) and the lower Maryland mainstem bay (Point No Point [PNPT]) during 1991 were similar to the long-term means at these stations. Fluxes at stations in the lower Potomac River (Ragged Point [RGPT]) and the middle Maryland mainstem bay (R-64) were lower than the long-term mean. Maximum summer fluxes at these two sites were considerably lower than in previous years.

6.2.4 Nitrate + Nitrite (NO_2^- + NO_3^-) Fluxes

Monthly nitrate plus nitrite fluxes (NO_2^- + NO_3^-)(Figures 6-2.2a. and 6-2.2b.) during the entire monitoring period (May, 1985 through October, 1991) ranged from about -230 μMN m^{-2} hr^{-1} at Broomes Island (BRIS) to 150 μMN m^{-2} hr^{-1} in the lower Choptank River (Horn Point [HNPT]). These fluxes are not an important indication of overall sediment-water nitrogen exchanges during summer months (June through September) at most stations because ammonium fluxes are so large. However, they do represent substantial exchanges during spring and some fall periods, especially at tributary stations (e.g. Horn Point [HNPT], St. Leonard Creek [STLC]).

The direction of nitrate plus nitrite (NO_2^- + NO_3^-) fluxes at the two long-term stations in the Patuxent River (St. Leonard Creek [STLC] and Buena Vista [BUVA]) has gradually shifted from a predominantly positive (sediment to water) to a negative flux (water to sediment). Positive NO_2^- + NO_3^- fluxes are a clear indication that nitrification is taking place in sediments which in turn indicates that sediments are at least partially oxidized. Oxidized sediments (and associated positive NO_2^- + NO_3^- fluxes) are considered to be a sign of "healthy" sediments (Boynton *et al.*, 1991). Fluxes of NO_2^- + NO_3^- from water to sediments is thought to be driven by the concentration gradient of NO_2^- + NO_3^- between sediments and water and that the eventual fate of the NO_2^- + NO_3^- taken up by sediments is denitrification. It appears that the latter process is becoming dominant at stations in the Patuxent River. At this point it is not clear why this apparent shift in direction of flux is occurring.

Lower nitrite plus nitrate (NO_2^- + NO_3^-) fluxes (in either direction) have routinely been found at the two mainstem bay stations (Point No Point [PNPT] and R-64). In this region of the bay NO_2^- + NO_3^- concentrations in bottom waters are seldom high, even in spring (Magnien *et al.*, 1990), and hence there is not the concentration gradient available to drive fluxes of these compounds from water to sediments. During summer months bottom waters and sediments are severely hypoxic or anoxic and hence nitrification is not possible. As a result there is no production of NO_2^- + NO_3^- in sediments to support a flux from sediments to overlying waters.

At most stations nitrite plus nitrate NO_2^- + NO_3^- fluxes recorded during 1991 were directed from water to sediments (negative fluxes) and the magnitude of these fluxes were among the largest yet recorded during the monitoring program.

It is probable that the NO_2^- + NO_3^- entering the sediments is rapidly denitrified (Jenkins and Kemp, 1984). This form of nitrogen is required for denitrification to occur. Substantial rates of denitrification represent an important terminal nitrogen loss from the system.

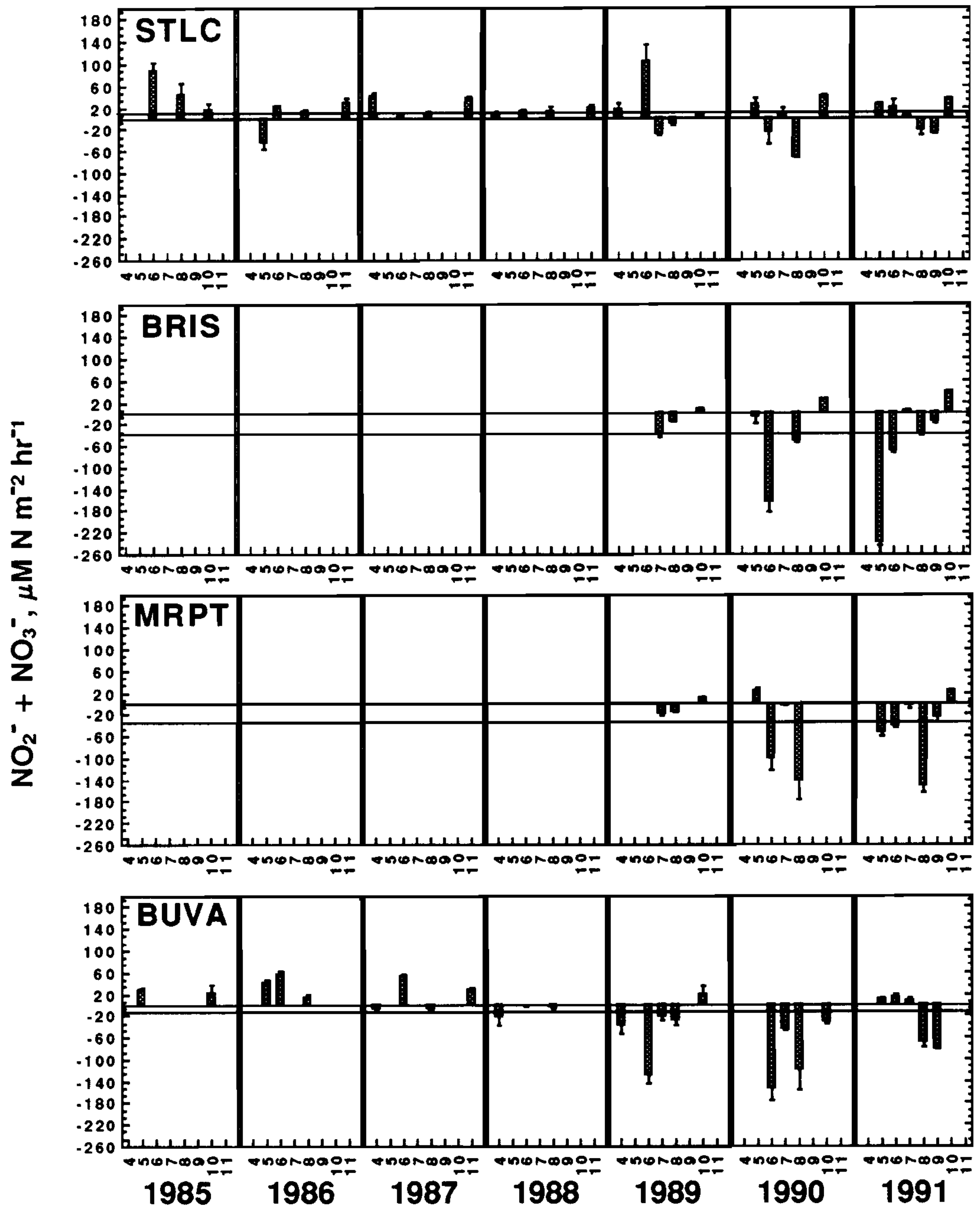


Figure 6-2.3a. Monthly nitrate plus nitrite (NO_2^- + NO_3^-) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the Patuxent River for the period May, 1985 - October, 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on 1989 and 1991 data. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

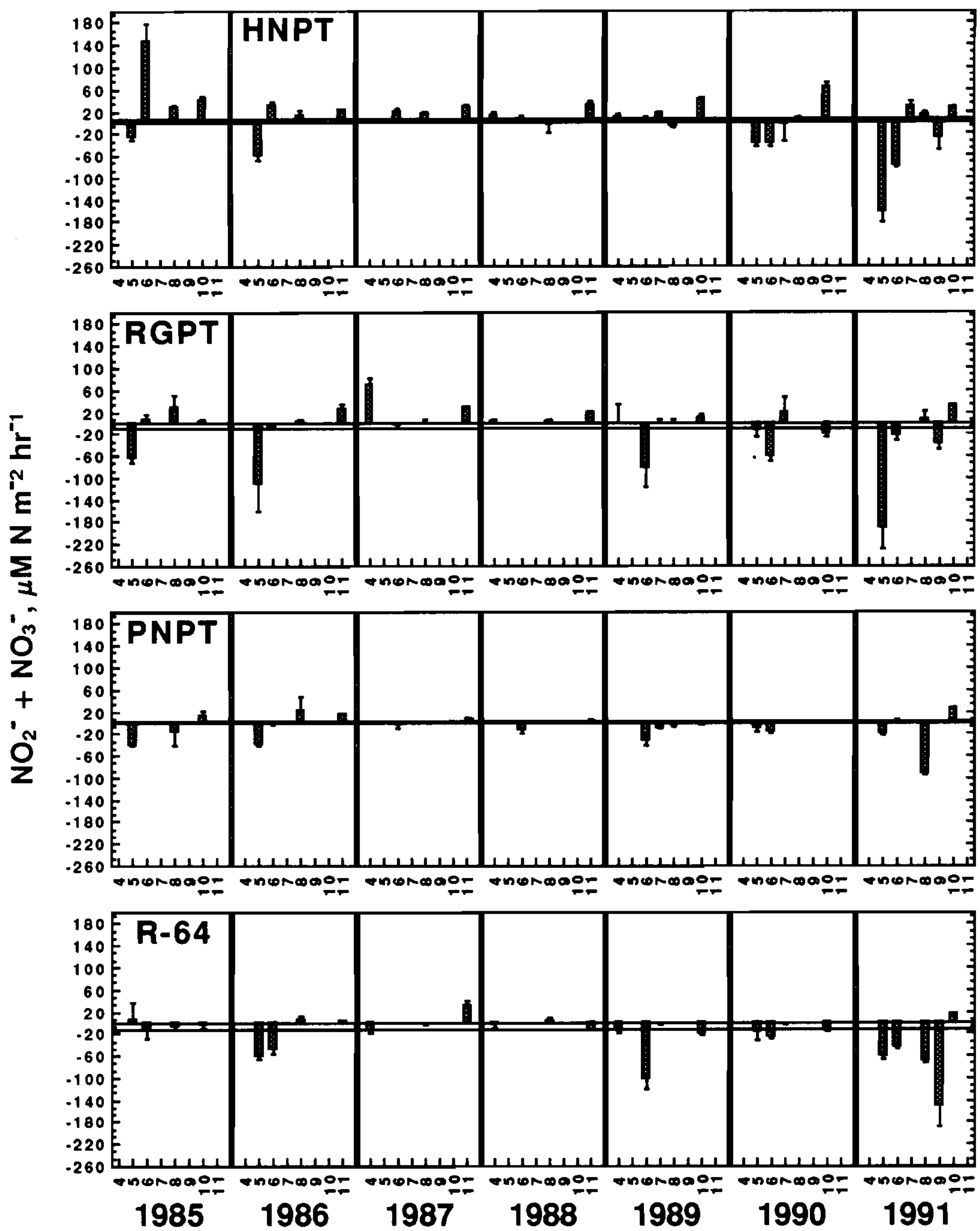


Figure 6-2.3b. Monthly nitrate plus nitrite (NO_2^- + NO_3^-) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the lower Choptank (Horn Point [HNPT]) and Potomac (Ragged Point [RGPT]) Rivers and at two sites in the Maryland mainstem bay (Point No Point [PNPT] and R-64) for the period May, 1985 - October, 1991. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

6.2.5 Dissolved Inorganic Phosphorus (PO_4^- or DIP) Fluxes

The overwhelming trend of data collected by the monitoring program indicates a net flux of dissolved inorganic phosphorus (PO_4^-) from the sediment to the overlying waters. Values ranged from -8 in the lower Maryland mainstem bay (Point No Point [PNPT]) to 170 μMP m^{-2} hr^{-1} in the upper Patuxent River (Figures 6-2.4a. and 6-2.4b.). Fluxes of dissolved inorganic phosphorus typically reached maximum values during the summer (July or August). With the exception of the station in the upper Patuxent River (Buena Vista [BUVA]), all large PO_4^- fluxes were associated with hypoxic or anoxic conditions in overlying waters. The high PO_4^- fluxes observed at Buena Vista (BUVA) may be caused, at least in part, by the burrowing and irrigation activities of the large benthic macrofaunal community present at this location (Holland *et al.*, 1989). Iron sulphur (Fe-S) reactions are probably responsible for high PO_4^- fluxes elsewhere under low dissolved oxygen conditions. Fluxes have been typically low (< 20 μMP m^{-2} hr^{-1}) at stations which do not experience chronic hypoxic conditions in deep waters or sediments (*e.g.* St. Leonard Creek [STLC], Horn Point [HNPT] and Point No Point [PNPT]).

Data collected during 1991 generally closely followed established trends; fluxes were highest during summer and fluxes were highest at stations experiencing hypoxic or anoxic conditions. However, there were several interesting modifications of this pattern evident. First, fluxes at R-64 (middle portion of the Maryland mainstem bay) followed the usual seasonal pattern but the magnitude of the flux was reduced compared to 1990 by a factor of two. It is possible that lower than normal river flow (and nutrient loading rates) to the mainstem bay in 1991 (Figure 6-1.3.) resulted in reduced deposition of organic matter to sediments and a smaller than normal pool of phosphorus available for release during summer months. Ammonium fluxes were also reduced at this station in 1991. It is interesting to note that the largest phosphorus fluxes observed in the lower Choptank River (Horn Point [HNPT]) were associated with the largest river flows observed in that system (1989) since the beginning of the monitoring program. Other relationships between sediment-water fluxes and nutrient loading rates have been reported (Boynton *et al.*, 1991). Data collected during 1991 tend to support these relationships.

