CEES

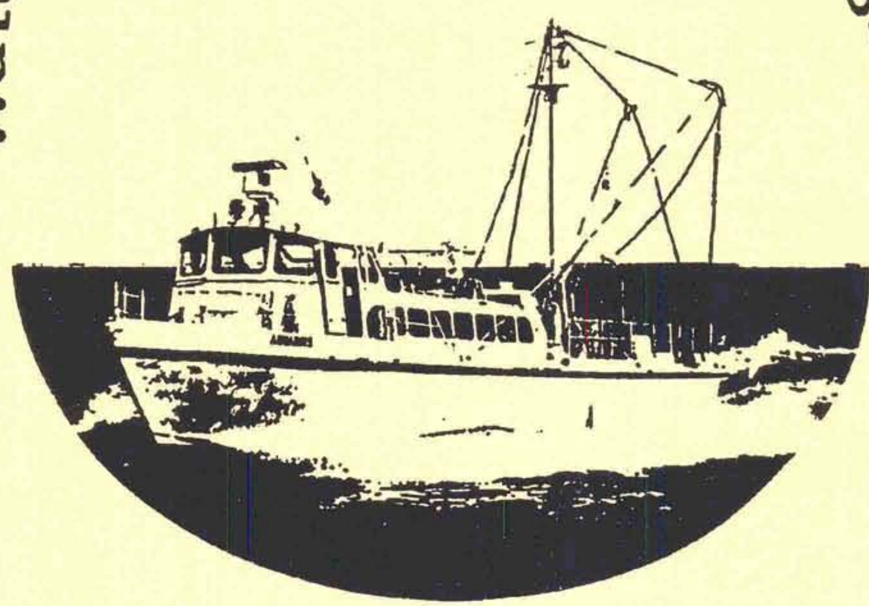
CENTER for ENVIRONMENTAL and ESTUARINE STUDIES

UNIVERSITY of MARYLAND SYSTEM

USA

Chesapeake Bay Water Quality Monitoring Program

ECOSYSTEMS PROCESSES COMPONENT (EPC)



LEVEL ONE DATA REPORT #10

Part 1: Interpretive Report

A Program Supported by the
Maryland Department of the Environment
State of Maryland

March 1993

[UMCEES]CBL Ref. No.93-030a

MARYLAND DEPARTMENT OF THE ENVIRONMENT

MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYSTEM PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT NO. 10

PART 1: INTERPRETIVE REPORT

(July 1984 - December 1992)

PREPARED FOR:

Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224

March, 1993

BY:

W.R. Boynton[1] Principal Investigator
W.M. Kemp[2] Co-Principal Investigator
J.M. Barnes[1] Sr. FRA, Field Program Co-ordinator
L.L. Matteson[1] Sr.FRA, Data Entry and Management
F.M. Rohland[1] Ass. Res. Sci., Data Management and Analyst
D.A. Jasinski[1] FRA, Field Program
H.L. Kimble[1] FRA, Field Program

University of Maryland System
Center for Environmental & Estuarine Studies

[1]Chesapeake Biological Laboratory (CBL)
Solomons, Maryland 20688-0038

[2]Horn Point Environmental Laboratories (HPEL)
Cambridge, Maryland 21613-0775

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Page No.

TABLE OF CONTENTS (Continued)

Page No.

TABLE OF CONTENTS (Continued)

Page No.

TABLE OF CONTENTS (Continued)

Page No.

PREFACE

This report is submitted in accordance with the Schedule of Deliverables set out in Contract 447-C-MDE 92 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).

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. The results of a series of statistical analyses completed on five SONE flux variables is presented in Section 8.

SONE and VFX data for all previous years, August 1984 through December 1991, were submitted as a four volume reference data set with the Level 1, Interpretive Reports. Data volumes I and II containing data for August 1984 through December 1989 were submitted with the Level 1, No. 7 Interpretive Report [UMCEES]CBL Ref. No. 90-062 (Boynton *et al.*, 1990). One set of changes pages has been inserted into Volumes I and II (Boynton, Rohland and Matteson, 1992). Volume III contains SONE data tables for 1990 through 1992 and Volume IV contains VFX data for 1990 through 1992 (Appendix C). The VFX program was terminated on 3rd June, 1992 when the sediment traps were finally retrieved. The VFX data set is now complete. These two volumes were part of Level One, Report No. 9 [UMCEES]CBL Ref. No. 92-042 (Boynton *et al.*, 1992b).

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.

Appendix D contains copies of programs developed by Dr Larry Douglass, Research Statistician at the University of Maryland System, College Park. Dr Douglass provided valuable assistance as a consultant with regard to the rigorous statistical testing of SONE sediment-water flux data presented in section 8.

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.

LIST OF FIGURES

LIST OF FIGURES (Continued)

Page No.

LIST OF FIGURES (Continued)

Page No.

LIST OF TABLES

LIST OF TABLES (Continued)

Page No.

LIST OF TABLES (Continued)

Page No.

APPENDIX B: (Continued)
(Volume III: Boynton et al., 1992: [UMCEES]CBL Ref. No. 92-042)

1992:
SEDIMENT OXYGEN AND NUTRIENT EXCHANGES (SONE)
DATA SET: (Continued)
DATA FILES FOR SONE PROGRAM: CRUISES 35 - 40
(January - December 1992)

LIST OF TABLES (Continued)

Page No.

LIST OF TABLES (Continued)

Page No.

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, 1992 at a total of eight mainstem bay and tributary river stations. Deposition rates were monitored almost continuously during late January through May 1992 at one mainstem bay location. This program was initiated in July 1984, and the basic data collection scheme has been followed through December 1992, with the exception of deposition rate measurements which were discontinued in May of 1992. This report includes data collected during the entire monitoring program but specifically evaluates data collected during the 1992 monitoring period.

Sediment trap data collected during 1992 indicate a poorly developed spring deposition period beginning in early March and ending in late May. There was one very high deposition measurement collected at mid-cup depth in late January (23 mg total chlorophyll-a m^{-2} day^{-1}) but it is not possible to determine if this was the last portion of an especially early deposition event or just an unusual brief period of deposition. Aside from this single observation, the highest rate of total chlorophyll-a deposition in 1992 was 7.0 mg m^{-2} day^{-1}. In contrast total chlorophyll-a deposition rate reached 36.6 mg m^{-2} day^{-1} during spring 1990. Deposition rates of total chlorophyll-a during the spring bloom were highest in 1985, 1988 and 1990 (1003 - 1075 mg m^{-2}), lowest in 1989 (347 mg m^{-2}) and intermediate (625 - 861 mg m^{-2}) in the remaining years, including 1992 (645 mg m^{-2}).

Sediment-water fluxes of oxygen (SOC) tended to be larger than those observed in previous years, particularly in the Patuxent River. It appears that slightly elevated dissolved oxygen concentrations in deep waters were responsible for these higher rates. Ammonium (NH_4^+) fluxes during 1992 tended to be lower than the long term average at most SONE stations but this pattern was particularly distinct in the lower Potomac River and at stations in the mainstem bay (R-64 and PNPT). Nitrate plus nitrite (NO_2^- + NO_3^-) fluxes from sediments to water (indicative of oxygenated sediments capable of supporting nitrification) were progressively rarer over the years (1985 - 1991). However, during 1992 nitrate plus nitrite fluxes tended to be either less negative or positive at all stations except the lower Potomac. During 1992, inorganic phosphate (DIP) fluxes were also reduced at most sites, similar to ammonium fluxes. Silicate fluxes (Si) were comparable to previous years, except in the upper Patuxent and lower Potomac Rivers where fluxes were slightly higher than the long term average.

Efforts to detect relationships between major EPC Program variables (*e.g.*, sediment-water oxygen and nutrient fluxes and deposition rates) and selected environmental variables were continued using 1992 data and the following patterns were indicated:

(1) 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.

(2) Sediment releases of ammonium and phosphorus tended to be reduced in 1992 compared to other years. These reductions occurred in a year with lower than normal runoff (reduced diffuse source nutrient loading rates). Deep water dissolved oxygen concentrations tended to be higher in summer 1992 than in previous years at most stations (particularly in the Patuxent River) and sediment Eh values were also more positive, both being indicative of improved water and sediment quality conditions. These observations are all consistent with reduced sediment nutrient releases.

(3) Spring deposition rates measured at one location in the mainstem bay, were correlated with an index of nutrient loading rates.

(4) Rates of oxygen decline in deep waters of the mainstem bay were also well correlated with spring deposition rates but not with particulate material concentrations in the water column, temperature or the degree of vertical water column stratification

(5) A series of statistical analyses were performed using the SONE flux data set to examine long term trends, to develop estimates of the levels of detection as well as the power of the current sampling procedure. The data set contained data for eight stations in three estuaries and the Chesapeake mainstem, and 5 flux variables for which data was available for more than three months and more than three years. Analysis of variance was used to test the significance of long term trends. Two models were used, year and flow year. The input variables (x) were mean annual flux rates of change with units μMx m^{-2} hr^{-1} yr^{-1}. Consistent trends were detected for most flux variables in the Potomac River. These trends were decreasing and were consistent with conditions under which nutrient loading decreases. Few trends were identified at other SONE stations where nutrient loading rates both increased and decreased during the monitoring period. Attempts to normalize fluxes for differing inter-annual nutrient loading rates (using river flow as a substitute variable for nutrient loading rates) did not improve the analysis. Power analysis indicated that small differences (10% of average fluxes) could be detected. The levels of detection will improve as additional years of sampling are added.

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 sustain 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.*, 1985a, 1986, 1987, 1988, 1989, 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 1992 are presented in this report and a statistical analysis conducted to determine the magnitude and significance of trends in sediment-water exchanges.

3. PROJECT DESCRIPTION

Measurements of sediment-water oxygen and nutrient exchanges were made six times during 1992 at eight locations in the mainstem bay and in each of three major tributary rivers (Patuxent, Choptank, and Potomac). Deposition measurements at one station were 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 1992.

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. A comprehensive listing of all SONE, 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 1992, two of the eight 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 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, 1985a 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 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.

The VFX program was discontinued in June 1992 due to budgetary constraints. The last trap was retrieved on June 3, 1992.

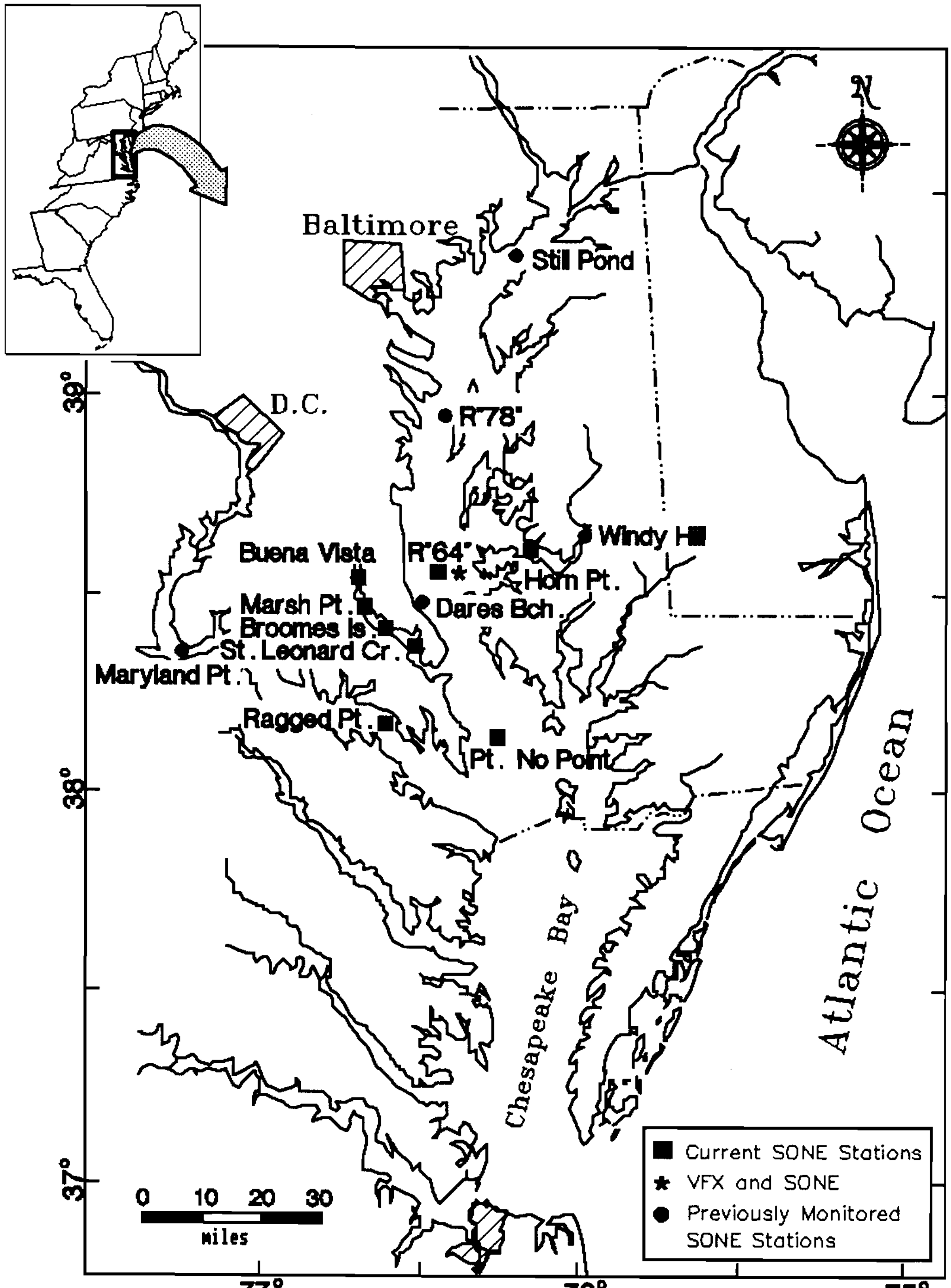


Figure 3-1. Location of current and previous SONE and VFX Monitoring Stations in the Maryland Portion of Chesapeake Bay

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

REGION	STATION NAME	STATION CODE NAME	SAMPLING ORDER[3] A	SAMPLING ORDER[3] 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	
	Still Pond	SLPD	10	

NOTES:

A = Stations sampled in SONE 1 - 20, August 1984 - June 1989. Numerical ranking indicates the order in which they appear in the data tables.

B = Stations sampled beginning with SONE 21 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).

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'	75° 58.30'	3.8	NONE	ET5
Potomac River					
RGPT	38° 09.86'	76° 35.52'	16.5	XBE9541	LE2
MDPT	38° 21.37'	77° 11.49'	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
SLPD	39° 20.87'	76° 10.87'	10.4	MCB2.2	CB2

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

NOTES:

* 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
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

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). Characteristics of sediment water nutrient and oxygen exchanges typically include the following: relatively high sediment oxygen consumption (SOC) rates, nitrate uptake by sediments and low exchange rates of other nutrients.

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). Characteristics of sediment water nutrient and oxygen exchanges typically include the following: low sediment oxygen consumption (SOC) and nitrate flux rates, very high releases of ammonium (NH_4^+), phosphate (PO_4^-) and silicate ($Si(OH)_4$).

3) A period in the fall when anoxia is not present and macrofaunal community abundance is low but re-establishing (October - November). Characteristics of sediment water nutrient and oxygen exchanges typically include the following: increased sediment oxygen consumption (SOC) flux rates, intermediate release rates of ammonium (NH_4^+), phosphate (PO_4^-) and silicate ($Si(OH)_4$) and occasional nitrate release.

4) A winter period when fluxes are very low due primarily to low temperature. 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, 1992. 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 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 (11 times in 1992). 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 1990-1992 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.

The VFX study was terminated on June 3, 1992 when the sediment traps were finally retrieved. This program was discontinued due to budget cut backs.