6.2.6 Dissolved Silicate Fluxes

Monthly silicate fluxes (Figures 6-2.5a. and 6-2.5b.) during the entire monitoring period (May, 1985 through October, 1991) ranged from about 30 μM Si m^{-2} hr^{-1} at Broomes Island (BRIS) to 1300 μM Si m^{-2} hr^{-1} in the upper Patuxent River (Buena Vista [BUVA]). There were no marked differences among sites for silicate fluxes as was the case for other nutrient and oxygen fluxes. In fact, the most striking aspect of these monthly data is the similarity among sites, especially in light of the very different TN and TP loading rates to which different sites are exposed. In addition, seasonal patterns were not well developed. For example, while such flux variables as NH_4^+ and PO_4^- exhibited higher values during summer, this was not consistently true for silicate even though at times values for the months of June or July were marginally higher than in adjacent months, May and August. At least in part the similarity in average silicate fluxes may reflect the fact that the three tributary rivers in which monitoring stations are located and the Maryland mainstem bay have similar freshwater fill times despite large differences in areas and volumes (Boynton *et al.*, 1992). Since silicate is exclusively delivered to estuarine waters from diffuse source drainage, the loading rates of silicate are similar among these different portions of the bay system. In addition, silicate is generally depleted from the water column following the spring bloom, although there are inter-annual and spatial difference in the degree of depletion. However, depletion indicates that silicate available in the water column is taken up by diatoms which sink to the sediments following the termination of the bloom. In effect, it seems reasonable

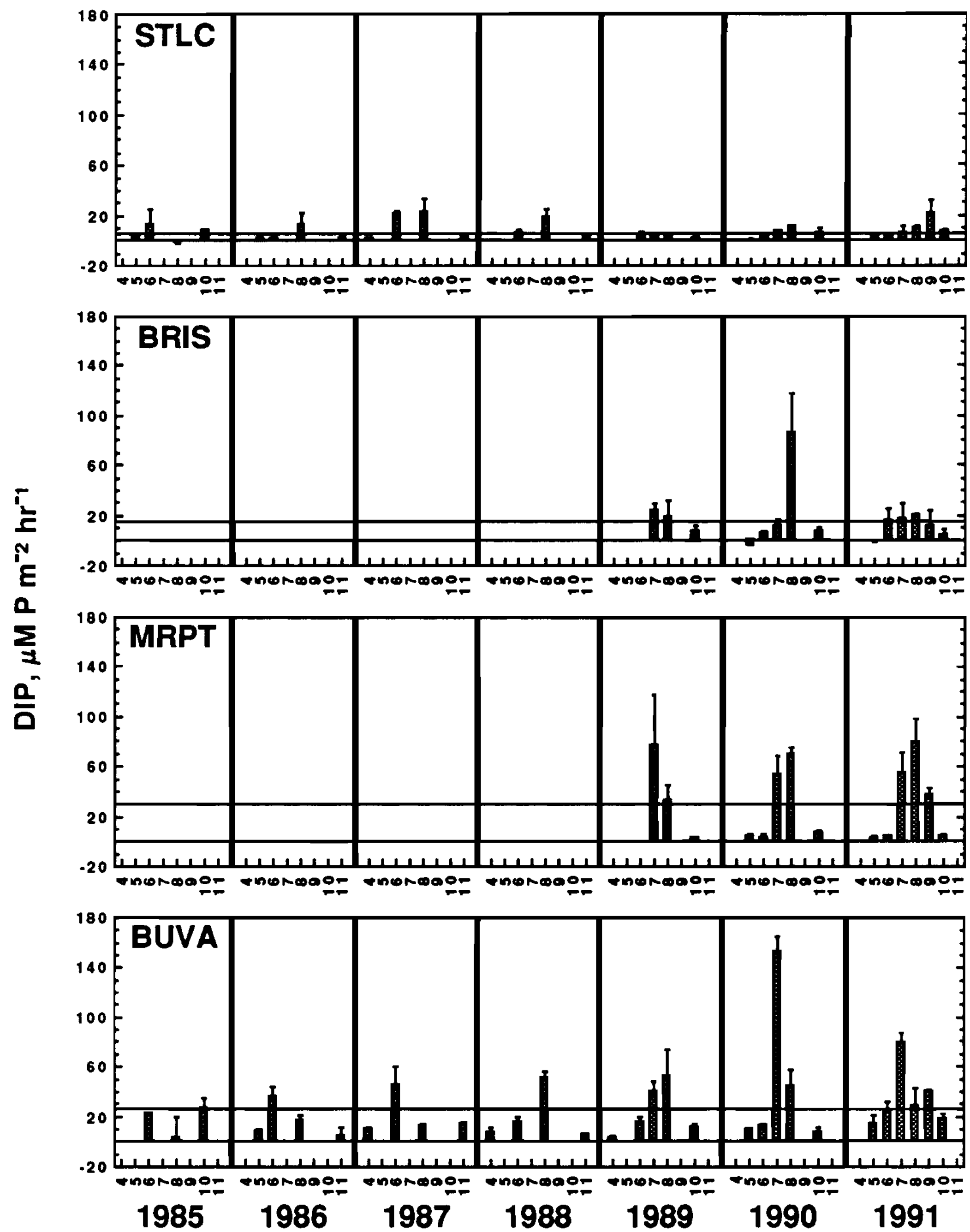


Figure 6-2.4a. Monthly phosphorus (PO_4^- or DIP) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the Patuxent River for the period May, 1985 - October, 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on 1989 and 1991 data. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

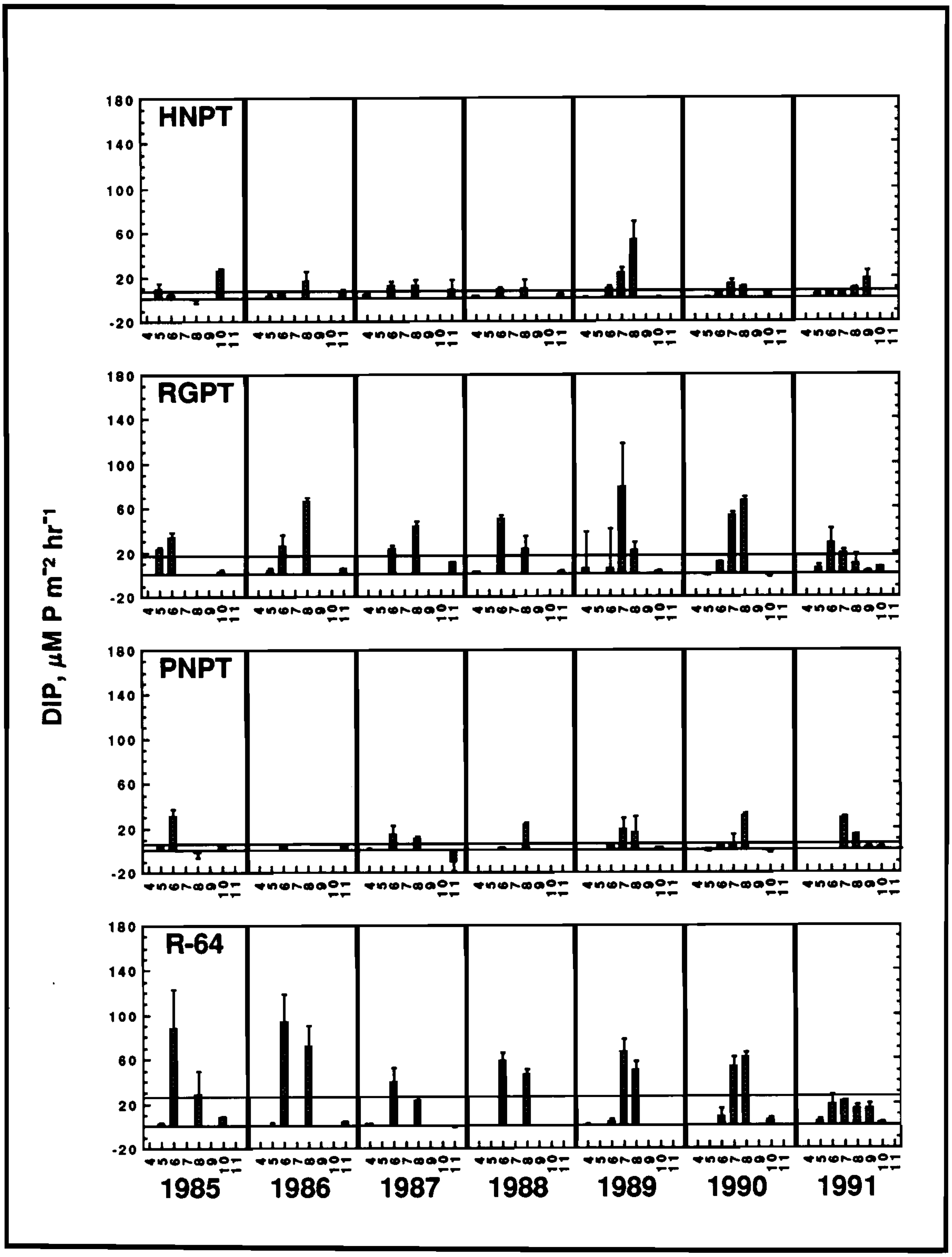


Figure 6-2.4b. Monthly phosphorus (PO_4^- or DIP) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the lower Choptank (Horn Point [HNPT]) and Potomac (Ragged Point [RGPT]) Rivers and at two sites in the Maryland mainstem bay (Point No Point [PNPT] and R-64) for the period May, 1985 - October, 1991. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

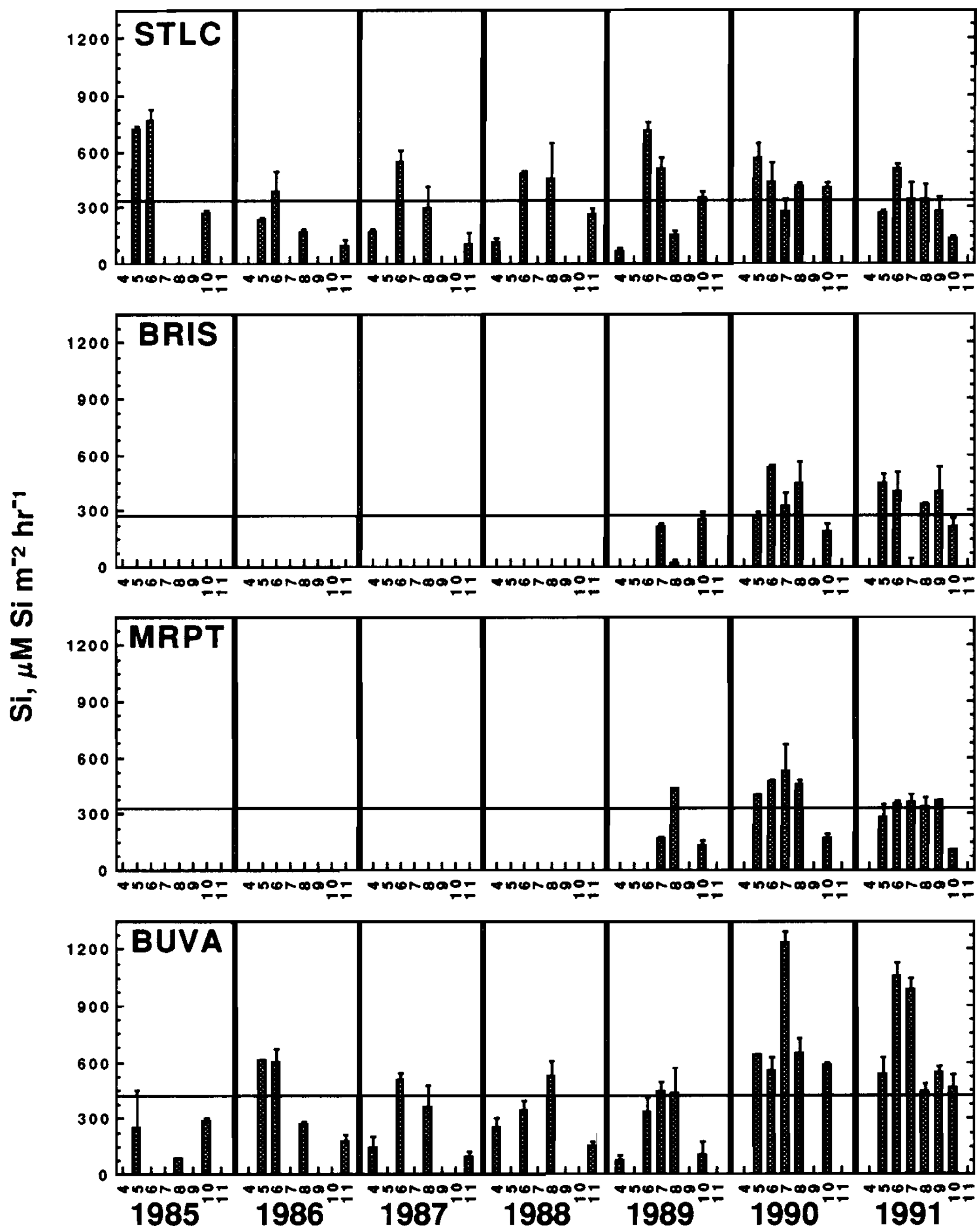


Figure 6-2.5a. Monthly silicate (Si) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the Patuxent River for the period May, 1985 - October, 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on 1989 and 1991 data. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

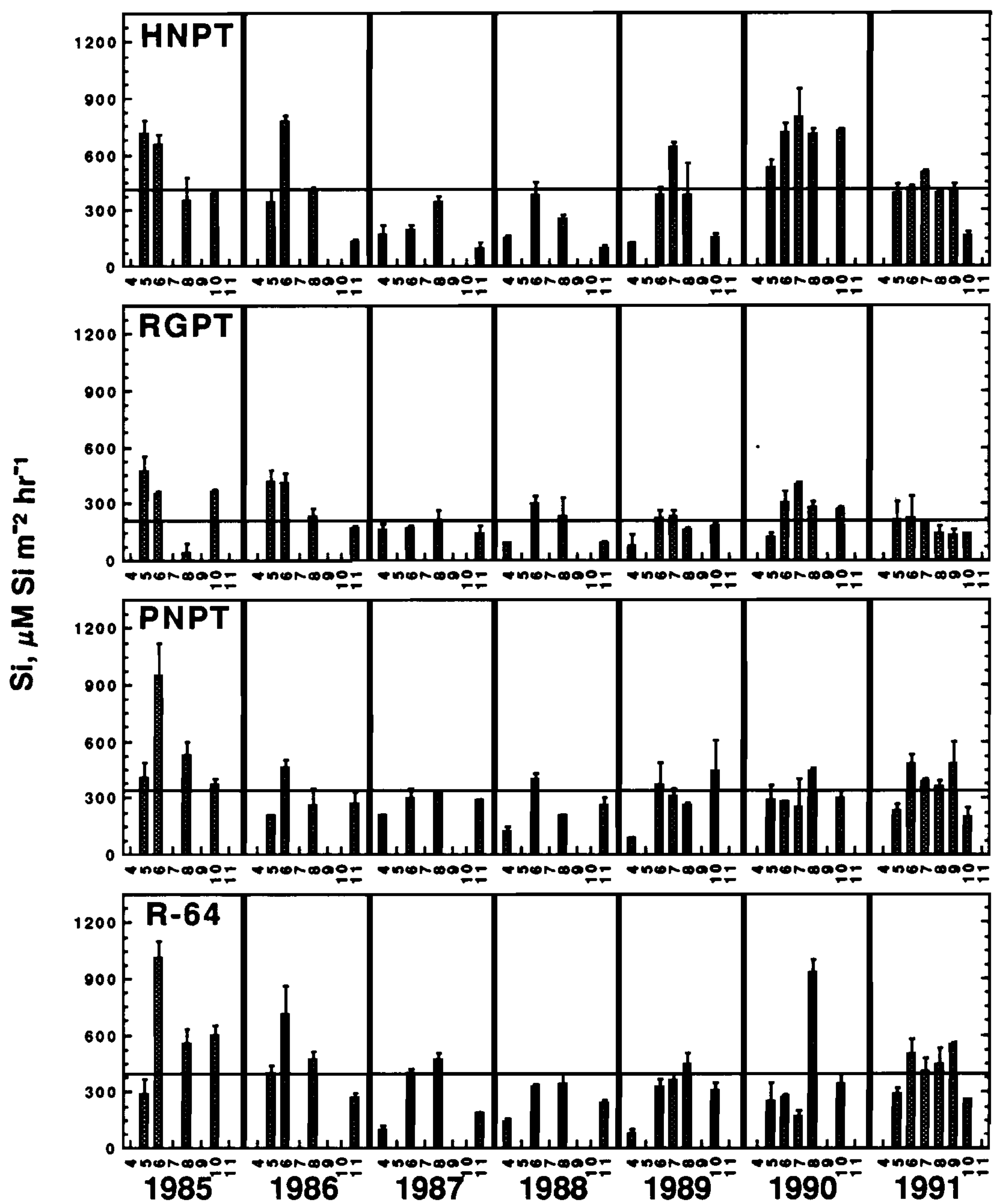


Figure 6-2.5b. Monthly silicate (Si) fluxes (mean and standard deviation of triplicate measurements) at SONE stations located in the lower Choptank (Horn Point [HNPT]) and Potomac (Ragged Point [RGPT]) Rivers and at two sites in the Maryland mainstem bay (Point No Point [PNPT] and R-64) for the period May, 1985 - October, 1991. The horizontal line in each panel indicates the average flux for the entire monitoring period at that station. Station locations are shown in Figure 3-1.

to conclude that the similarity in silicate fluxes results from similarity in silicate loading rates to these different sites and similar silicate deposition rates to sediments.