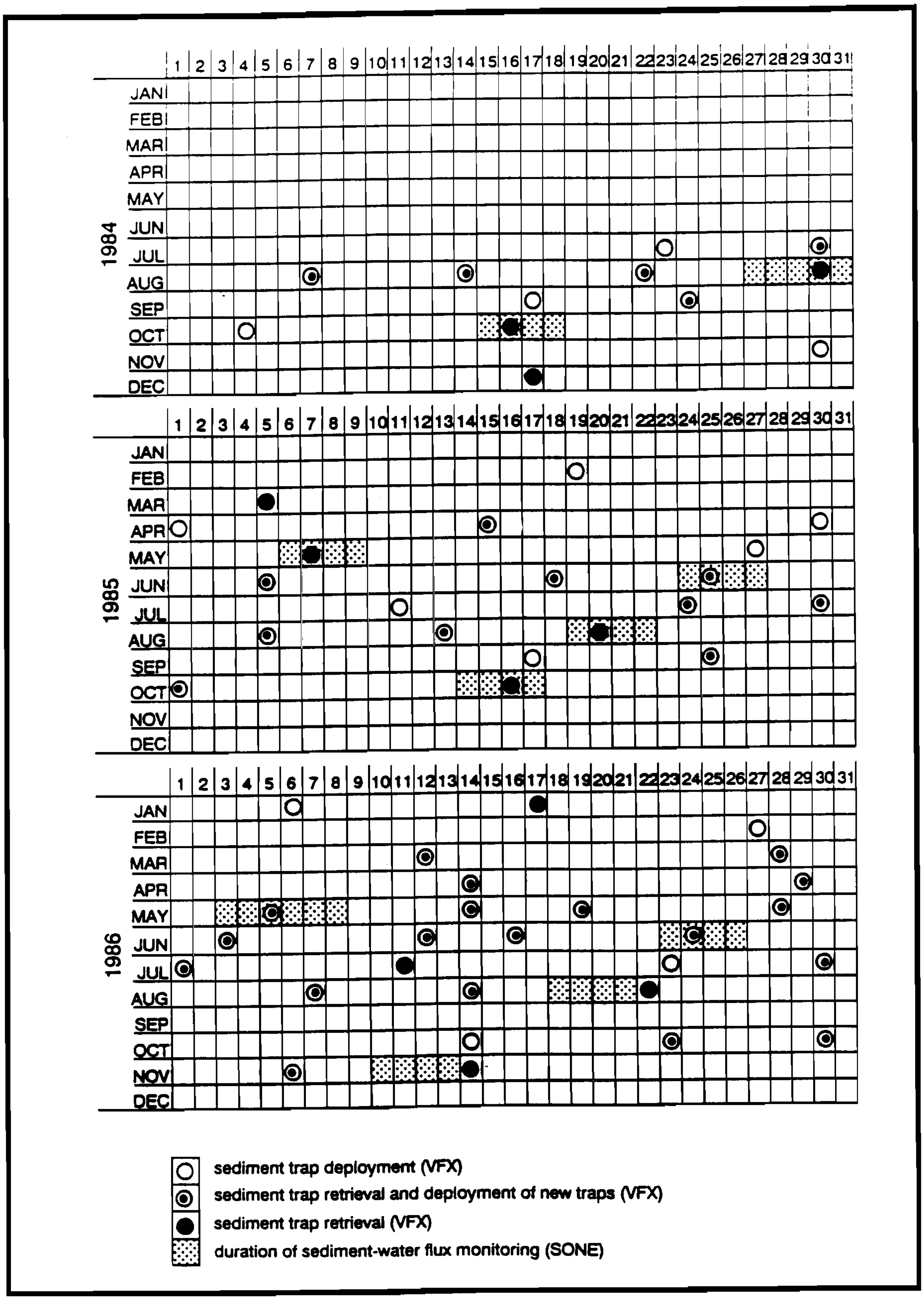


Figure 3-3.1. SONE and VFX Sampling Schedule for 1984-1986

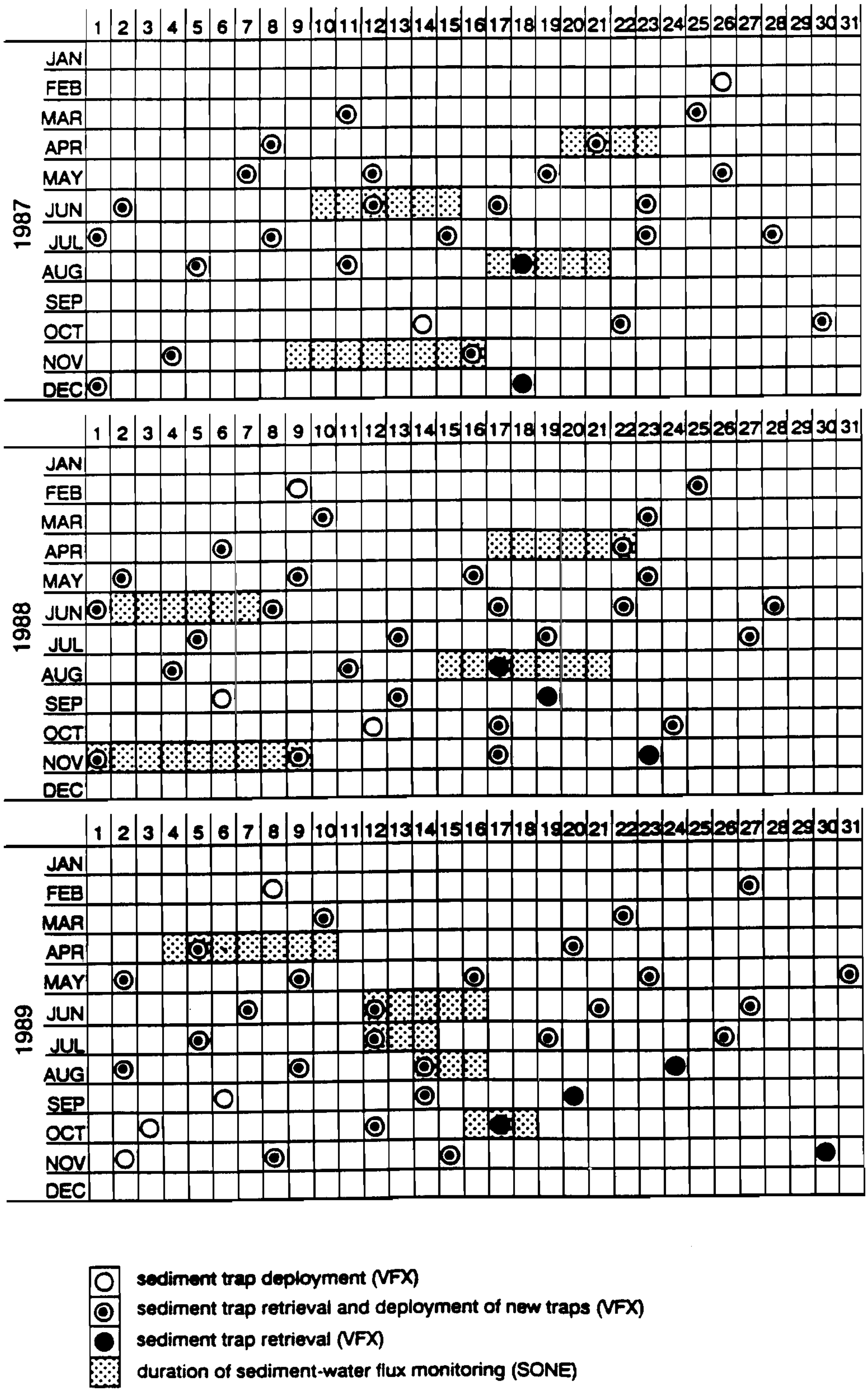


Figure 3-3.2. SONE and VFX Sampling Schedule for 1987 - 1989

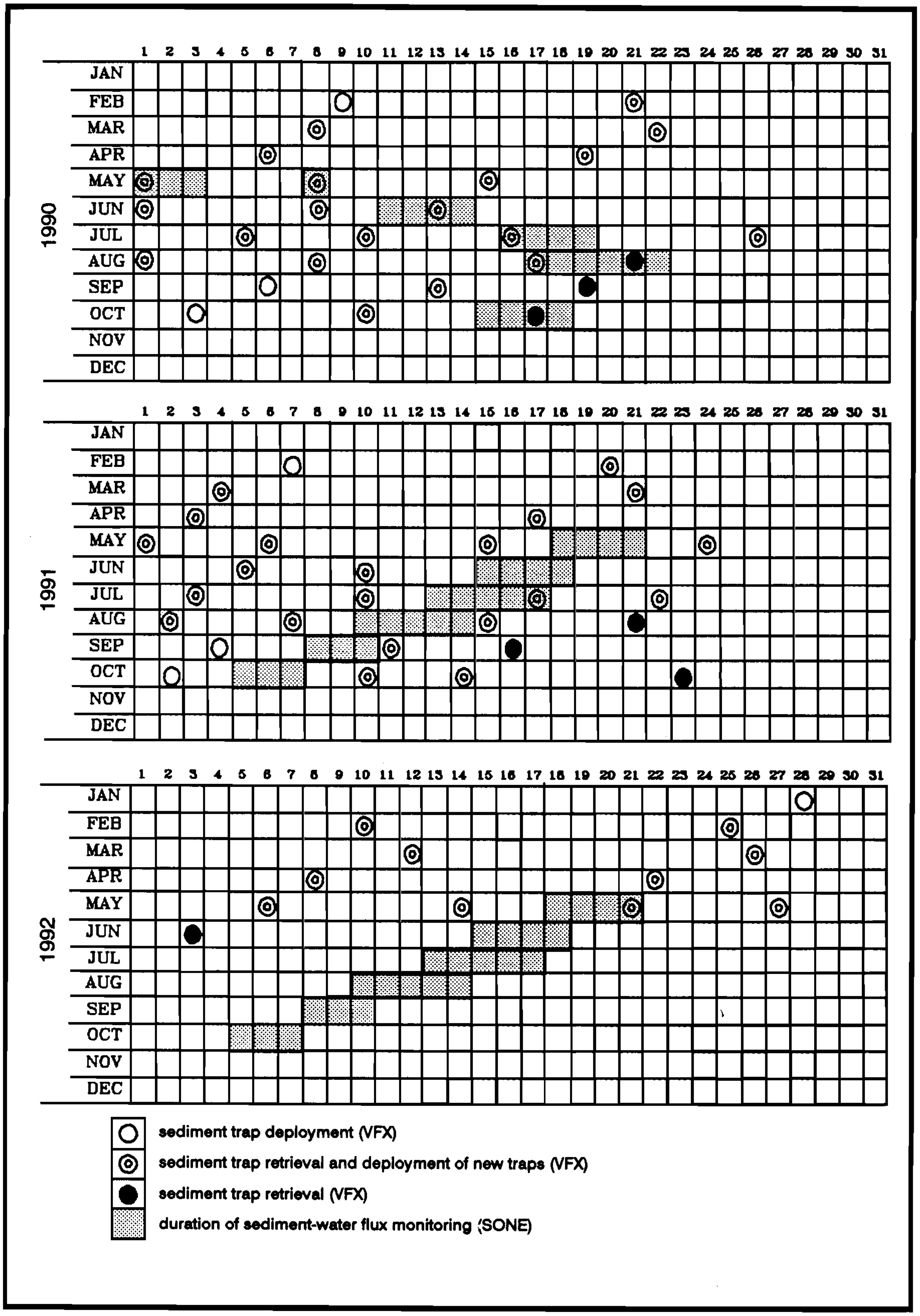


Figure 3-3.3. SONE and VFX Sampling Schedule for 1990 - 1992

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 3-4.1. SONE Cruise Identifier (Continued)

CRUISE	DATE	BEGIN DATE	END DATE	RESEARCH VESSEL
SONE 35	MAY 1992	18 MAY	21 MAY	Aquarius
SONE 36	JUN 1992	15 JUN	18 JUN	Aquarius
SONE 37	JUL 1992	13 JUL	17 JUL	Orion
SONE 38	AUG 1992	10 AUG	14 AUG	Aquarius
SONE 39	SEP 1992	08 SEP	10 SEP	Aquarius
SONE 40	OCT 1992	05 OCT	08 OCT	Aquarius

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	Aguarius
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 3rd June 1992) for Station R-64 and Dares Beach (11th July 1985 to 14th November 1986).[1] - Continued

DATE	CRUISE NO.	RESEARCH VESSEL	DATE	CRUISE NO.	RESEARCH VESSEL
16 NOV 1987	1003	Aquarius	20 APR 1989	1093	Aquarius
01 DEC 1987	1005	Aquarius	02 MAY 1989	1426	Orion
18 DEC 1987	1335	Orion	09 MAY 1989	1098	Aquarius
09 FEB 1988	1341	Orion	16 MAY 1989	1429	Orion
25 FEB 1988	1346	Orion	23 MAY 1989	1104	Aquarius
10 MAR 1988	1352	Orion	31 MAY 1989	1432	Orion
23 MAR 1988	1355	Orion	07 JUN 1989	1435	Orion
06 APR 1988	1015	Aquarius	12 JUN 1989	1110	Aquarius
22 APR 1988	1017	Aquarius	21 JUN 1989	1441	Orion
02 MAY 1988	1366	Orion	27 JUN 1989	1112	Aquarius
09 MAY 1988	1368	Orion	05 JUL 1989	1114	Aquarius
16 MAY 1988	1370	Orion	12 JUL 1989	1118	Aquarius
23 MAY 1988	1372	Orion	19 JUL 1989	1120	Aquarius
01 JUN 1988	1027*	Aquarius	26 JUL 1989	1122	Aquarius
08 JUN 1988	1027*	Aquarius	02 AUG 1989	1450	Orion
17 JUN 1988	1376	Orion	09 AUG 1989	1128	Aquarius
22 JUN 1988	1378	Orion	14 AUG 1989	1129	Aquarius
28 JUN 1988	1034	Aquarius	24 AUG 1989	1131	Aquarius
05 JUL 1988	1380	Orion	06 SEP 1989	1455	Orion
13 JUL 1988	1038	Aquarius	14 SEP 1989	1457	Orion
19 JUL 1988	1039	Aquarius	20 SEP 1989	1458	Orion
27 JUL 1988	1385	Orion	03 OCT 1989	1141	Aquarius
04 AUG 1988	1043	Aquarius	12 OCT 1989	1464	Orion
11 AUG 1988	1389	Orion	17 OCT 1989	1146	Aquarius
17 AUG 1988	1047	Aquarius	02 NOV 1989	1469	Orion
06 SEP 1988	1392	Orion	08 NOV 1989	1470	Orion
13 SEP 1988	1050	Aquarius	15 NOV 1989	1155	Aquarius
19 SEP 1988	1395	Orion	30 NOV 1989	1156	Aquarius
12 OCT 1988	1401	Orion	16 JUL 1990	1195	Aquarius
17 OCT 1988	1404	Orion	26 JUL 1990	1515	Orion
24 OCT 1988	1066	Aquarius	01 AUG 1990	1198	Aquarius
01 NOV 1988	1067*	Aquarius	08 AUG 1990	1522	Orion
09 NOV 1988	1067*	Aquarius	17 AUG 1990	1203	Aquarius
17 NOV 1988	1070	Aquarius	21 AUG 1990	1203	Aquarius
23 NOV 1988	1408	Orion	05 SEP 1990	1525	Orion
08 FEB 1989	1082	Aquarius	06 SEP 1990	1526	Orion#
27 FEB 1989	1084	Aquarius	13 SEP 1990	1208	Aquarius
10 MAR 1989	1087	Aquarius	19 SEP 1990	1529	Orion
22 MAR 1989	1089	Aquarius	03 OCT 1990	1213	Aquarius
05 APR 1989	1091	Aquarius	10 OCT 1990	1536	Orion

Table 3-4.4. VFX Cruise Dates (23rd July 1984 to 3rd June 1992) 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
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

DATE	CRUISE NO.	RESEARCH VESSEL
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
28 JAN 1992	1294	Aquarius
10 FEB 1992	1604	Orion
25 FEB 1992	1607	Orion
12 MAR 1992	1609	Orion
26 MAR 1992	1611	Orion
08 APR 1992	1613	Orion
22 APR 1992	1614	Orion
06 MAY 1992	1616	Orion
14 MAY 1992	1308	Aquarius
21 MAY 1992	1311	Aquarius
27 MAY 1992	1619	Orion
03 JUN 1992	1621	Orion

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 incubator maintained at ambient temperature 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}) sediment oxygen consumption (SOC) rate measurements underestimate actual sediment metabolism because much of the decomposition of organic matter is supported through anaerobic pathways (primarily sulphate reduction). Additionally sediment oxygen consumption (SOC) rates made under low dissolved oxygen (DO) conditions do not capture the eventual oxygen demand that is exerted by the reoxidation of reduced compounds (primarily H_2S) formed during anaerobic periods. Prior to 1989, between five and seven of the SONE stations rarely if ever experienced low bottom water dissolved oxygen (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 sediment oxygen consumption (SOC) rates. This represents a methodological limitation which is more serious given the current configuration of stations in the study. A method for measuring total sediment metabolism (dissolved inorganic carbon flux) is being developed (but is at present not yet ready for use in the monitoring program) which is independent of oxygen conditions. During 1990, 1991 and 1992, a series of preliminary measurements of sulfate reduction ($SO_4^=$) were made. It appears that this method may be useful for measuring anaerobic metabolism (the majority of which is carried out via sulfate reduction [$SO_4^=$] reduction) which is amenable 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 chromatography as a detection method. Results from 1992 are not yet available. An evaluation will be conducted when analyses are completed. If this approach proves successful, a complete description of the method will be included in the reports and will be inserted into the data dictionary (Boynton and Rohland, 1990).

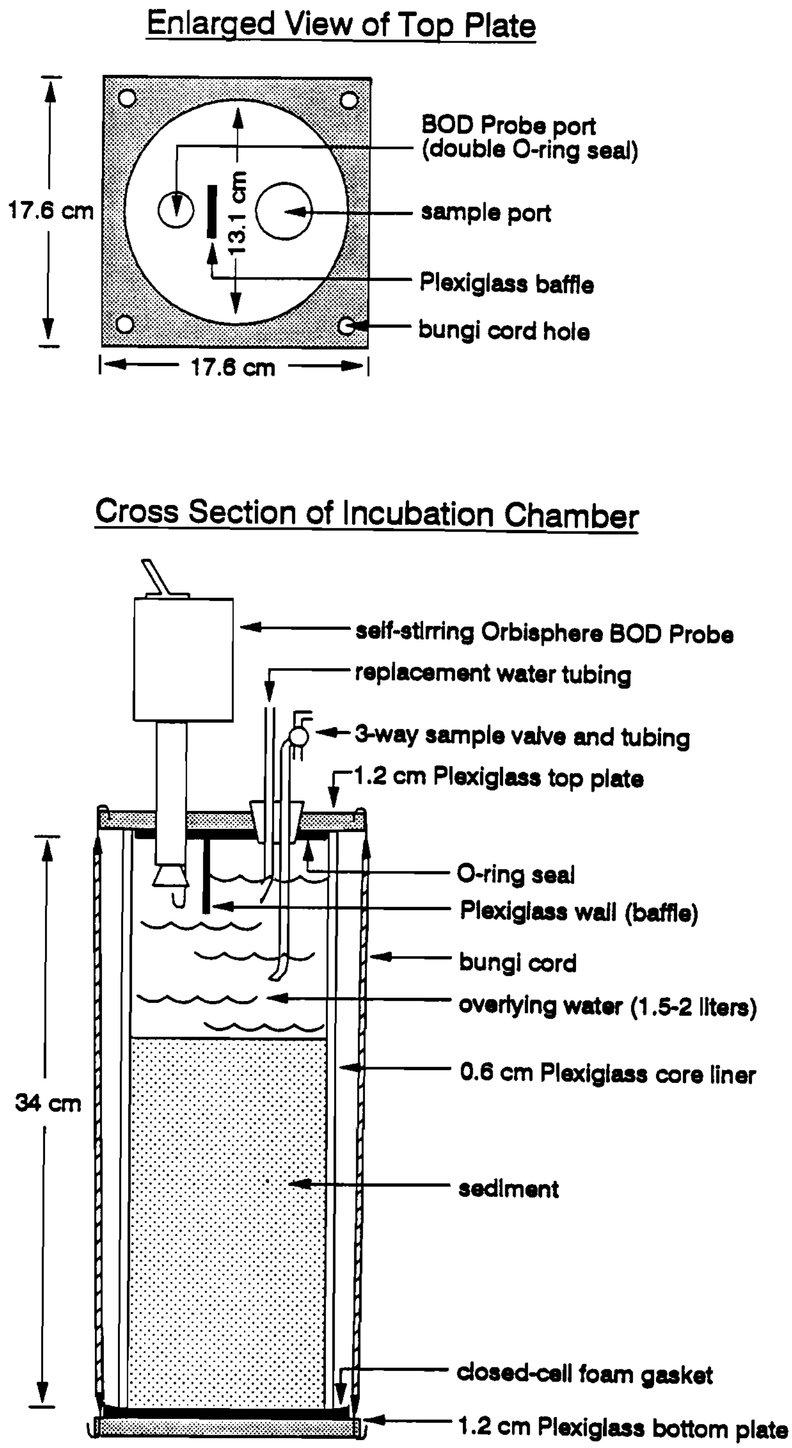


Figure 4-1. Schematic Diagram of the Incubation Chamber

4.1.2 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.

4.1.2.1 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.

4.1.2.2 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.).

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

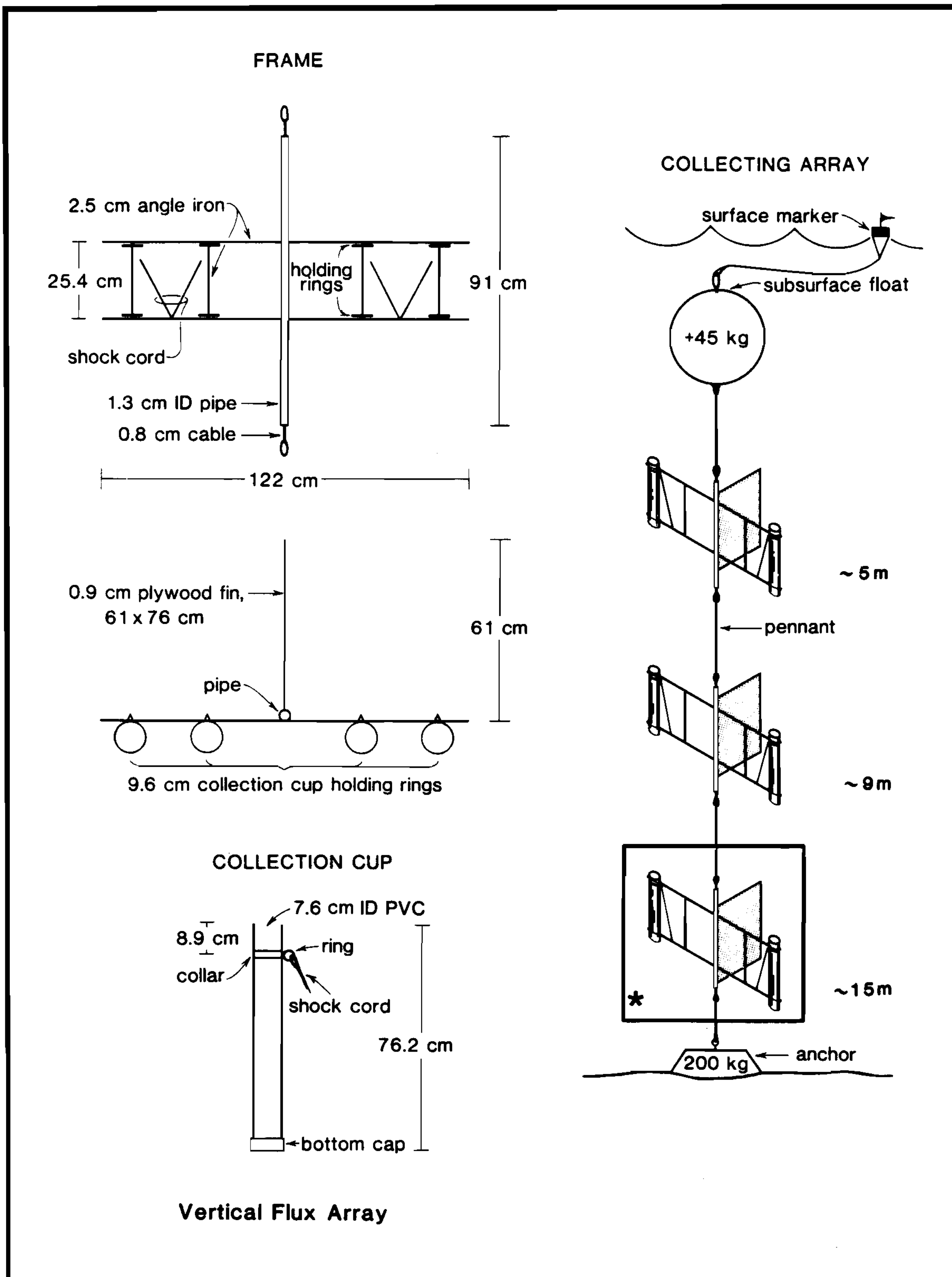


Figure 4-2. Schematic Diagram of the Sediment Trap used in VFX Monitoring
*** Measurements are only made using surface and mid cups.**
Bottom array has not been deployed or retrieved since July 8, 1987.
Sediment traps were finally retrieved on June 3, 1992.

monitoring program are provided in Boynton *et al.* (1985b), Garber *et al.* (1987) and Boynton and Rohland (1990).

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. This program was terminated with the final retrieval of the sediment traps on June 3, 1992.

4.1.3 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.

- International Council for the Exploration of the Sea (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 1991, were submitted in four volumes. Volumes I and II were appended to Level 1, No 7 Interpretive Report Part II: Data Tables [UMCEES]CBL Ref. No. 90-062 (Boynton *et al.*, 1990) and Volumes III and IV were appended to Level 1, No 9 Interpretive Report Part II: Data Tables [UMCEES]CBL Ref. No. 92-042 (Boynton *et al.*, 1992b).