The 1991 flux data were similar to the long-term average at most stations. However, fluxes during both 1990 and 1991 appeared to be larger than usual at the most up-river station in the Patuxent River (BUVA). As mentioned earlier, SOC rates also exhibited this pattern at this station.

6.3 Upper Bay Sediment-Water Oxygen and Nutrient Exchanges: A Review and Assessment

6.3.1 Overview of Upper Bay Sediment-Water Oxygen and Nutrient Exchange Studies

Routine measurements of sediment-water oxygen and nutrient exchanges in the upper bay were discontinued as a part of the EPC SONE program after June, 1989. As a result, the status of these fluxes have not been discussed in an detail in the subsequent EPC Program Interpretive Reports. However, measurements of sediment-water nutrient and oxygen exchanges have continued in the upper bay region supported by other research and monitoring programs (Land Margin Ecosystem Research Program, NSF; Pooles Island Dredge Survey Program, Maryland Environmental Services [MES]). Several years of data have accumulated it is now appropriate to review these data and compare results with work done in other portions of the bay. The following sections summarize available observations of flux variables and associated water column and sediment characteristics for the upper bay. A more complete version of this section is available in Boynton *et al.* (1992b).

Measurements of sediment-water exchanges of oxygen and nutrients were first made at two locations, Worton Creek (WNCK) and Hart-Miller Island (HMIS), in the upper bay in August, 1980 and again at these same two stations in May, 1981 (Figure 3-2. and Table 3-3.). These measurements (EPA Program 1) were part of the comprehensive nutrient assessment of the Chesapeake Bay supported by the U.S. Environmental Protection Agency's first Chesapeake Bay program. Sediment flux studies had been conducted in other regions of the bay beginning in the 1970's, however there is no record of any measurements prior to these in the upper bay. The results of this study are described in Boynton and Kemp (1985). These data have not been entered into any formal data management system.

Routine sediment-water flux measurements in the upper bay were initiated in August, 1984 as a part of the Maryland Chesapeake Bay Water Quality Monitoring Program. These sediment-water oxygen and nutrient exchange (SONE) measurements were made on a quarterly basis (April or May, June, August and October or November) at one station Still Pond (SLPD) in the upper bay through June, 1989 when measurements were discontinued, in part because of budget limitations (Figure 3-2. and Table 3-3.). The first two sets of measurements (August and October, 1984) are not included in the analysis of the data due to the unreliable nature of these initial measurements associated with technical problems. These data are available from the Maryland Department of Environment (MDE-SAS system).

Fortunately, when monitoring program activities in the upper bay were discontinued, measurements were continued under the auspices of two additional programs. The first was the Benthic Exchanges and Sediment Transformations Component (BEST) Program, also supported by the U.S. Environmental Protection Agency. This program was devoted to obtaining information needed for the calibration and verification of the Chesapeake Bay Water Quality Model.

Sediment-water flux measurements were made at several locations in the upper bay on an occasional basis during 1988 and 1989 (Figure 3-2. and Figure 3-3.). These data will be available from the MDE-SAS system in late 1992. The second program was supported by the National Science Foundation's Land Margin Ecosystem Research (LMER) Program. In this study measurements were made at the same location as the SONE Program. During 1989 measurements were made on nine occasions representing the most intensive data set available for the upper bay. Since 1989 measurements have been made on a quarterly basis (April, May, July or August and November) and are expected to continue through 1993. These data have been summarized in Boynton *et al.* (1992b).

The final set of measurements available for the upper bay are associated with the recent dredge disposal monitoring program conducted in the vicinity of Pooles Island (PIDS Program). In July 1991, the first set of measurements were taken at one location in the upper bay area. A second set was taken in August, 1991 and these measurements will be repeated in June, 1992 at the conclusion of the first phase of this program (see Appendix E). In July and August, 1992 and June, 1993 these same measurements will be made at two locations in the vicinity of Pooles Island.

At present there is a considerable record of sediment-water fluxes and associated water column and sediment data available for one location in the upper bay (Still Pond [SLPD], Figures 3-1. and 3-2.). However, this site is about 15 km north of the Pooles Island site. Information relating both to spatial and temporal coverage at the Pooles Island station remains limited but this situation will improve markedly as the Pooles Island Dredge Survey program (PIDS) continues. At this point the flux data available suggest that the magnitude of fluxes increases in a down-bay direction. Comparisons between fluxes measured at Still Pond (SLPD) during the SONE and LMER Programs and those measured at Pooles Island (GCNT) need to be made with caution. At this point it does not appear reasonable to assume that fluxes are the same at both locations.

In the following sub-sections, 6.3.2 through 6.3.5, the results of three programs, SONE, LMER and PIDS, are presented using a series of graphs to provide a general characterization of sediment-water fluxes in the upper bay region. Water column data, sediment characterization data and sediment-water flux data from all five programs are provided in Boynton *et al.*, (1992b, Appendices A, B, C, D and E).

6.3.2 Selected Water Column Characteristics

In this section bottom water temperature, salinity and dissolved oxygen concentrations are characterized based on data from the SONE, LMER and PIDS Programs. Bottom water temperatures ranged from about 9 C in spring to 29 C in late summer (Figure 6-3.1.) and appear to be in the range expected for this region of the bay. These data compare well with the extensive data record available for the upper bay region for these two seasons compiled by Magnien *et al.* (1990). For the most part, flux data and associated environmental data have been collected between April and November. Very few flux measurements have been made in this or other regions of the bay during the winter season and hence there are minimal flux, temperature or other environmental data available for the coldest portions of the year.

Bottom water salinity ranged from near zero to about 9 ppt (Figure 6-3.2.). Values were generally low in winter-spring and increased through fall. However, this portion of the bay is in close proximity to the mouth of the Susquehanna River and because of this, is especially sensitive to changes in river flow. As a result, salinity, and other environmental characteristics, can change rapidly in this region. For example, during the fall period of 1990 and 1991 salinity was low in this region of the bay during a season generally characterized by high salinity. Presumably, the depressed salinities recorded are the result of higher than normal freshwater flows associated with fall storms. In general, however, salinities were similar to those reported by Magnien *et al.* (1990) for this region of the bay.

Bottom water concentrations of dissolved oxygen ranged from about 5 to 13 mg l^{-1} (Figure 6-3.2.) and in this range are indicative of good water quality conditions. At these study sites concentrations were reasonably close to saturation, even during the summer (June through August) when low oxygen conditions commonly occur in bottom waters of other portions of the bay. It should be noted that lower oxygen conditions may occur in deeper, dredged channel portions of the upper bay. The sites where sediment-water flux measurements were made in all previous upper bay area programs were selected to be representative of average depths, rather than extreme depths. These data were also in general agreement with those of Magnien *et al.* (1990) for this region of the bay. The relatively high oxygen concentrations observed in these waters have important implications for sediment nutrient processes referred to in Section 6.3.4.2.

The Maryland Chesapeake Bay Water Quality Monitoring Program has compiled a comprehensive record of water quality and habitat conditions in the upper bay. The following data are available: water column nutrient concentrations (Magnien *et al.*, 1990), algal speciation, algal chlorophyll-a concentrations and production rates (Sellner, 1989), microzooplankton speciation and densities (Sellner, 1989), macrozooplankton speciation and densities (Jacobs, 1989) and benthic animal speciation and abundance (Holland *et al.*, 1989). These data provide background information which make possible more detailed interpretation of sediment-water flux measurements. In general the upper bay area is characterized by very high nitrate and relatively low phosphate concentrations, high water column suspended sediment loads, low levels of light penetration, moderate algal standing crops and low primary production rates. Benthic animal communities can be very dense at some locations. These features influence sediment-water exchange rates and will be referred to in section 6.3.4.

6.3.3 Surficial Sediment Nutrient Concentrations and Nutrient Ratios

In a number of earlier studies of sediment-water oxygen and nutrient exchanges it was found that concentrations of essential metabolic materials (*i.e.*, carbon, nitrogen) in sediments were well correlated with the magnitude and other characteristic of fluxes (Boynton *et al.*, 1991; Jensen *et al.*, 1990; Kelly and Nixon, 1984). In particular, concentrations of these materials near the sediment-water interface were of particular importance in determining the nature of exchanges. For this reason, surficial sediments (near surface sediments) were routinely sampled for particulate carbon, nitrogen and phosphorus concentrations throughout the SONE program but less frequently during other upper bay programs.

Concentrations of surficial sediment particulate carbon (PC), nitrogen (PN) and phosphorus (PP) collected at the Still Pond (SLPD) location during the SONE Program are shown in Figure 6-3.3. Concentrations of PC ranged from about 2 to over 6% of sediment dry weight. In most years concentrations were highest in spring and then declined through fall suggesting that deposition of the spring phytoplankton bloom or deposition of terrestrial detritus associated with the spring freshet were responsible for high spring concentrations. Metabolism of deposited organics was presumably the main mechanism responsible for the decline in concentrations through the year. The PC concentrations measured at this upper bay site are similar to those in the upper reaches of some tributary rivers (*e.g.*, Patuxent and

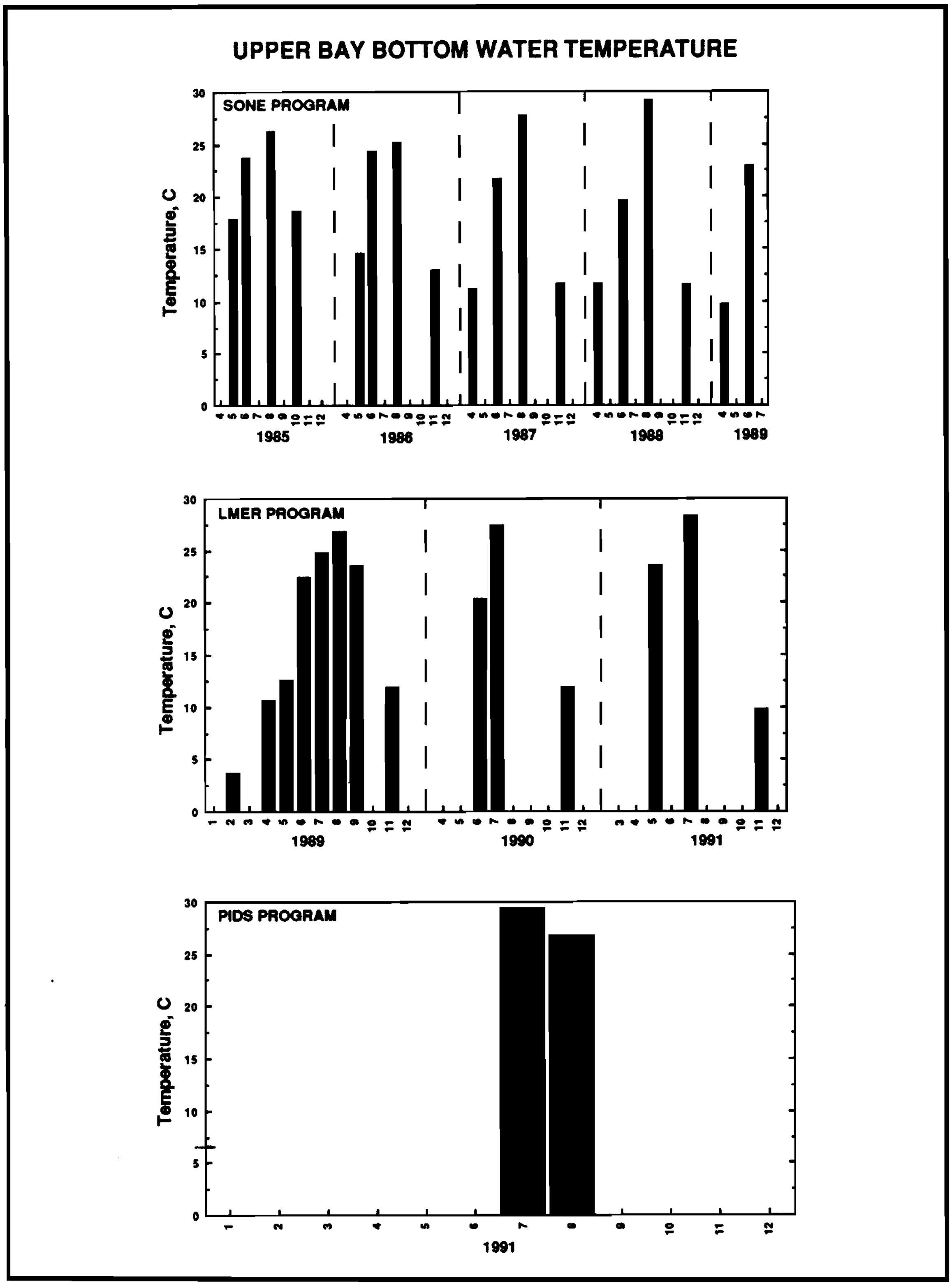


Figure 6-3.1. Bar graphs summarizing bottom water temperatures in upper bay areas based on measurements obtained during three research programs: Sediment Oxygen and Nutrient Exchanges (SONE) Program, Land Margin Ecosystem Research (LMER) Program and Pooles Island Dredge Survey (PIDS) Program. Additional program information, including study duration and station locations, is given in Table 3-3.

Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

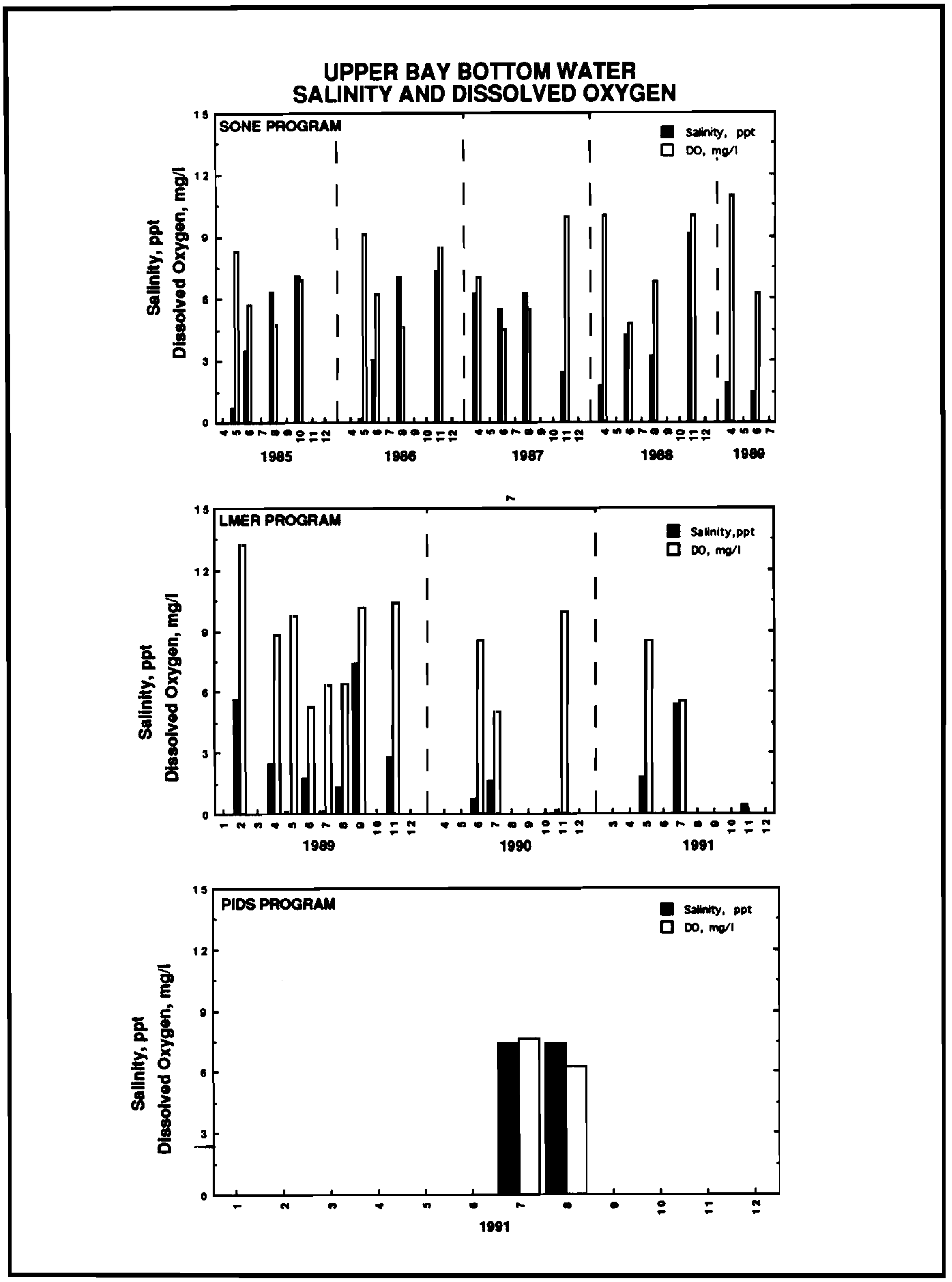


Figure 6-3.2. Bar graphs summarizing bottom water salinity and dissolved oxygen concentrations in upper bay areas based on measurements obtained during three research programs: Sediment Oxygen and Nutrient Exchanges (SONE) Program, Land Margin Ecosystem Research (LMER) Program and Pooles Island Dredge Survey (PIDS). Additional program information, including study duration and station locations, is given in Table 3-3.

Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

Potomac Rivers), are higher than those observed in the central portion of the bay but much higher than those routinely measured near the mouth of the bay.

Concentrations of sediment PN were not particularly high ranging from 0.1% to about 0.3% of sediment dry weight. Concentrations in the central portion of the bay and in the lower Potomac River are generally higher, at times by a factor of two. The temporal data record is not sufficiently intense to infer too much about seasonal patterns of PN concentrations. However, in 3 of the 4 years for which annual data are available, there is a evidence of higher PN concentrations in spring. The origin of this material may have been from the deposition of the spring phytoplankton bloom, deposition of terrestrial detritus or a combination of both.

Concentrations of sediment PP ranged from about 0.04% to almost 0.1% of sediment dry weight. These concentrations are relatively high compared with those found in other mainstem bay areas and comparable to those commonly observed in the upper reaches of tributary rivers. It appears that concentrations generally decrease from spring through fall although there is considerable variability in these data.

A number of investigators have pointed out that not only the amount of sediment organic matter but the "nutritional quality" of the material influences the magnitude and other characteristics of sediment-water exchanges (*e.g.*, Hargrave, 1972). Some preliminary insight into this issue can be gained by examining the relative abundances of PC, PN and PP in sediments (Figure 6-3.5.). In general the material delivered to sediments in this region of the bay can vary from very refractory terrestrial detritus to very labile phytoplankton cells. The former are typified by having high ratios of C to N or P while the latter have much lower ratios. As indicated in Figure 6-3.4. C:N ratios (weight based) varied from about 10 to 33, C:P ratios from 30 to 120 and N:P ratios from 2.5 to about 9. As expected, C:N ratios were high relative to most other portions of the mainstem bay and lower portions of the tributaries, reflecting deposition of terrestrial detritus in the upper bay which is typically poor in nitrogen. In other portions of the bay C:N ratios are typically in the range of 5 to 10. In contrast, C:P ratios were not uniformly high as might be expected in an area receiving terrestrial detritus (which is characterized by high C:P ratios). It appears that considerable phosphorus is simply adsorbed to sediment particles and is measured as PP. Some unknown fraction of this material is associated with organic matter and preliminary measurements indicate that this fraction is small (Keefe C.W., *pers comm.*). While there is a good deal of PP in upper bay sediments, the relative availability of this material to biological processes is not known but appears to be low. Finally, the N:P ratio of sediments is unusually low in the upper bay ranging from about 2.5 to 9.0. In contrast, N:P ratios of healthy phytoplankton are in the range of 30 to 40 (weight basis; Redfield, 1934). . The very low N:P ratios of the upper bay result from the relatively low PN and high PP content of sediments. Overall, the organic matter in upper bay sediments appear to be a composite of terrestrial and phytoplanktonic debris and does not appear to be as labile or metabolically reactive as sediments having more planktonic material.

6.3.4 Sediment-Water Oxygen and Nutrient Exchanges

6.3.4.1 Overview of Flux Data

While a considerable number of sediment-water flux estimates have been made in the upper bay, only two sets of measurements (SONE and LMER programs) have been taken during more than one annual cycle. In this section, the results from these programs together with the initial set of Pooles Island (GCNT) measurements are presented as a series of bar graphs. Fluxes include sediment oxygen consumption (SOC), ammonium (NH_4^+), nitrate

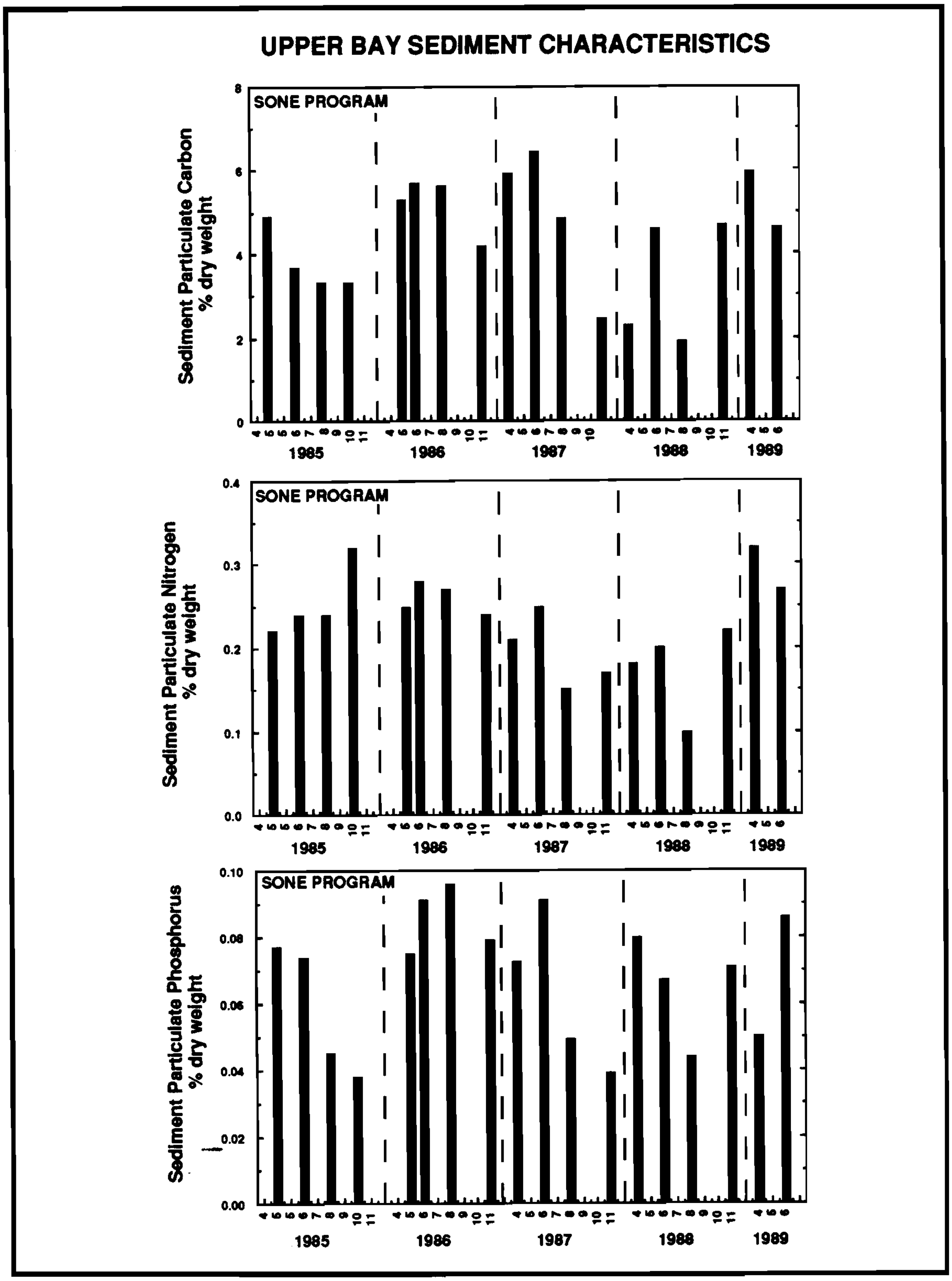


Figure 6-3.3. Bar graphs summarizing surficial sediment characteristics (PC, particulate carbon; PN, particulate nitrogen; and PP, particulate phosphorus) at an upper bay area based on measurements obtained at one location (Still Pond [SLPD], Sediment Oxygen and Nutrient Exchanges (SONE) Program).

Study duration and station location are given in Table 3-3.

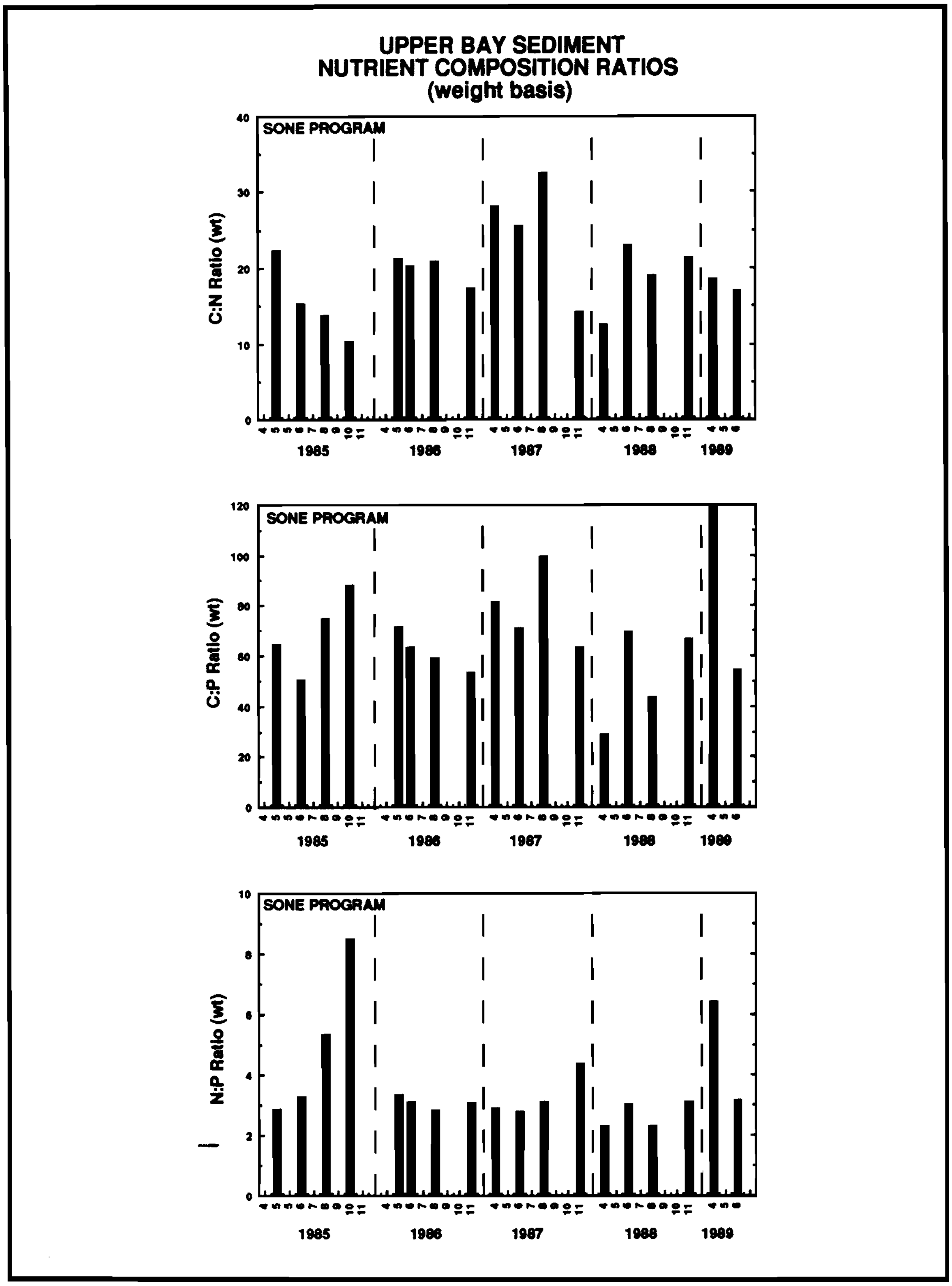


Figure 6-3.4. Bar graphs summarizing surficial sediment ratios (C:N, C:P and N:P) at an upper bay area based on measurements obtained at one location (Still Pond [SLPD], Sediment Oxygen and Nutrient Exchanges (SONE) Program).

Duration of study and station location are given in Table 3-3.

(NO_3^-), and phosphate (PO_4^-). It should be noted that the Still Pond (SLPD) station was used in both the SONE and LMER programs and that the Pooles Island (GCNT) station is located approximately 15 km down-bay. As a result, direct comparisons between GCNT and the two Still Pond (SLPD) data sets should be made with caution.