Appendices B and C of this report contain data table listing for variables measured between January and December 1992 for SONE and between January and June 3, 1992 for VFX respectively. 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 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 Vertical Flux (VFX) Study

Vertical Flux (VFX) data collected, during January through June 1992 at which time the study was terminated, 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.

5.3 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 and VFX studies have been added.

5.4 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.

5.5 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

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.

comprises about 90% of the available data. The two remaining data sets will be loaded by mid-year 1993. 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 mid-year 1993.

A statistical study of sediment-water fluxes was initiated to determine if significant temporal and spatial trends could be detected. In addition, this analysis also included the determination of the statistical power inherent in this study (*i.e.* the estimation of the magnitude of change in flux values needed for statistical significance). This study was conducted in consultation with Professor Larry Douglass, Research Statistician at the University of Maryland, College Park. The results are presented in Chapter 8.

6. 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 sources) 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 full period of time (1984 - 1992) evaluated in this report.

6.1.2 Average Annual River Flows

Annual average river flows for the period 1978 through 1992 are shown in Figure 6-1.1. The fifteen year average (1978 - 1991) flows to each system during this period are indicated by horizontal lines on this figure (James *et al.*, 1990; J. Hornlein, *pers. comm.*). The fifteen year average in the Maryland mainstem bay was 37,736 cubic feet per second (cfs), in the Potomac Estuary 11,652 cubic feet per second, in the Patuxent Estuary 354 cubic feet per second and in the Choptank Estuary 129 cubic feet per second. 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 the fifteen year average in 1978 and 1979, below this average from 1980 to 1982, higher than this average during 1983 and 1984, generally lower than the fifteen year average from 1985 through 1988 and above this average in 1989 (except in the Potomac River in 1989). Flows during 1990, 1991 and 1992 were progressively lower than the fifteen year average in all systems except the Susquehanna which was characterized by values above the fifteen year average in 1990 (48,556 cfs) and lower than this average in 1991 (29,750 cfs) and 1992. Flows from the Potomac River during 1985 through 1992, the period for which EPC Program data are available, were below the fifteen year average as they were in the Susquehanna except in 1989 and 1990 when flows were comparable to the fifteen year average and above this average, respectively. Flows in the Choptank and Patuxent Rivers were well below the fifteen year average except in 1989 when flows were above this value. In 1990, 1991 and 1992 flows in both of these rivers were again below the fifteen year average. In general, river flows have either been near the fifteen year average or below this average value 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.

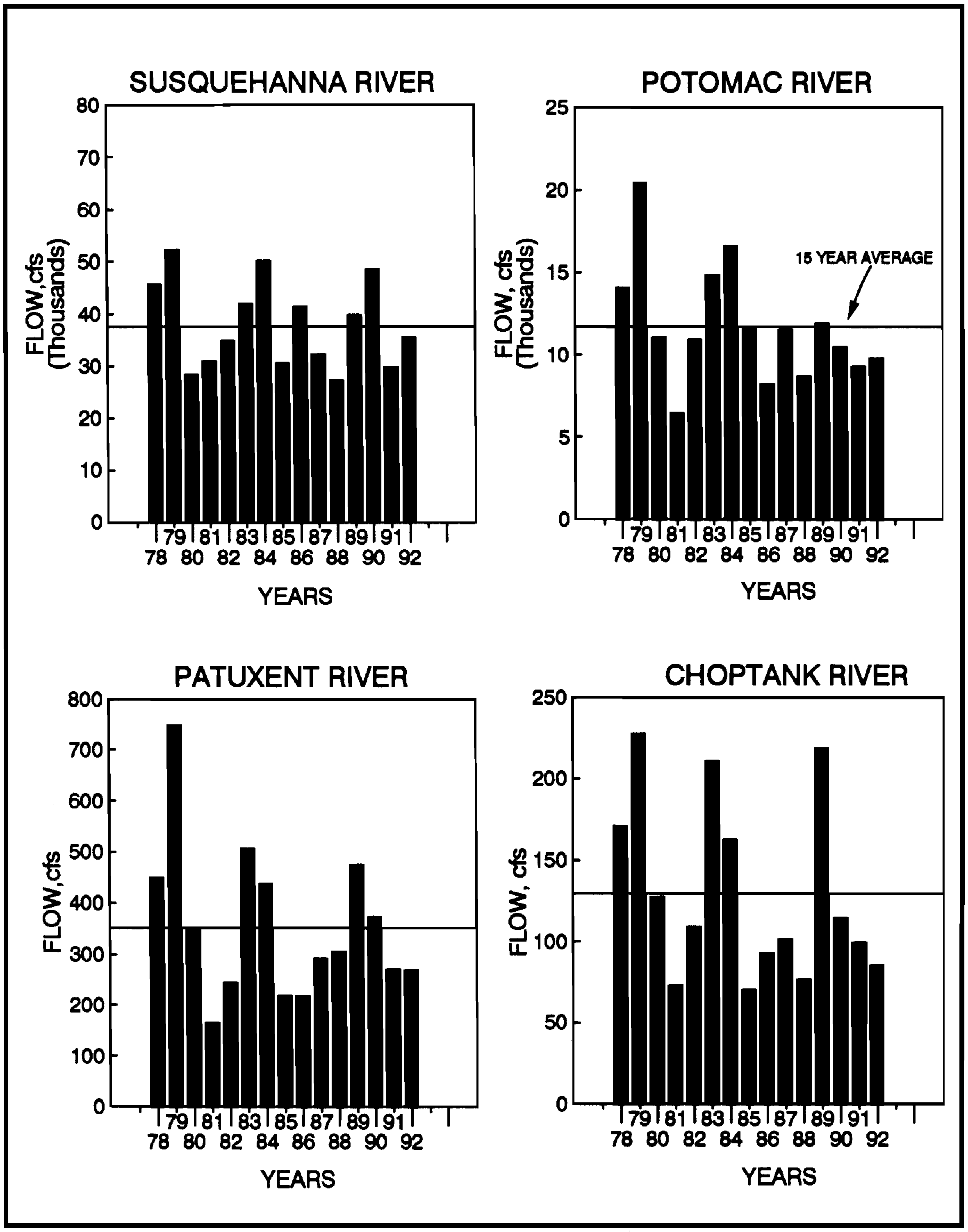


Figure 6-1.1. Bar graphs of average annual river flow from the Susquehanna, Potomac, Patuxent and Choptank Rivers for the period 1978 through 1992 (James *et al.*, 1990; J. Horlein, *pers. comm.*). Flows were measured at Conowingo, MD; Washington, D.C.; Bowie, MD and Greensboro, MD for the four systems, 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 (Figure 6-1.2.). In this figure the vertical bars represent average monthly flows for 1992 while the bold dots represent average monthly flows calculated over longer time periods (1978-1992). The data available for 1992 are incomplete. Not all months are available from the United States Geological Survey (U.S.G.S.) office. In 1992 flows in the Susquehanna and Potomac Rivers were near or below the fifteen year monthly average flow value. The Patuxent and Choptank Rivers exhibited large departures from the fifteen year mean conditions with especially low flows during the winter and spring of 1992.

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 in governing relationships between nutrient loading rates and sediment-water nutrient and oxygen exchange rates in Chesapeake Bay.

6.2 Characteristics of Sediment-Water Oxygen and Nutrient Exchanges

6.2.1. Overview

In this section monthly average 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 ($Si(OH)_4$). Data collected over a period of seven calendar years, 1985 through 1991, were used in the series of five figures (Figures 6-2.1a to 6-2.1e). Each bar represents the mean flux value for a particular month of this seven year period, while the error bar indicates the standard deviation from this mean. Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment. In those cases where the standard error of a monthly mean is large, this almost always indicated that there was considerable inter-annual difference in monthly fluxes rather than that the variability among replicates from any particular measurement was high. Data collected during 1992 (SONE cruises 35 through 40; mean flux value of three replicates) are shown as bold dots superimposed on the bar. The order of the eight stations in these figures reflects their spatial position in the Chesapeake Bay. The four stations on the left side of the figures are located in the Patuxent River from the lower estuary (St. Leonard Creek [STLC]) to the middle regions of the estuary (Broomes Island [BRIS] and Marsh Point [MRPT]) to the turbidity maximum zone (Buena Vista [BUVA]). The right half of the figure shows one station in the lower Choptank River (Horn Point [HNPT]), one in the lower Potomac River (Ragged Point [RGPT]) and two stations in the mainstem bay (Point No Point [PNPT] and R-64 [R-64]). Error bars are not indicated for those months for which only one year of data are available. In this section of the report, seasonal and inter-annual patterns of flux are described and in section 6.3 the factors responsible for these patterns are discussed.

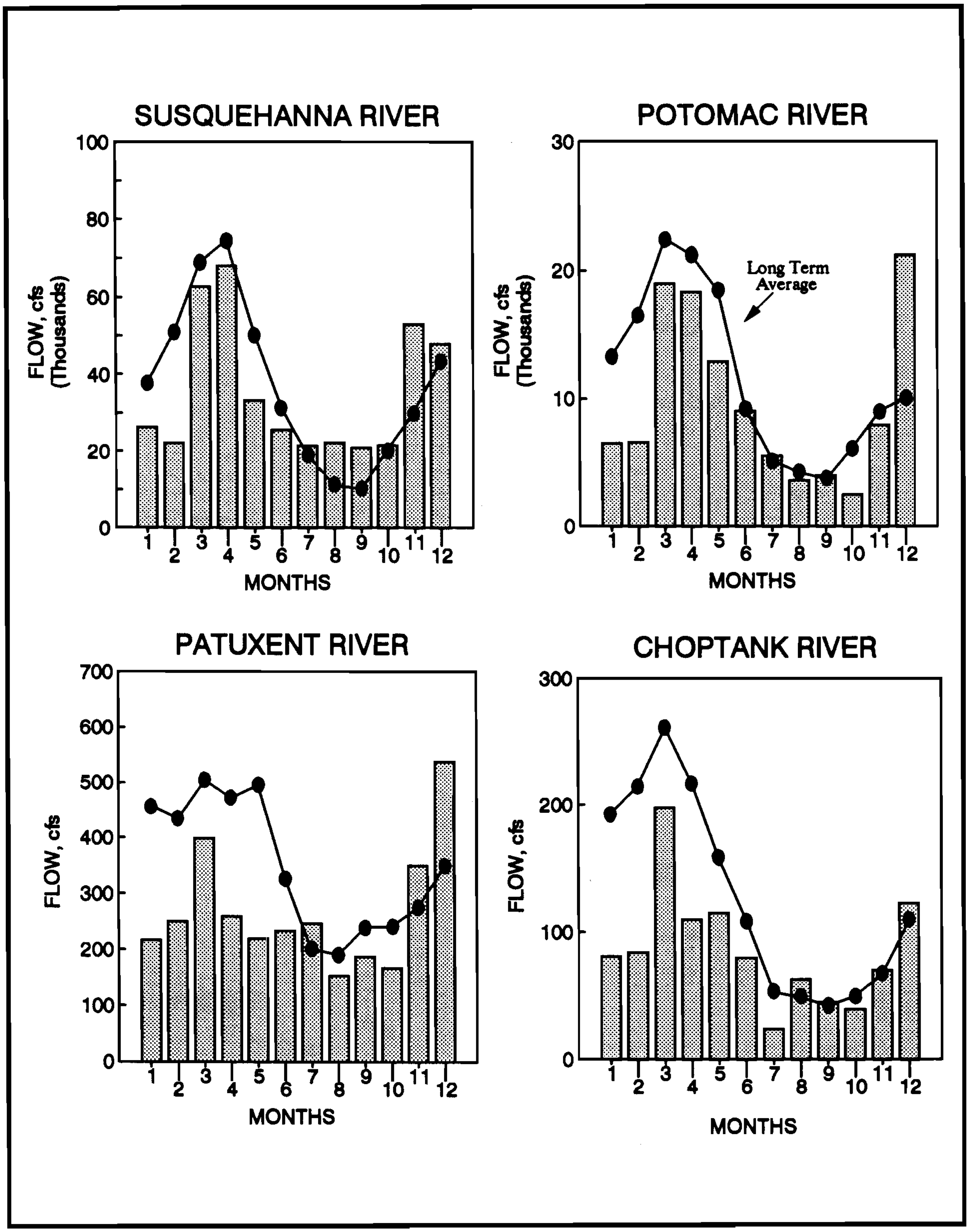


Figure 6-1.2. Bar graphs of average monthly river flow from the Susquehanna, Potomac, Patuxent and Choptank Rivers for 1992. The bold dots indicate long term average monthly flows calculated for the period 1978 through 1992. Flows were measured at Conowingo, MD; Washington, D.C.; Bowie, MD and Greensboro, MD for the four rivers, respectively.

6.2.2 Sediment Oxygen Consumption (SOC)

Mean monthly sediment oxygen consumption (SOC) fluxes ranged from zero (0.0) at Point No Point (PNPT) to -2.6 g O_2 m^{-2} day^{-1} at Buena Vista (BUVA), and were generally higher in the Patuxent and Choptank Rivers than at other sites (Figure 6-2.1a). *Note that: larger negative sediment oxygen consumption (SOC) flux values indicate larger rates of SOC.* In all cases a seasonal pattern was evident with peaks or increased rates of sediment oxygen consumption (SOC) in the springtime (May and June), depressed values in the summer (August) and increased rates in the fall (October). The largest fluxes were recorded in May and June, with a secondary peak recorded in October.

The 1992 data followed the same general pattern as previous years. Fluxes at hypoxic stations (Figure 6-3.1) were not nearly as depressed in July 1992 as was the case in all previous years. This appears to be the direct result of higher than normal oxygen concentrations in deep waters at these sites during July of 1992. In effect, aerobic sediment metabolism (*i.e.*, sediment oxygen consumption [SOC]) persisted longer in 1992 than in previous years because of higher dissolved oxygen (DO) concentrations in these waters. In terms of the goals of the Monitoring Program, these results (particularly in the Patuxent River) may indicate a sediment response to nutrient management. In 1992, river flow to the Patuxent estuary was quite low (Figure 6-1.2) and as a result diffuse source nutrient loads were probably lower than normal. In addition, nitrogen removal was instituted at a major sewage treatment plant (Western Branch; river mile 35 which is upstream of all SONE stations) during fall of 1991. Quantitative estimates of nutrient loads or load reductions are not available for 1992, but it seems clear that loads were reduced compared to other years in the recent past. The conceptual model which has guided EPC Program work indicates that when nutrient loads are reduced the production and deposition of organic matter to sediments also decreases. This in turn leads to lower nutrient release rates and better oxygen conditions in deep water. Results observed in 1992 are consistent with predictions of this conceptual model.

Spring and fall sediment oxygen consumption (SOC) rates at most SONE stations are of sufficient magnitude to constitute a substantial direct dissolved oxygen loss (Kemp and Boynton, 1992). Sediment oxygen consumption (SOC) is not an adequate measure of sediment metabolism during periods of low oxygen conditions which often occur at some SONE stations during summer (August 1992 data at R-64; Figure 6-2.1a). The sediment oxygen consumption (SOC) rates reported here during periods of low oxygen concentrations grossly underestimate sediment metabolism and eventual oxygen demand exerted by reduced sulphur compounds (Roden, 1990). The EPC program is attempting to add a routine measure of anaerobic sediment metabolism to better estimate total sediment oxygen demand (Section 4.1.1.4).

6.2.3 Ammonium Fluxes

Average monthly ammonium fluxes ranged from about 5 μMN m^{-2} hr^{-1} at St Leonard Creek (STLC) to 500 μMN m^{-2} hr^{-1} in the middle Patuxent River (Marsh Point [MRPT]). The high value at Marsh Point (MRPT) is based on one set of measurements taken in September, 1991 and should be considered preliminary. In most cases highest values were recorded in the summer months (July, August or September). Several interesting spatial patterns were also evident (Figure 6-2.1b). 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 which serves as substrate supporting ammonium and other fluxes. In fact, deposition rates measured at six sites along the longitudinal axis of the Patuxent River in the late 1970's indicated a

FACING PAGE 41:

Figure 6-2.1a Mean monthly sediment oxygen consumption (SOC) rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

- Monthly means and standard deviations were calculated using all flux data available for a specific month at each station.
- Station locations are shown in Figure 3-1.
- In general there was one set of triplicate flux values available for each month for 1985 through 1991. Outlier values were only identified later during the statistical testing of SONE data (Chpater 8) and were **NOT** excluded in the calculation of average fluxes and standard deviations.
- Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991.
- September values for all stations only include data from 1991.
- The bold dots indicate average monthly fluxes recorded in 1992.
- Negative values indicate fluxes from water to sediment.

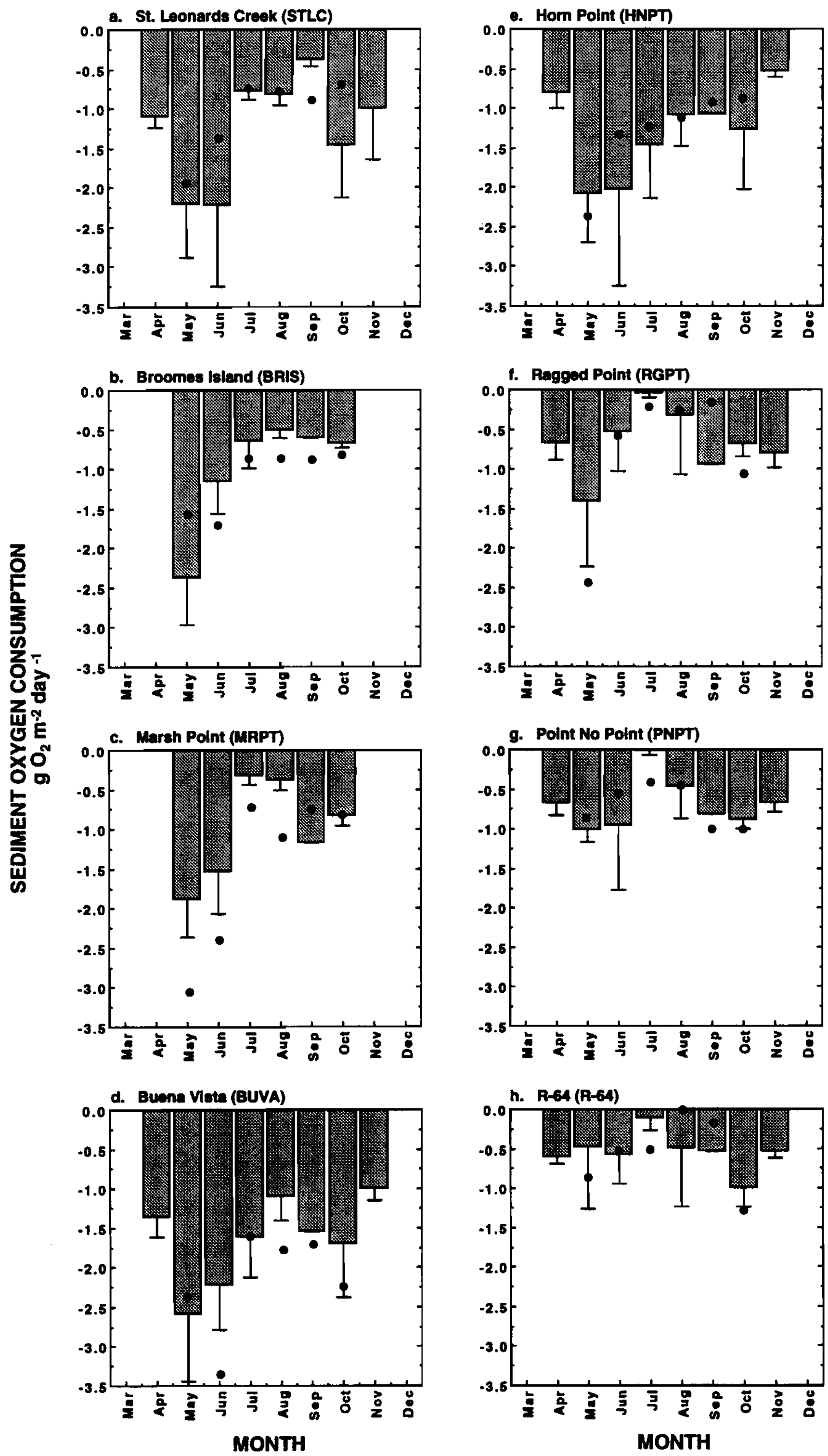


Figure 6-2.1a Mean monthly sediment oxygen consumption (SOC) rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

FACING PAGE 43:

Figure 6-2.1b Mean monthly ammonium (NH_4^+) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

- Monthly means and standard deviations were calculated using all flux data available for a specific month at each station.
- Station locations are shown in Figure 3-1.
- In general there was one set of triplicate flux values available for each month for 1985 through 1991. Outlier values were only identified later during the statistical testing of SONE data (Chpater 8) and were **NOT** excluded in the calculation of average fluxes and standard deviations.
- Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991.
- September values for all stations only include data from 1991.
- The bold dots indicate average monthly fluxes recorded in 1992.
- Positive values indicate fluxes from sediment to water.