6.3.4.2 Sediment Oxygen Consumption Rates (SOC)

Sediment oxygen consumption rates ranged from 0.2 to 2.4 g O_2 m^{-2} d^{-1} (Figure 6-3.5.). These rates are moderate to large (Boynton *et al.*, 1991) when compared with other regions of the mainstem and tributary rivers and under some conditions could contribute to chronic hypoxic conditions. Seasonal maximum rates occurred in spring or early summer during the SONE and LMER programs. This pattern is similar to that observed in other portions of the bay. There is not nearly enough data to speculate on seasonal SOC patterns at Pooles Island (GCNT) but the rates observed in July and August, 1991 were large. If this site has a seasonal pattern similar to that at Still Pond (SLPD) then spring rates could be expected to be even higher. The mechanism responsible for this seasonal SOC pattern seems to be related to the fact that in spring sediments are exposed to ample supplies of labile organic matter (from the deposition of the spring bloom) and also have sufficient bottom water oxygen concentrations (> 2.0 mg l^{-1}) to support aerobic respiration. Rates later in the year seem to be limited by both factors in many areas, but not by oxygen concentrations in the upper bay. Perhaps the most striking aspect of the SOC data is the sharply declining rates observed between 1985 and 1991. Rates as high as 3.0 g O_2 m^{-2} d^{-1} were observed during the May and June, 1985 but declined by a factor of three by spring 1991. It may be that rates are strongly influenced by river flow in this region of the bay and specifically by the organic matter associated with river flow. During the period of record (1985 through 1991) river flow from the Susquehanna River has been generally low. The two lowest flow years in the past twenty years occurred in 1988 and 1991. However, river flow was particularly high in 1984. It is possible that SOC was stimulated by the organic matter delivered by the high flow of 1984 and also, to a lesser extent, that of subsequent years. River flow was also high in the early 1980's and the limited SOC rates available for that period were also high. The 1991 rates at Pooles Island (GCNT) were high relative to those observed at Still Pond (SLPD) in 1991 suggesting a gradient of SOC rates within the upper bay region. Data from the early 1980's exhibits the same pattern, but to a lesser degree. Some of these speculations will be clarified as monitoring continues at the Pooles Island (GCNT) and Still Pond (SLPD) stations.

6.3.4.3 Ammonium Fluxes

Ammonium fluxes ranged from -30 to 300 μMN m^{-2} hr^{-1} at the Still Pond ([SLPD] SONE, LMER programs) and Pooles Island (GCNT) station (Figure 6-3.6.). As with SOC rates, there was a substantial decline in NH_4^+ fluxes between 1985 and 1991 at SONE and LMER sites. During most of 1989 NH_4^+ was consumed by sediments at the Still Pond ([SLPD], LMER program) station, although uptake rates were low. Ammonium fluxes were moderate to low at the Pooles Island (GCNT) station during the summer of 1991 and were comparable to values observed during the first upper bay survey in 1980. It is probable that rates of organic matter deposition coupled with well oxygenated sediments combined to produce the observed long-term temporal decrease in NH_4^+ fluxes. We suspect that organic matter loading rates to sediments were quite high in 1984 and then remained low through 1991 due to low discharge from the Susquehanna River. This situation would result in a depleted supply of organic matter available for remineralization to NH_4^+ and flux to overlying waters. In well oxygenated sediments NH_4^+ can be converted to nitrate via the activity of nitrifying bacteria. Nitrate (NO_3^-) is frequently released from upper bay sediments (see Section 6.3.4), providing clear evidence of the activities of this class of

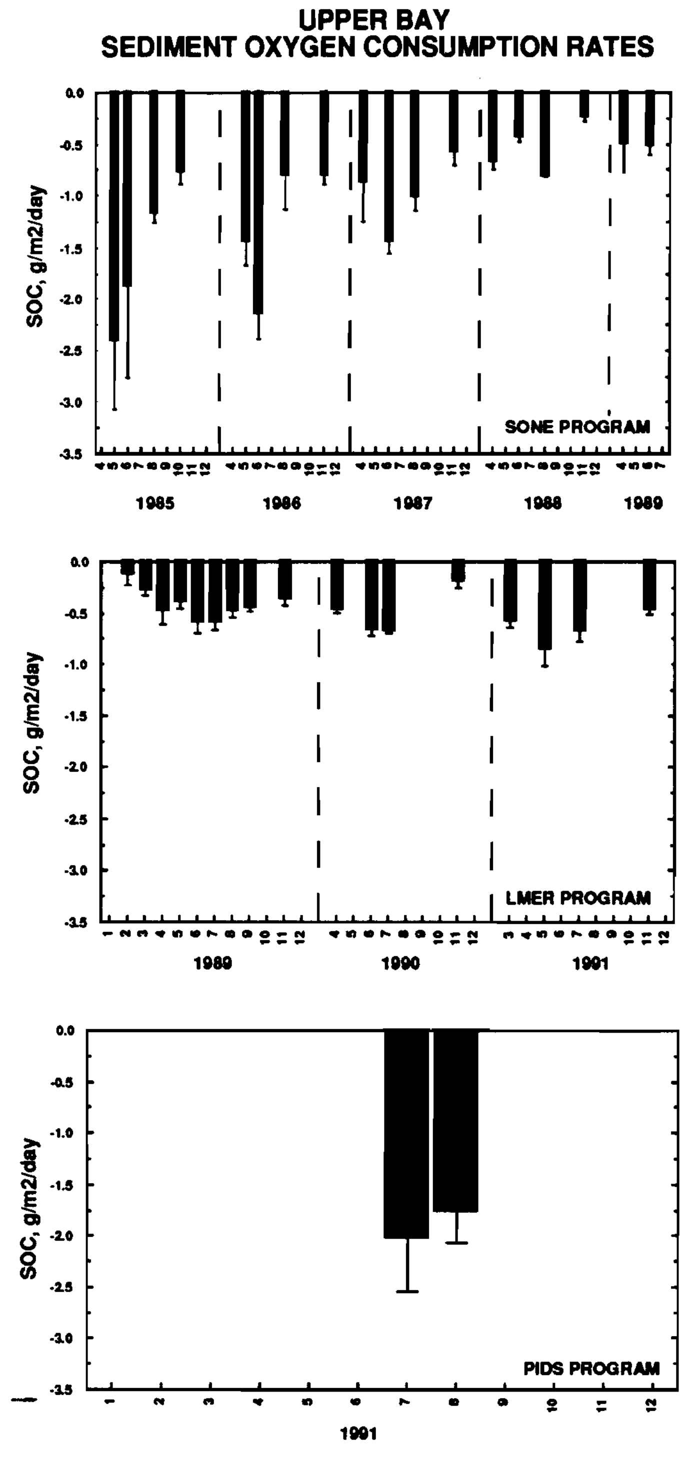


Figure 6-3.5. Bar graphs summarizing sediment oxygen consumption (SOC) rates (mean and standard deviation of triplicate measurements) obtained during three research programs: Sediment Oxygen and Nutrient Exchanges (SONE) Program, Land Margin Ecosystem Research (LMER) Program and Pooles Island Dredge Survey (PIDS) Program. Additional program information, including study duration and station locations, is given in Table 3-3.
Negative values indicate fluxes from water to sediments.
Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

bacteria. Ammonium fluxes (NH_4^+) were very low in 1989 and NH_4^+ frequently moved from overlying waters to sediments, further supporting this idea. In the spring of 1989 river flow was particularly low and no spring diatom bloom developed. In this case organic matter supplies at the sediment-water interface were probably very low, limiting NH_4^+ fluxes and at times allowing NH_4^+ to diffuse from the water to sediments. Compared with the downstream areas of the mainstem bay and most tributaries, NH_4^+ fluxes in the upper bay were low (Boynton *et al.*, 1991).

6.3.4.4 Nitrate Fluxes

Nitrate fluxes ranged from -125 to 50 μMN m^{-2} hr^{-1} at the Still Pond ([SLPD] SONE and LMER program) and the Pooles Island (GCNT) stations (Figure 6-3.7.). The majority of nitrate fluxes were directed from overlying waters to sediments. This type of flux pattern results when water column concentrations of NO_3^- are high and sediment uptake rates are, in general, proportional to concentrations in overlying waters (Boynton and Kemp, 1985). It appears that the nitrate diffusing into sediments is rapidly denitrified (*i.e.* converted to N_2 gas). This is an important process because denitrification effectively removes nitrogen from the system. Nitrate also occasionally escapes from sediments (i.e. positive fluxes) and this is an indication that nitrifying bacteria are active in these sediments. It is of particular interest to note that large nitrate uptake rates did not occur in early 1989, but in June when river flow increased and delivered large amounts of nitrate to this region of the bay. Such observations are consistent with the concept that sediments respond rapidly to changing environmental conditions in predictable ways. Nitrate fluxes (both positive and negative) in this region of the bay are large compared to other areas of the mainstem and lower portions of tributary rivers. Fluxes are similar in magnitude to those observed in the upper reaches of most tributaries where nitrate concentrations are also large (Boynton *et al.*, 1991; and Magnien *et al.*, 1990)

6.3.4.5 Phosphate Fluxes

Fluxes of phosphate ranged from -17 to 12 μMP m^{-2} hr^{-1} at the Still Pond ([SLPD] SONE and LMER program) and Pooles Island (GCNT) stations (Figure 6-3.8.). For the most part PO_4^- fluxes were directed from sediments to overlying waters. However, on a few occasions, and in particular during the low river flow spring of 1989, fluxes were directed from water to sediments. This unusual situation has previously been observed and is almost always associated with sites located in low salinity environments (Boynton *et al.*, 1991). The exact mechanism involved is not clear but it seems probable that dissolved PO_4^- at these sites is being 'scavenged' from the water column by silt-clay particles which are in high concentrations at these locations. Fluxes of PO_4^- at upper bay sites were low compared with other areas of the mainstem and tributary rivers and much lower than at sites which experience hypoxic conditions during summer (June through August) periods. It is probable that phosphorus is adsorbed to oxyhydroxides or combined into insoluble iron-manganese phosphate complexes, both of which occur under oxic conditions (Klump and Martins, 1981). If dredging activities or some other modification of the environment promoted the development of hypoxic or anoxic conditions, we would expect that large amounts of phosphorus would rapidly be released from sediments and cause some degree of water quality deterioration.

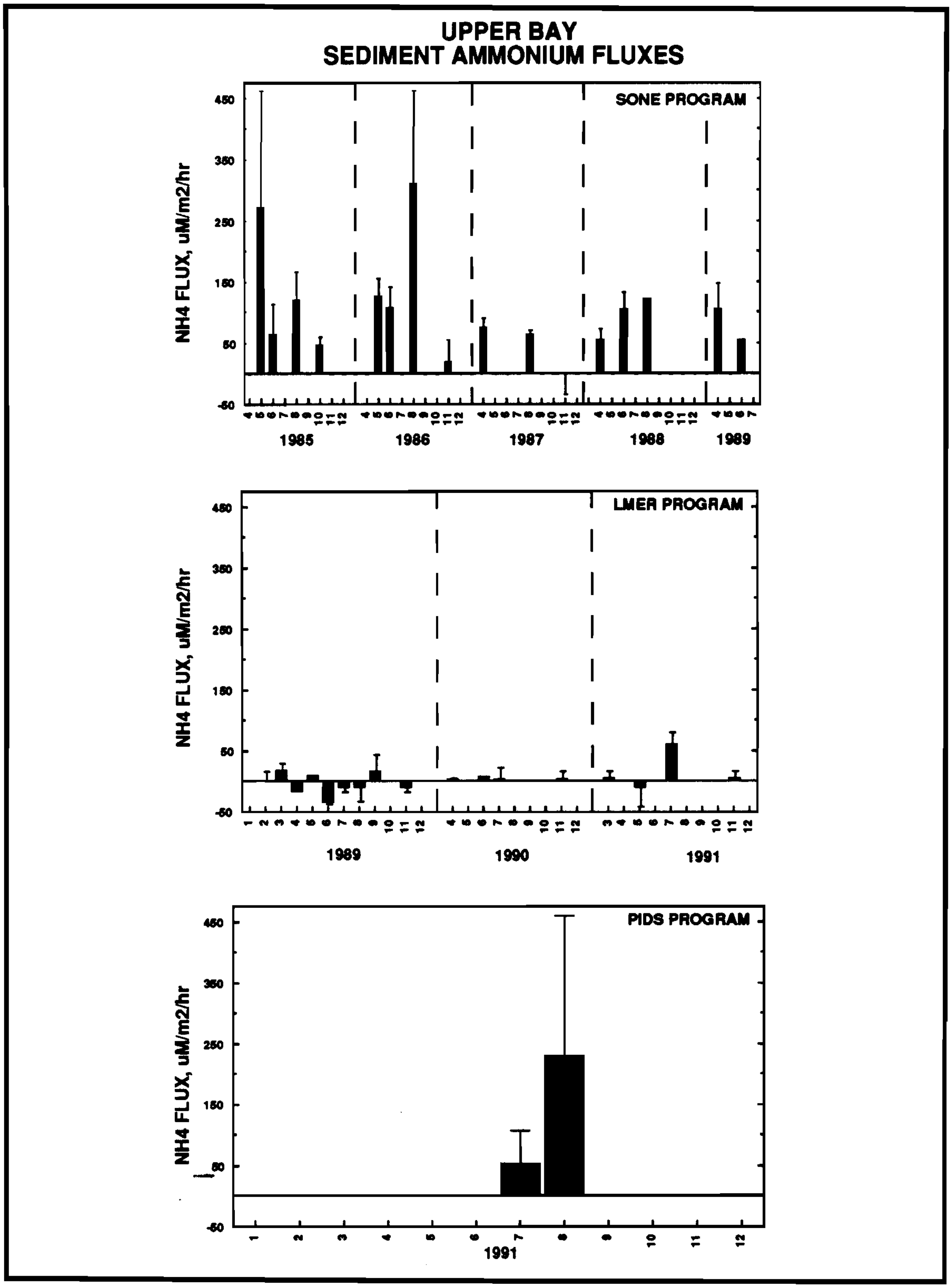


Figure 6-3.6. Bar graphs summarizing ammonium (NH_4^+) fluxes (mean and standard deviation of triplicate measurements) obtained during three research programs: Sediment Oxygen and Nutrient Exchanges (SONE) Program, Land Margin Ecosystem Research (LMER) Program and Pooles Island Dredge Survey (PIDS) Program. Additional program information, including study duration and station locations, is given in Table 3-3.

Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment.

Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

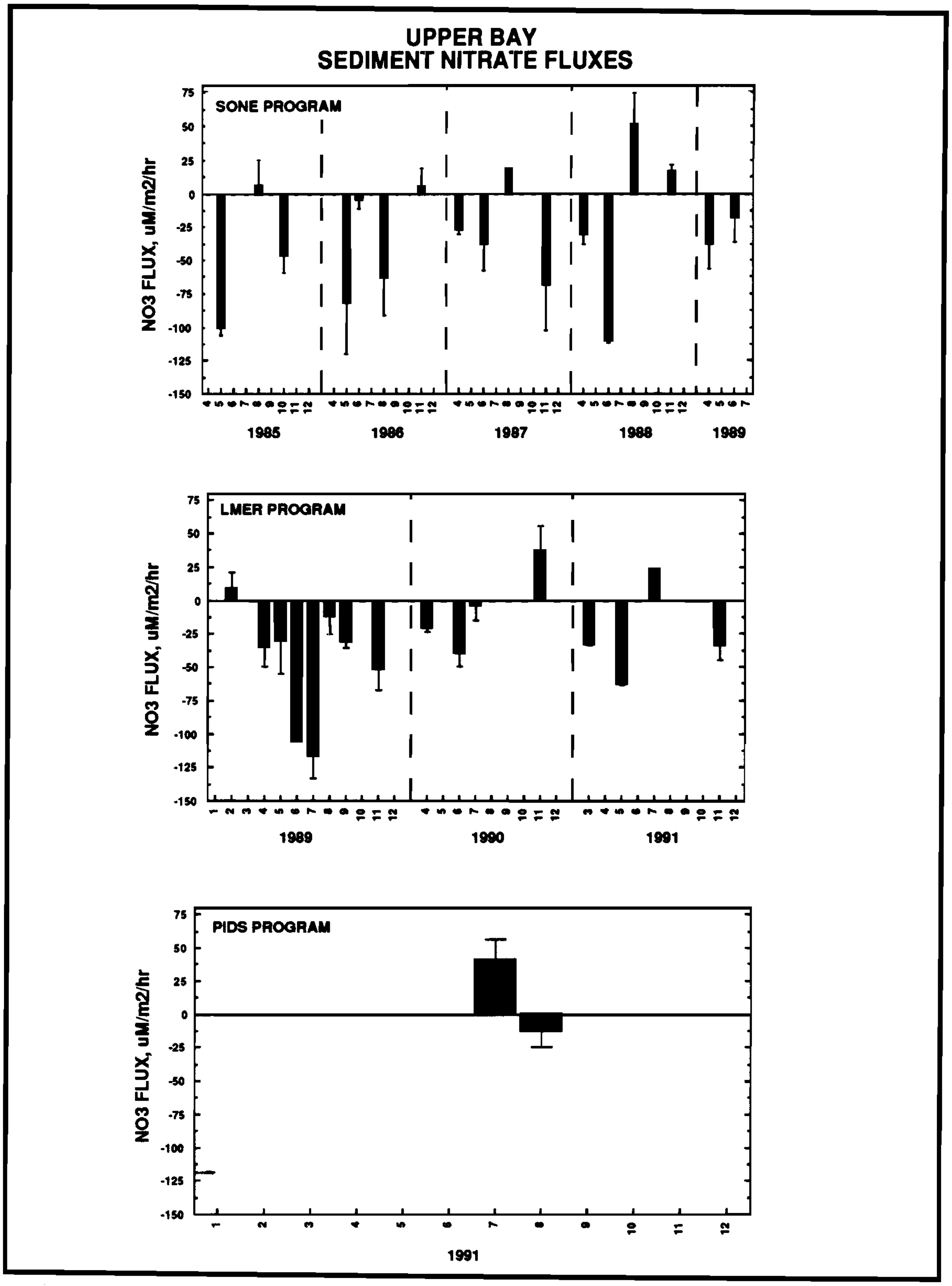


Figure 6-3.7. Bar graphs summarizing nitrate (NO_3^-) fluxes (mean and standard deviation of triplicate measurements) obtained during three research programs: Sediment Oxygen and Nutrient Exchanges (SONE) Program, Land Margin Ecosystem Research (LMER) Program and Pooles Island Dredge Survey (PIDS) Program. Additional program information, including study duration and station locations, is given in Table 3-3.

Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment.

Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

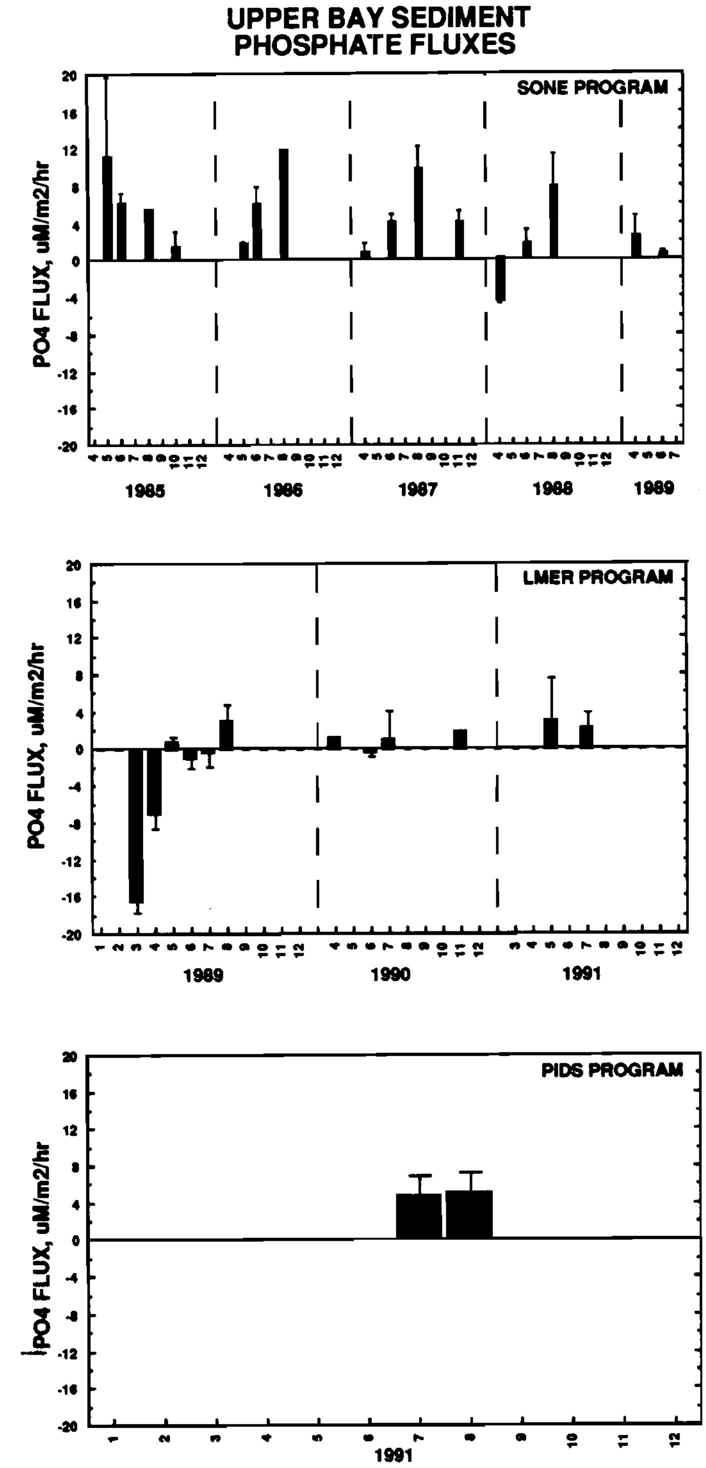


Figure 6-3.8. Bar graphs summarizing phosphate (PO_4^-) fluxes (mean and standard deviation of triplicate measurements) obtained during in three research programs including the current monitoring program at Pooles Island (PIDS). Program designations, study duration and station locations are given in Table 6-3.1.

Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment.

Each bar represents a single monitoring event; bar widths do not reflect more intensive sampling effort.

6.3.5 Potential Impact of Sediment-Water Oxygen and Nutrient Exchanges on Water Quality of the Upper Bay

The relative impact of sediment processes on overlying water quality can be viewed in terms of the impact of these processes on water column oxygen and nutrient budgets. Specifically, in this section the magnitude of sediment processes are compared to:

(1) oxygen stocks in the water column,

(2) the rate of nutrient supply from the Susquehanna River and

(3) phytoplankton demand for nitrogen and phosphorus.

Sediment oxygen consumption rates (SOC) were appreciable in this area of the bay, especially during 1985 and 1986 (see Section 6.3.4.2). If we use an SOC rate of 2.0 g O_2 m^{-2} day^{-1} (as an upper estimate of SOC rates) we can then compare this to the amount of oxygen present in the water column and thus determine a potential turnover time. During summer periods (June through August), we are able to calculate a turnover time of 12 days based solely on SOC rates, using a mean depth of about 4 m for this section of the bay and an average oxygen concentration of 6 mg l^{-1}. Extensive measurements of water column respiration rates are not available for this section of the bay but we suspect they would be at least as large as SOC rates (Boynton and Kemp, 1985). The inclusion of water column respiration rates would decrease oxygen turnover time to 6 days and probably less. However, there are two additional sources of oxygen which would compensate for losses due to biological respiration. First, phytoplankton produce oxygen during daylight hours as a product of photosynthesis and it has often been observed that water column respiration is tightly coupled to water column production. In essence then, oxygen losses due to water column respiration may be largely compensated by water column production of oxygen. This is probably not quite the case in the upper bay because the Susquehanna River introduces considerable amounts of terrestrial detritus which would consume but not produce any oxygen. Second, this area of the bay is vertically well-mixed due to wind and tidal action. If oxygen concentrations in the water begin to decrease oxygen can diffuse across the air-water interface and be rapidly mixed throughout the water column. In well-mixed areas air-water diffusion of oxygen provides a very effective buffer against development of low oxygen conditions. It would appear that despite the potential for high rates of SOC, the development of low oxygen conditions in this area of the bay is unlikely. It would appear that there would have to be some increase in stratification as well as substantial increases in oxygen consumption rates for hypoxic or anoxic conditions to develop.

A second approach to evaluating the impact of sediment-water nutrient exchanges on overall water quality is to examine the magnitude of nutrient fluxes to or from sediments to the magnitude of nutrient inputs from external sources. In the case of the upper bay (defined here as the area of the bay from the mouth of the Susquehanna River to the bay bridge at Annapolis) most of the nutrient load comes from the Susquehanna River. On an annual basis nitrogen and phosphorus loads amount to about 97 g N m^{-2} yr^{-1} and 3.4 g P m^{-2} yr^{-1} (Summers, 1989). These are very substantial loading rates when compared to other portions of Chesapeake Bay and to most other estuarine areas (Nixon, 1981). If we assume that ammonium fluxes in this portion of the bay average about 100 μMN m^{-2} hr^{-1} (Figure 6-3.6. for 1985-1986 period, as an upper bound of observed NH_4^+ fluxes), then this is equivalent to a loading rate of about 12 g N m^{-2} yr^{-1} or only about 12% of the external loading rate. In other areas of the bay, sediment releases of ammonium are as large or several times larger than external inputs. In the upper bay sediment releases of ammonium are small relative to external sources of nitrogen. In actuality the impact of sediment ammonium releases is even smaller than indicated above because sediments also remove nitrate (another biologically reactive form of nitrogen) from overlying waters (Figure 6-3.7.). Using an average nitrate uptake rate of about 50 μMN m^{-2} hr^{-1} we find that sediments remove this form of nitrogen at a rate of about 6 g N m^{-2} yr^{-1} or at about one half the rate nitrogen is being added as ammonium. If the same sort of calculation is done for phosphorus, we find that sediment releases of phosphorus amount to about 1.4 g P m^{-2} yr^{-1}. Sediment releases of phosphorus represent about 40% of external loads which is more substantial than the case for nitrogen but still small relative to the situation in most other areas of the bay. While these calculations are crude, they suggest that nitrogen and phosphorus releases from sediments are small compared to nutrient loads from point and diffuse sources.

A final manner in which to place sediment nutrient releases in perspective is to examine the amount of nitrogen and phosphorus supplied by sediments relative to the amount needed by phytoplankton, the dominant autotrophic group in the upper bay region. Primary production rates in the upper bay have been found to be on the order of 100 gC m^{-2} yr^{-1} (Sellner, 1989). If this production rate is converted to nitrogen and phosphorus equivalents using "Redfield composition ratios" (Redfield, 1934) we find phytoplankton nitrogen and phosphorus utilization rates of 150 μMN m^{-2} hr^{-1} , and 10 μMP m^{-2} hr^{-1} , respectively. Using the same average annual rates for sediment nitrogen and phosphorus releases we find that sediments could provide about 50% and 50% of the nitrogen and phosphorus needs, respectively. These percentages are substantial but it must be remembered that phytoplankton production rates are low in the upper bay and it is the low rate of primary production that makes sediment nutrient releases appear to be substantial.

At this point it appears that the overall role of sediments in determining water quality in this region of the bay is relatively small, at least as far as oxygen, nitrogen and phosphorus dynamics are concerned. However, the data base is extremely limited in the region of Pooles Island and there appear to be some difficulties in extrapolating data collected at lower salinity sites to this region. We have found that there are few, if any, substitutes for carefully designed and consistent monitoring of various environmental variables as a means of arriving at realistic and defensible evaluations of potential environmental modifications. In view of this we would recommend that monitoring be continued at the Pooles Island site for several years and that monitoring efforts be directed towards the warm seasons of the year when sediment-water processes are at annual maxima.

7. VERTICAL FLUX (VFX) RESULTS AND DISCUSSION:
Temporal Patterns of Organic Matter Distribution and Deposition in the Mainstem Bay (Station R-64)

7.1 Overview

There are several ecological concepts that are central underpinnings of nutrient control programs applied to estuarine systems such as Chesapeake Bay. One of these is that algal biomass levels have upper bounds that are ultimately set by the degree of nutrient loading to which the system is exposed and that biomass levels will respond to loading rate changes. A second, and more recent concept, is that sediment processes in shallow systems play an important role in processing nutrients and organic matter. Some of the success experienced with the new Chesapeake Bay water quality model is apparently a result of explicit incorporation of a sediment sub-model within the main modeling structure. In systems that are moderately stratified, as are portions of the bay, primary production (and algal biomass accumulation) and decomposition processes are separated in space, the former occurring primarily in the upper mixed layer while a large percentage of the latter occurs beneath the pycnocline and at the sediment-water interface. Deposition of particulate organic materials is one of the key mechanisms linking processes of production and decomposition.

From a management viewpoint, information related to deposition rates is important because it is a measure of the amount of organic matter reaching deep waters serving to support decomposition processes which, in some areas, causes oxygen depletion and habitat loss. Our conceptual model suggests that as nutrient loads decrease in response to management actions, so too will algal biomass levels, deposition rates and oxygen depletion of deep waters.

Particle deposition rates have been measured at one station, R-64, in the mesohaline reach of Chesapeake Bay since the summer of 1984. In the previous EPC Interpretive Report (Boynton *et al.*, 1991) data for six complete calendar years (1985-1990) were presented for both particulate carbon and total chlorophyll-a deposition rates measured in the upper mixed layer (surface collecting cups) and at depths in the vicinity of the pycnocline (mid-depth collecting cups). A description of the patterns of particulate carbon and total chlorophyll-a concentration and deposition rates for the 1991 period at station R-64 in the mainstem bay follows.

7.2 Particulate Carbon and Total Chlorophyll-a Concentrations at R-64

Concentrations of particulate organic carbon from surface and mid-depth waters and total chlorophyll-a from ~~the~~ same depth are shown in Figures 7-1.1. and 7-1.2. These data were collected at station R-64 during 1991. Particulate carbon concentrations ranged from 400 to 2300 mg l^{-1} in surface waters and from 400 to 2700 mg l^{-1} in mid-depth waters. Except for one observation (circa day 55) there was very good correspondence in temporal concentration patterns between surface and mid-depth samples. However, there were some large differences in the magnitude of concentrations and the degree to which concentrations changed over time. For example, both surface and mid-depth samples showed a spike in concentration on day 125 but the magnitude of the spike was much greater in mid-depth than surface samples, while on day 240 the larger spike occurred in surface samples. Finally, average concentrations during the summer period (days 150-270) were almost twice as high in surface waters than in mid-depth waters.