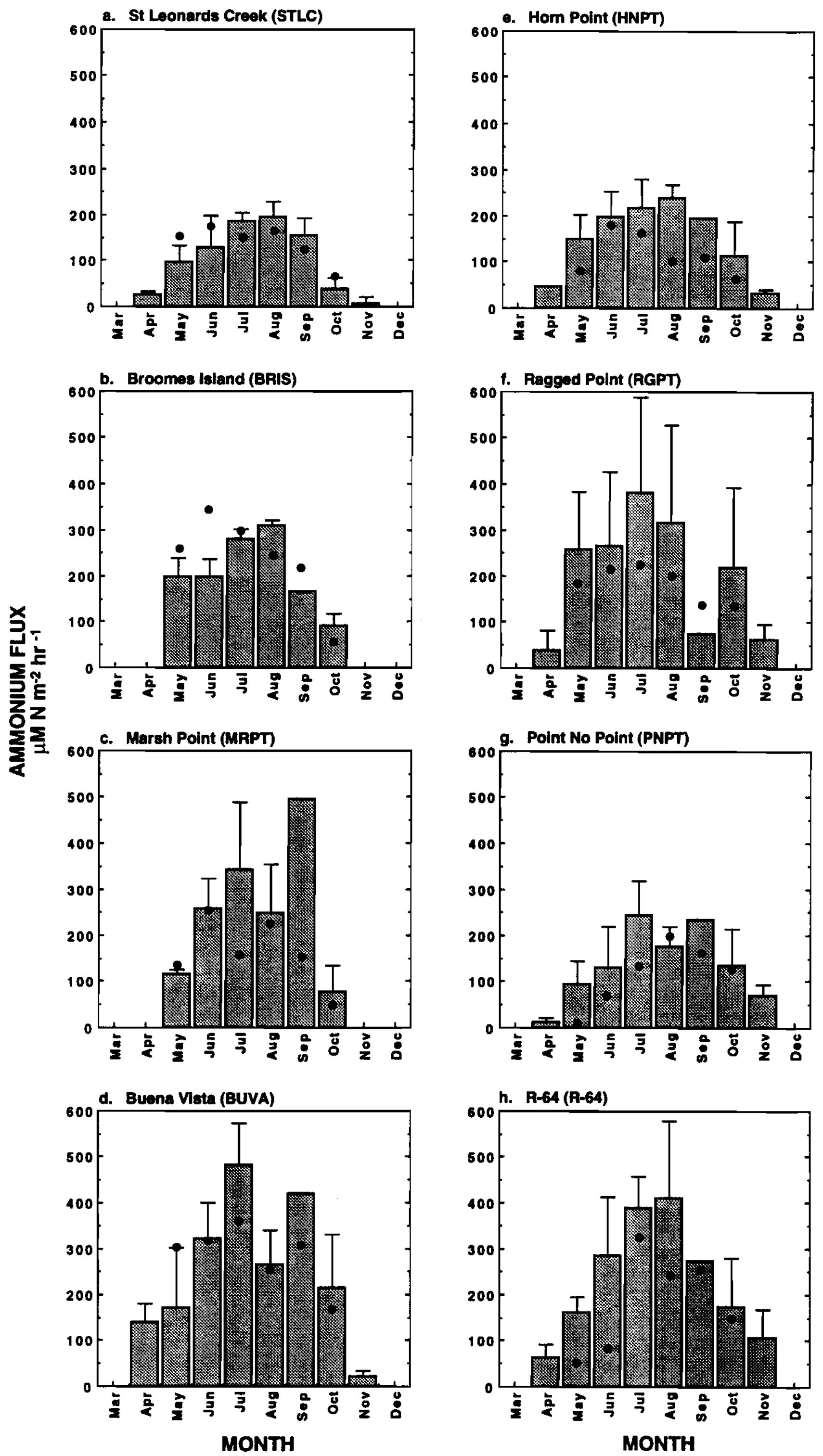


Figure 6-2.1b Mean monthly ammonium (NH_4^+) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

FACING PAGE 45:

Figure 6-2.1c Mean monthly nitrite plus nitrate (NO_2^- + NO_3^-) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

- Monthly means and standard deviations were calculated using all flux data available for a specific month at each station.
- Station locations are shown in Figure 3-1.
- In general there was one set of triplicate flux values available for each month for 1985 through 1991. Outlier values were only identified later during the statistical testing of SONE data (Chpater 8) and were **NOT** excluded in the calculation of average fluxes and standard deviations.
- Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991.
- September values for all stations only include data from 1991.
- The bold dots indicate average monthly fluxes recorded in 1992.
- Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment.

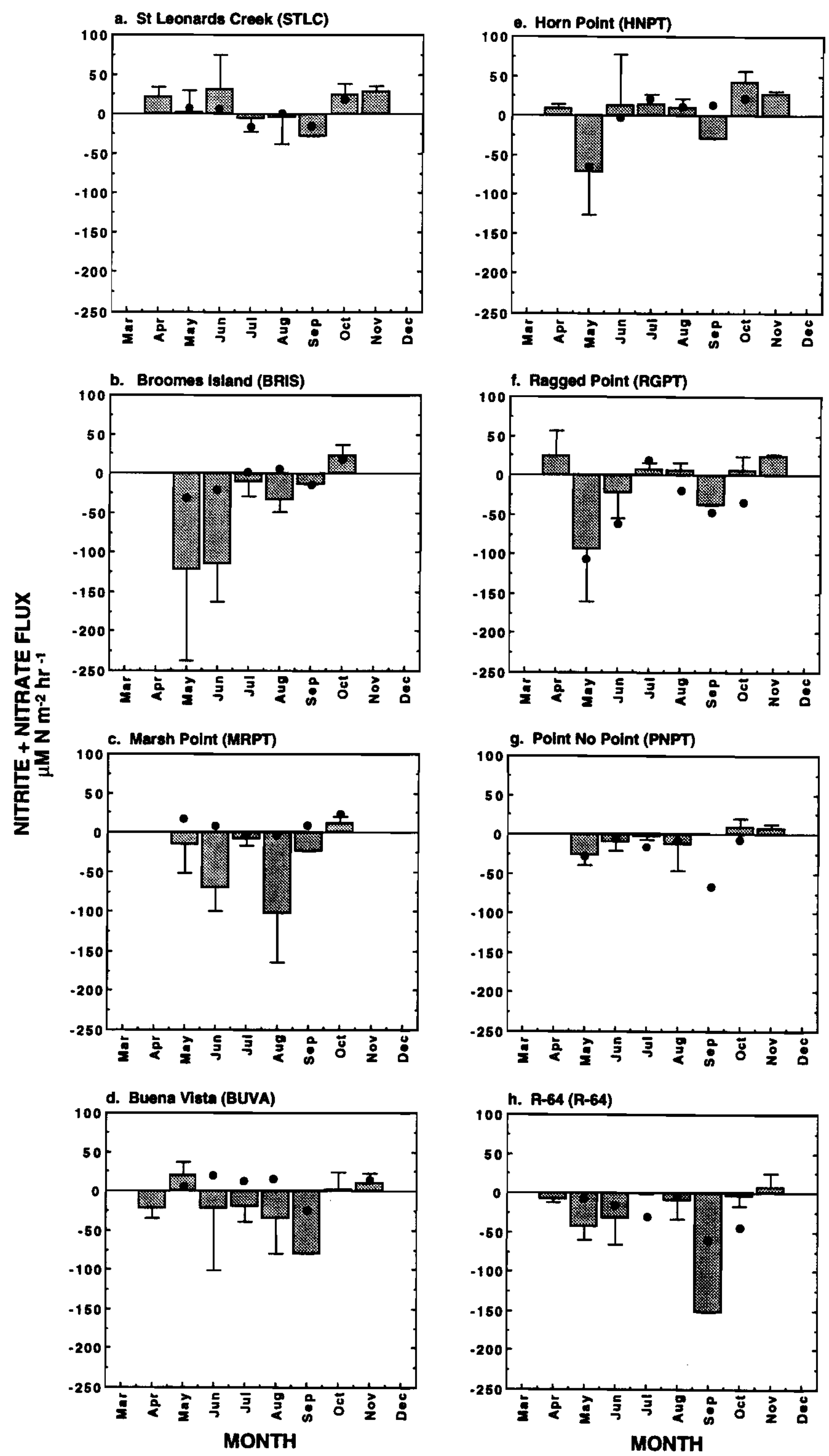


Figure 6-2.1c Mean monthly nitrite plus nitrate (NO_2^- + NO_3^-) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

FACING PAGE 47:

Figure 6-2.1d Mean monthly phosphorus (PO_4^- or DIP) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

- Monthly means and standard deviations were calculated using all flux data available for a specific month at each station.
- Station locations are shown in Figure 3-1.
- In general there was one set of triplicate flux values available for each month for 1985 through 1991. Outlier values were only identified later during the statistical testing of SONE data (Chpater 8) and were **NOT** excluded in the calculation of average fluxes and standard deviations.
- Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991.
- September values for all stations only include data from 1991.
- The bold dots indicate average monthly fluxes recorded in 1992.
- Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment.