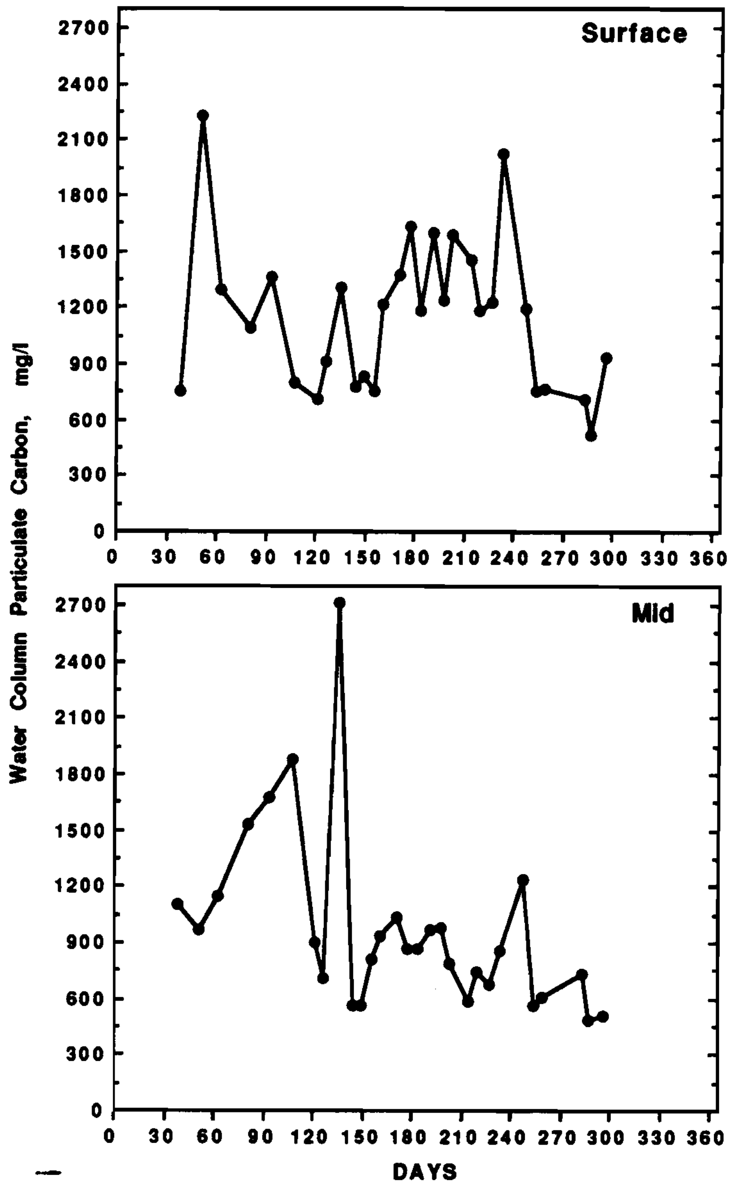


Figure 7-1.1. Plots of surface and mid-depth concentrations of particulate organic carbon from station R-64 collected during 1991.

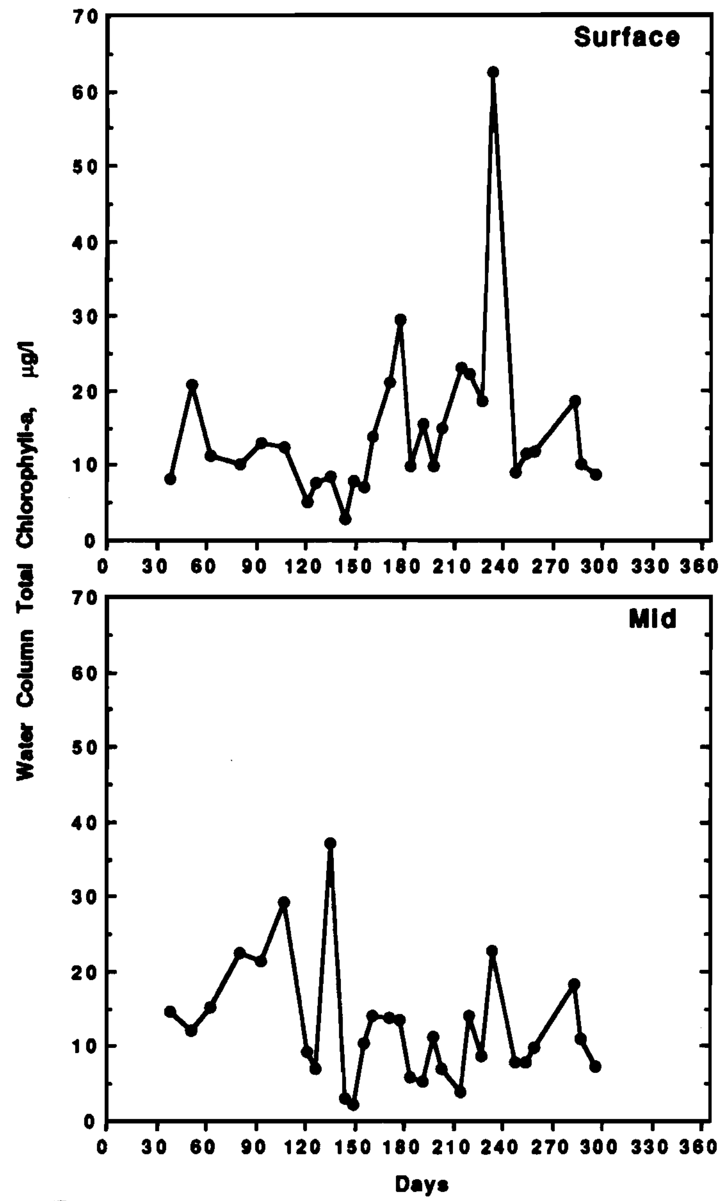


Figure 7-1.2. Plots of surface and mid-depth concentrations of total chlorophyll-a from station R-64 collected during 1991.

Total chlorophyll-a concentrations ranged from 2 to 63 $\mu g\ l^{-1}$ and 2 to 38 $\mu g\ l^{-1}$ in surface and mid-depth samples, respectively. Once again, with an occasional exception, there was good correspondence in temporal concentration patterns between surface and mid-depth samples. In general chlorophyll-a concentrations were higher at mid-depth during spring and higher in surface waters during summer.

The patterns of particulate carbon and total chlorophyll-a observed in 1991 were similar to those observed in other years which had a spring bloom event. A noticeable exception to this pattern was observed in 1989 when the spring bloom was severely attenuated, probably in response to a delayed spring freshet.

7.3 Particulate Carbon Deposition Rates

Particulate carbon deposition rates based on data collected during 1991 from surface and mid-depth collecting cups (deployed at depths of 5 and 9 meters from the surface) are shown in Figure 7-2.1. These deposition rates have not been corrected for resuspension effects. The height of each bar indicates the amount of deposition and the width of each bar represents the period from the time of deployment to the time of retrieval. The average length of deployment varied from four to fourteen days. During spring the traps were deployed for longer periods than during summer months because during summer and early fall fouling organisms (epiphytic plants and animals) fell into collecting cups and grew on the surface of cups, masking the collection rate of newly depositing particulates. Zero (0.0) values (or the absence of bars) indicate periods when traps were not deployed rather than periods of time characterized by non-detectable deposition rates.

Deposition rates estimated from surface collections made in previous years varied between 350 and 1005 mg $m^{-2}\ d^{-1}$ in 1985; 280 and 1900 mg $m^{-2}\ d^{-1}$ in 1986; 220 and 1205 mg $m^{-2}\ d^{-1}$ in 1987; 200 and 1700 mg $m^{-2}\ d^{-1}$ in 1988; 300 and 1200 mg $m^{-2}\ d^{-1}$ in 1989 and 220 and 1000 mg $m^{-2}\ d^{-1}$ in 1990. During 1991 deposition rates varied between 200 and 1050 mg $m^{-2}\ d^{-1}$. In most years, including 1991, there was an increase in deposition rates during mid spring (circa day 100) which coincided with the spring phytoplankton bloom period. Additionally, in four of the six years (1986, 1987, 1988 and 1989) high rates of particulate carbon deposition (> 1000 mg C d^{-1}) were recorded during the summer, between the end of June and the middle of August. Finally, in 1985, 1987, 1989 and 1990 deposition rates increased sharply for a brief period in the fall, presumably in response to the deposition of the fall diatom bloom. Deposition rates during summer of 1991 averaged about 850 mg $m^{-2}\ d^{-1}$ and there was not an indication of a fall bloom period of deposition.

The seasonal pattern for particulate carbon deposition rates to a depth of 9 meters (mid-depth collecting cups), is much stronger than in surface collections, and values were generally greater than in surface collections, often by a factor of two or more (Figure 7-2.1.). In part these differences were due to the fact that mid-depth cups were closer to the sediment surface and hence more prone to collect resuspended material than were surface cups. However, the tops of the mid-depth collecting cups were always above or in the pycnocline during 1991 and hence the effects of collecting locally resuspended material were probably small. It seems more likely that mid-depth cup collections were larger because they were exposed to a longer water column from which to collect new material. Additionally, some portion of the spring bloom is concentrated in deeper waters and deposition of this material is more available to mid-depth cups. The magnitude of rates varied from 400 to 1800 mg $m^{-2}\ d^{-1}$ in 1985, 450 to 1690 mg $m^{-2}\ d^{-1}$ in 1986, 380 to 1500 mg $m^{-2}\ d^{-1}$ in 1987, 405 to 1600 mg $m^{-2}\ d^{-1}$ in 1988, 420 to 2417 mg $m^{-2}\ d^{-1}$ in 1989 and 310 to 1510 mg $m^{-2}\ d^{-1}$ in 1990. Collection rates varied from 300 to 1650 mg $m^{-2}\ d^{-1}$ in 1991. The spring bloom was clearly seen in all years, including 1991 (Figure 7-2.1.). During four years

(1987, 1989, 1990 and 1991) there was also a strong peak in deposition rates during the fall period. Values obtained during the summer months did not show any striking trends but there were brief periods when rates were substantial.

In an earlier EPC Report (Boynton *et al.*, 1991) several approaches were used to evaluate the effectiveness of the sediment traps as devices for measuring deposition rates of particulate organic matter. Deposition estimates derived from traps were found to be close to those generated using alternative approaches for estimating net deposition rates. These deposition rates corresponded to the difference between water column production and consumption rates (referred to as net community production) rather than rates at which organic matter is produced. In short, only that material which is not consumed in the upper portion of the water column is available for deposition. For example, during spring production rates are modest but water column respiration rates are small, possibly because of cool temperatures. Deposition rates in spring have often been large. In summer water column production rates are maximal but so also are respiration rates and hence much of the material produced in the water column is consumed before being deposited and deposition rates are generally lower in summer than in spring. In fact the occasional large, but brief, deposition events that do occur during summer may well be the result of a small mis-match between water column production and consumption rates.

7.4 Total Chlorophyll-a Deposition Rates

Data collected during 1991 to estimate total chlorophyll-a deposition rates to surface and mid-depth collecting cups (deployed at a depth of 5 and 9 meters from the surface) are shown in Figure 7-2.2. Total chlorophyll-a values have not been corrected for resuspension effects, but we believe corrections would be small because chlorophyll-a is labile and hence would not last long enough to be subjected to cycles of resuspension and redeposition (Sections 6.9, Boynton *et al.*, 1991). The height of each bar indicates the rate of deposition while the width of each bar represents the period from the time of deployment to the time of retrieval. The length of deployment period varied from four to fourteen days. During spring the traps were deployed for longer periods than during summer months because during summer (and early fall) fouling organisms (epiphytic plants and animals) were abundant and their inclusion in samples would mask the rate of collection of newly depositing particulates. Zero (0.0) values (or the absence of bars) indicate periods when traps were not set rather than periods when deposition rates were below detection levels.

Total chlorophyll-a deposition rates may present a clearer picture of deposition rates of "new material" than uncorrected estimates based on particulate organic carbon, nitrogen or phosphorus because resuspension effects are probably minimal in the case of chlorophyll-a. The magnitude of total chlorophyll-a deposition rates in the surface layer varied from 1.5 to 25.5 mg m^{-2} d^{-1} during the monitoring period. If chlorophyll-a deposition rates are converted to carbon (using a carbon : chlorophyll-a ratio of 50), rates of 0.1-1.3 gC m^{-2} d^{-1} are obtained and are probably close to being unbiased by resuspension effects. These rates represent a substantial percentage (40-60%) of annual phytoplanktonic production in surface waters and indicate the strength of benthic-pelagic coupling in the central bay region. In most years there was a readily interpretable seasonal pattern of total chlorophyll-a deposition. Rates were high for a period in the spring (circa day 100), variable but generally lower during summer (days 150-275) and briefly elevated during early fall (circa day 300). Spring deposition is in response to the settling of the spring diatom bloom. Spikes in summer deposition rates are probably the result of settling of summer algal blooms. In most years, but not all, there is a brief fall diatom bloom (Magnien *et al.*, 1990) and the settling of this bloom is reflected in increased deposition rates. Deposition rates during 1991

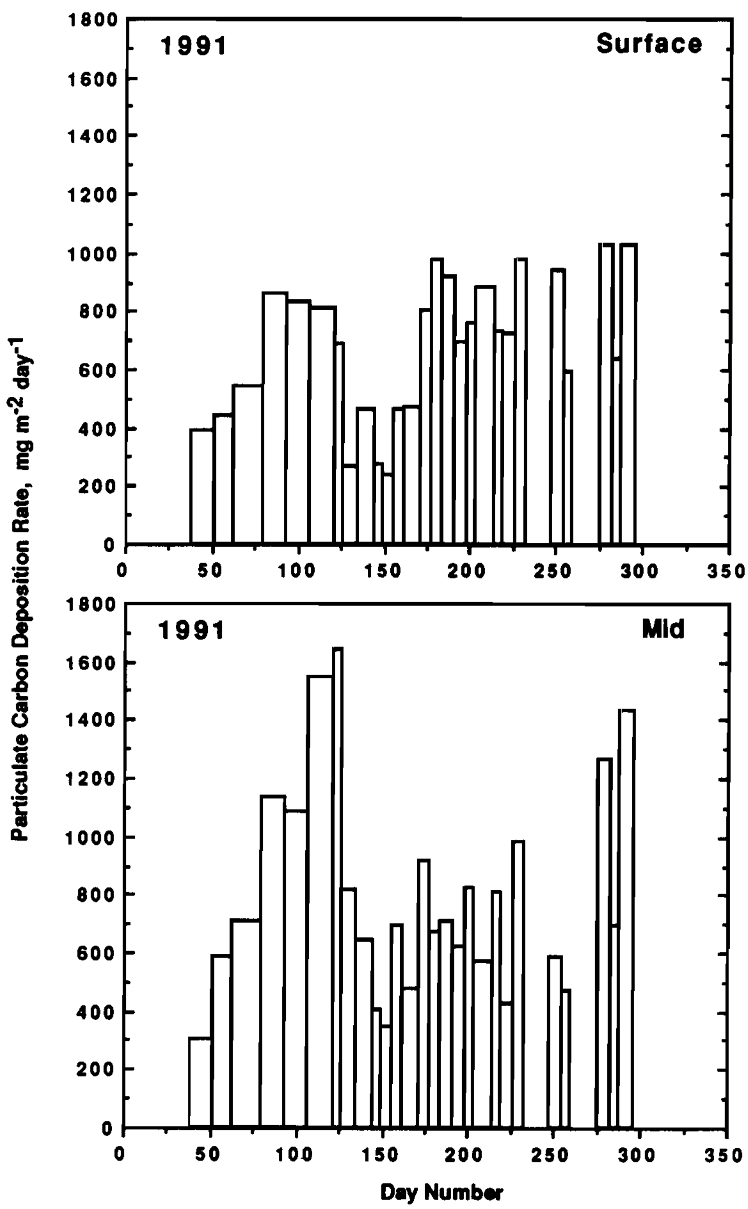


Figure 7-2.1. Bar graphs showing estimated particulate organic carbon deposition rates for 1991 based on data collected from surface water collecting cups (5 meter depth) and mid-depth collecting cups (9 meter depth) at station R-64 in the mid Chesapeake Bay. Values are uncorrected for resuspension. The height of each bar indicates the estimated rate of deposition of particulate organic carbon while bar widths represent the time interval the collecting cups were deployed.

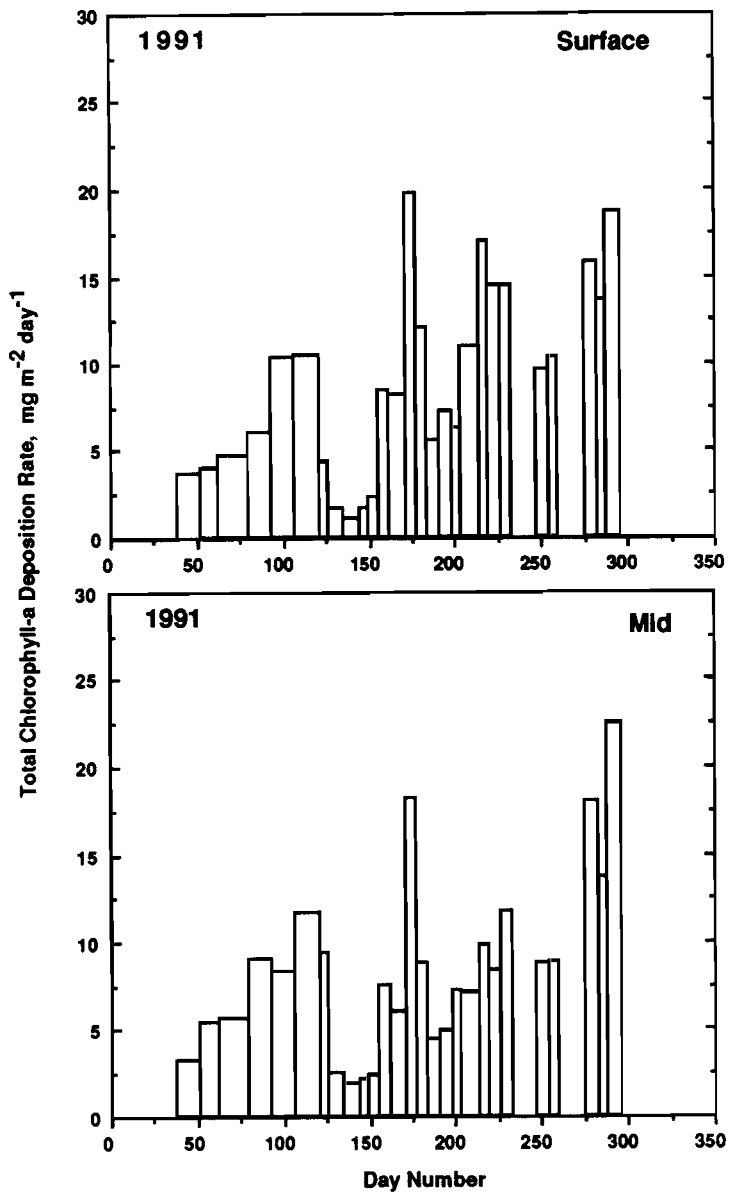


Figure 7-2.2. Bar graphs showing estimated total chlorophyll-a deposition rates for 1991 based on data collected from surface water collecting cups (5 meters) and deep water collecting cups (9 meter depth) at station R-64 in the mid Chesapeake Bay. Values are uncorrected for resuspension. The height of each bar indicates the estimated rate of deposition of total chlorophyll-a while bar widths represent the time interval the collecting cups were deployed.

were within the range of values reported in earlier years. In 1991 both spring and fall deposition periods were evident.

Estimates of total chlorophyll-a deposition based on mid-depth cup collections ranged from 2.4 to 36.6 mg m^{-2} d^{-1} during the monitoring period. Rates varied from 2 to 23 mg m^{-2} d^{-1} during 1991 and both spring and fall deposition periods were evident. More typical rates were in the range of 5-15 mg m^{-2} d^{-1}. In carbon equivalents these rates range from 0.1 to 0.8 gC m^{-2} d^{-1} with maximum rates reaching 1.8 gC m^{-2} d^{-1}. In general, mid-depth collection rates were only somewhat greater than surface collections. As noted above, this was not the case for particulate carbon deposition rates, where mid-depth collections were considerably greater possibly because of resuspension effects. The seasonal pattern of chlorophyll-a deposition was very similar to that observed in surface waters but was more distinct at depth. Additionally, inter-annual differences were also more apparent from mid-depth collections. For example, there was but a small indication of a spring bloom in 1989, as noted in other portions of the monitoring program (Magnien *et al.*, 1990; Sellner, 1989), but well developed bloom signals in other years.

A strong and repeatable patterns of deposition been found, which appear to be related to inter-annual variations in nutrient loading and plankton dynamics. Additionally, a substantial fraction of primary production from overlying waters is deposited in deeper waters.

7.5 Spring Deposition and Hypoxia in the Mainstem Bay

In the previous EPC Interpretive Report, water column and deposition rate data for the spring (March - May) periods from 1985-1990 were examined for indications of biological influences on initiation of hypoxic conditions in this region of the bay. This analysis has now been extended to include data collected during 1991.

One of the main water quality problems in the bay is the yearly development of zones of hypoxic or anoxic water in deep areas during summer periods. The conceptual model used to guide the EPC program indicates that as nutrient loads to the bay decrease (in response to management actions), algal biomass accumulation in the euphotic zone, deposition rates of organic matter to deep waters and deep water and sediment oxygen consumption rates should also decrease. The end result would be a diminution of low oxygen conditions. One of the main goals of the 1991 reevaluation effort was to determine just how much nutrient loads need to be reduced to alleviate low oxygen conditions.

Developing relationships between nutrient loading rates and oxygen conditions is not a simple task. A state-of-the-art mathematical simulation model has been developed to address this and other questions. One of the more difficult aspects of this problem is separating the influence of stratification, which inhibits oxygen supplies to waters beneath the pycnocline, from other sources of oxygen demand which are ultimately based on organic matter availability. EPC data are not adequate to entirely resolve this problem but it does appear possible to develop relationships between deep water oxygen characteristics and organic matter deposition rates for an region of the mainstem bay where seasonal oxygen problems are chronic.

Data collected by the EPC, and other components of the monitoring program (Magnien *et al.*, 1990), exhibited deep water oxygen characteristics in the mainstem bay which suggested that deposition-oxygen status relationships might exist. First, severe hypoxic or anoxic conditions have developed in deep waters for some period of time during each year since the monitoring program began in 1984. Even the lowest nutrient loading conditions observed during this period produced enough phytoplankton biomass to "organic matter saturate" the system and produce low oxygen concentrations. In other words, there is more organic matter produced in the system than there is oxygen available to oxidize this material during summer periods. Second, in 1989 the spring freshet (and associated nutrient load) did not enter the bay until mid-May. The spring phytoplankton bloom did not develop to any significant extent and deep water oxygen depletion was delayed for about a month.

These results suggested that deep water oxygen conditions were regulated, at least in part, by the amount of organic material deposited during spring. Vertical mixing of oxygen from surface to deep waters, which is influenced by the degree of water column stratification, is also involved. Separating the effects of biological and physical processes is one of the most difficult aspects of this problem to resolve. Finally, since it appears that the system usually receives enough organic matter to produce hypoxic/anoxic conditions, the inter-annual pattern of oxygen decline may be largely determined by the magnitude of early spring deposition. Deposition later in spring and early summer may have little to do with creating poor oxygen conditions but more to do with maintaining such conditions.

Bottom water oxygen concentrations are routinely measured, on a biweekly or weekly basis, at the VFX site located adjacent to station R-64 (Figure 3-1.) in the mainstem bay. Water depth at this site is about 17 meters and vertical stratification characteristics are typical of this region of the bay. The daily rate of change in oxygen concentration (dO2/dt) and percent saturation (dO_2 sat/dt) were calculated using these data for spring periods for the years 1985-1991. The time period over which rates of change were calculated varied slightly among years but generally included the period from the beginning of March through the middle of May. The criteria used to determine the starting point was that the first observation to be used was not followed by any oxygen measurements of higher concentration. Typically, during late winter and early spring deep water oxygen concentrations exhibit both small increases and decreases over time but are generally close to saturation. The final oxygen measurement used was the last value greater than 1 mg l-1. The rates of oxygen decline for the years 1985 through 1991 calculated from these data were very linear (r^2 values associated with linear regressions > 0.92) and differed appreciably among years (0.092 mg l^{-1} d^{-1} to 0.169 mg l^{-1} d^{-1}).

The "organic matter saturation" concept described above suggested that dissolved oxygen declines were most strongly caused by early deposition events rather than events that occurred later in spring or summer. Accordingly, average spring deposition rates of total chlorophyll-a (mid-depth collecting cups) were calculated for each year using deposition data collected between early February and the beginning of May. Chlorophyll-a rather than particulate carbon was selected as the primary variable investigated because it appears to be a better measure of new deposition relatively uncontaminated by local sediment resuspension. Chlorophyll-a also more closely approximates labile organic matter stocks than does a measure of total particulate carbon. In addition, maximum deposition rates were also organized for this period as were surface and deep water total chlorophyll-a concentrations. Significant relationships were found between the rate of oxygen decline (dO_2/dt and dO_2 sat/dt) and average total chlorophyll-a deposition rates during early spring periods (Figure 7-3.). Less significant relationships were also found between both measures of dissolved oxygen decline and maximum deposition rates during the same time period. Average deposition rates which included May or May and June data were not well correlated with dissolved oxygen rates of decline. Neither surface nor bottom water total chlorophyll-a concentrations were consistently related to measures of dissolved oxygen decline although trends were similar to those observed for deposition rates.

These results are interesting because they indicate the general influence of biological processes on oxygen declines and they relate oxygen declines to nutrient-related processes which are susceptible to management action. However, at least two alternative explanations exist and these, if true, do not readily lend themselves to management actions. First, it can be hypothesized that different spring rates of oxygen decline are caused by inter-annual differences in temperature regimes. Oxygen declines would be more rapid in warm years than in cool years simply because of the influence of temperature on respiration rates. In this scenario, organic matter needed to support respiration has never been limiting, even during the early spring period. This explanation seems unlikely to be the prime cause because inter-annual temperature differences have been small over the period of record. For the most part warm and cool springs were not correlated with high and low rates of oxygen decline, although temperatures during 1991 were low, consistent with this alternative explanation (Figure 7-3.). Second, it could be hypothesized that the cause is related to inter-annual differences in the degree of water column stratification. In years when the water column is highly stratified, less mixing of oxygen from surface to deep water would occur and oxygen rates of decline would be greater. Stratification certainly plays a major role in determining deep water oxygen characteristics but there appears to be less of a case to be made for stratification being a dominant factor in causing inter-annual differences in oxygen rates of decline. As shown in Figure 7-3. there are inter-annual differences in average spring salinity gradients (bottom minus surface salinity). However, the years of high and low stratification do not correspond to years of high and low rates of oxygen decline as they should if stratification was a prime factor in causing these differences (Figure 7-3.). The addition of data collected during 1991 strengthened the relationships shown in Figure 7-3. but the changes were small.

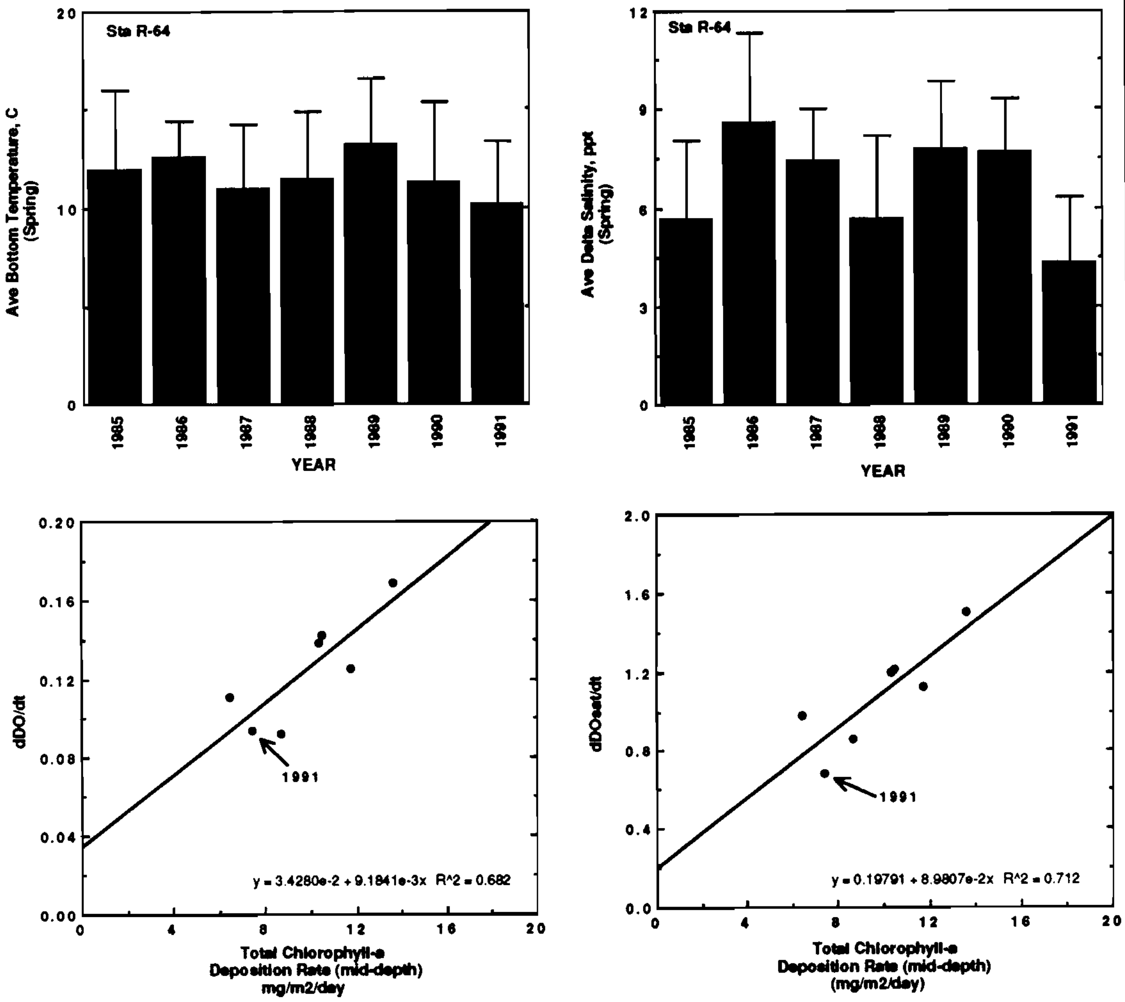


Figure 7-3. Bar graphs of average bottom water temperature and salinity gradient (bottom minus surface salinities) during spring periods of 1985-1991 at station R-64 in the mainstem bay. Also shown are scatter plots of rates of change of dissolved oxygen ($dO_2\backslash dt$) and dissolved oxygen saturation (d O_2 sat\dt) versus total chlorophyll-a deposition at mid-depth of the water column (Mid-depth Deposition Rate, mg m^{-2} d^{-1}). Deposition and dissolved oxygen data were also collected at station R-64 during spring periods of 1985-1991.

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