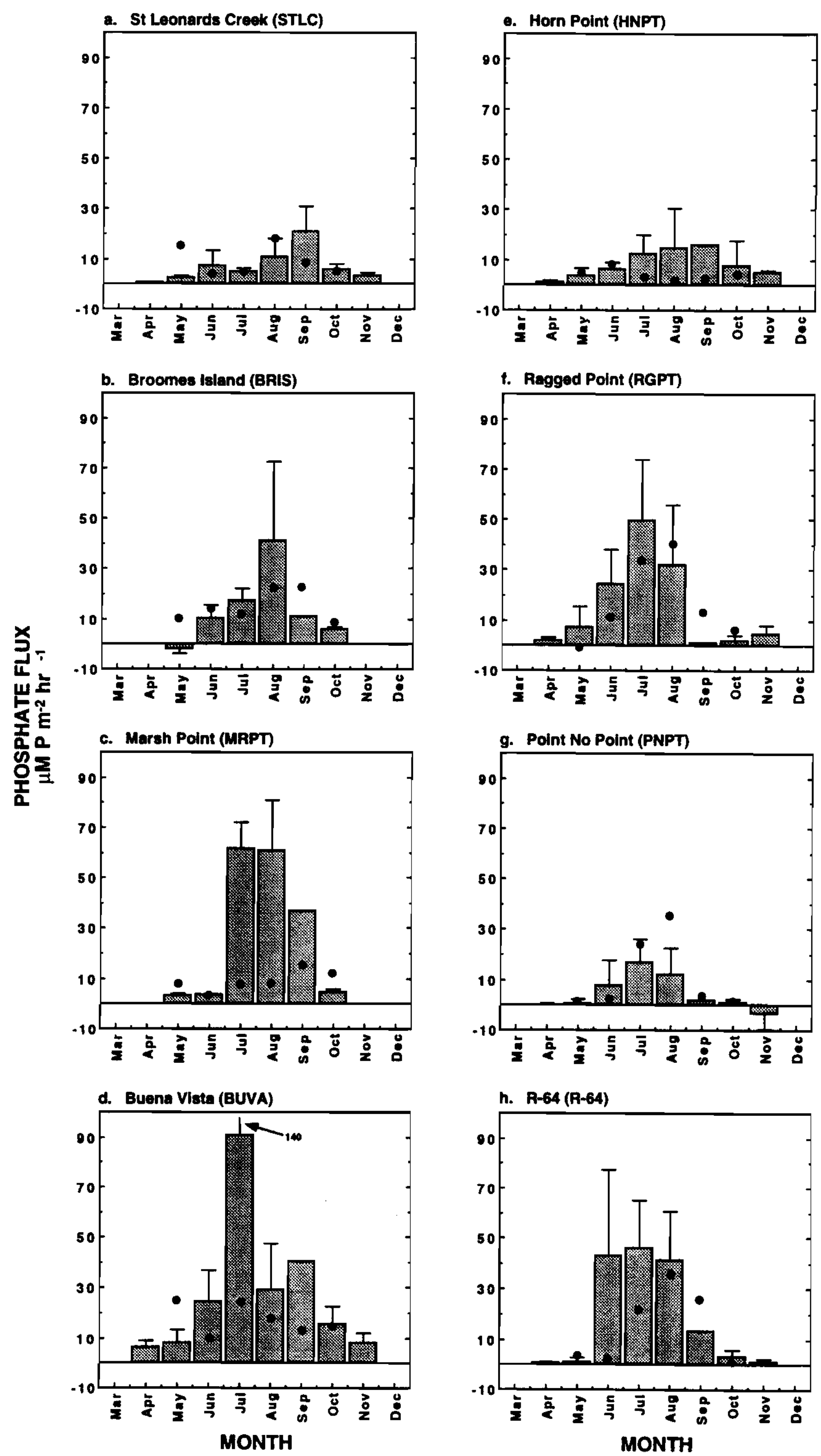


Figure 6-2.1d Mean monthly phosphorus (PO_4^- or DIP) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

FACING PAGE 49:

Figure 6-2.1e Mean monthly silicate ($Si(OH)_4$) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

- Monthly means and standard deviations were calculated using all flux data available for a specific month at each station.
- Station locations are shown in Figure 3-1.
- In general there was one set of triplicate flux values available for each month for 1985 through 1991. Outlier values were only identified later during the statistical testing of SONE data (Chpater 8) and were **NOT** excluded in the calculation of average fluxes and standard deviations.
- Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991.
- September values for all stations only include data from 1991.
- The bold dots indicate average monthly fluxes recorded in 1992.
- Negative values indicate fluxes from water to sediment.

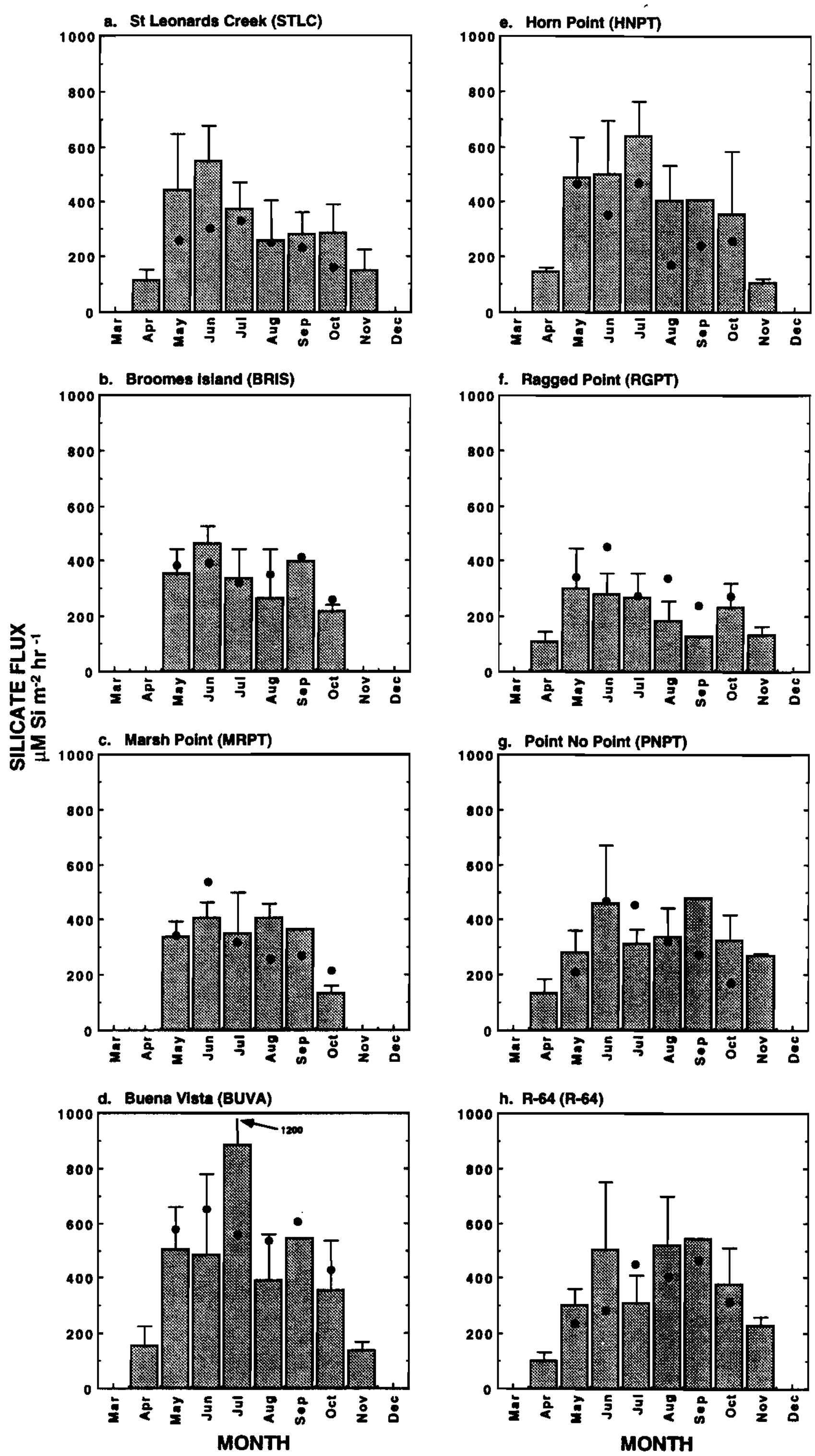


Figure 6-2.1e Mean monthly silicate ($Si(OH)_4$) flux rates (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.

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 a site farther down stream at Point No Point (PNPT) in an area where primary production, chlorophyll-a stocks and presumably deposition rates were considerably lower.

The values recorded in 1992 generally followed temporal trends exhibited in previous years. However at most stations, the magnitude of ammonium (NH_4^+) fluxes were below mean values for several summer months of 1992. The average ammonium (NH_4^+) flux at R-64 in the mainstem bay for 1992 was 118.64 μMN m^{-2} hr^{-1} , 51% of the long term average (232.25 μMN m^{-2} hr^{-1}). Similar but less dramatic reductions were evident at most stations. Several factors may have been responsible for these changes in ammonium (NH_4^+) flux rates during 1992. As indicated earlier, river flows (and diffuse source nutrient loads) were low during 1992 and point source nitrogen loads were reduced in the Patuxent River. This may have had the effect of reducing the amount of organic matter produced (due to nutrient limitation) in the water column and deposited on the sediment surface. Reduced amounts of labile organic matter delivered to sediments would limit the amount of nitrogen potentially available for remineralization. Other factors may have been involved as well. It seems possible that the degree of vertical water column stratification was also reduced during 1992 due to lower river flow. As a result, vertical mixing of oxygen rich surface waters with deeper waters may have occurred to a greater extent than normal. Data from the SONE program indicate this may have been the case at several stations where summer dissolved oxygen (DO) concentrations were higher than normal. With higher than normal oxygen concentrations at the sediment surface, nitrification of ammonium (NH_4^+) could take place, effectively reducing even more that amount of nitrogen available as ammonium (NH_4^+) for transport across the sediment-water interface. If this was the case, this is a signal of improving water and sediment quality conditions.

Recently, a series of laboratory experiments was completed in which intact sediment cores (identical to SONE cores) were treated with fresh organic matter (cultured diatoms) at rates equivalent to about one half of the deposition associated with an average spring bloom in the Maryland mainstem bay. Identical cores, which served as controls, were also incubated in this experiment but not treated with fresh organic matter (Jasinski *et al.*, *pers. comm.*). These experimental systems were maintained under well oxygenated conditions for a period of 30 days during which oxygen and nutrient exchanges across the sediment-water interface were monitored. The clearest signals observed were that in treated cores (versus control cores) sediment oxygen consumption (SOC) rates were elevated, nitrate uptake by sediments was large and fluxes of ammonium and phosphate were low, despite significant organic matter loading. These results indicate that nitrification (coupled to denitrification) was occurring in sediments and that phosphate was being sequestered, probably as oxy-hydroxides associated with iron. It appears that relatively small and persistent increases in oxygen concentrations at the sediment-water interface can have important influences on the magnitude and characteristics of sediment fluxes (Kemp and Boynton, 1992).

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

Average nitrite plus nitrate fluxes ranged between 42.25 μMN m^{-2} hr^{-1} at Horn Point (HNPT) and -151.34 μMN m^{-2} hr^{-1} at R-64 (Figure 6-2.1c). Positive values indicate fluxes from sediments to water while negative values indicate fluxes from water to sediment. In general the range of nitrite plus nitrate fluxes (either into or out of sediments) found at the two mainstem bay stations was narrower ranging between 5 and -75 μMN m^{-2} hr^{-1}, while a wider flux range was found at tributary sites, varying between 48 and -125 μMN m^{-2} hr^{-1}. With a few exceptions (*e.g.*, Broomes Island [BRIS] in May and June, 1991; R-64 in

September, 1991), NO_2^- + NO_3^- fluxes in either direction (into or out of sediments) were small compared to NH_4^+ fluxes. At many stations nitrite plus nitrate fluxes recorded during 1992 departed from previous trends. For example, two stations in the Patuxent River, Marsh Point (MRPT) and Buena Vista (BUVA), had nitrate plus nitrite (NO_2^- + NO_3^-) fluxes which were generally more positive in some months than in previous years. It is suspected that reduced nutrient loading rates in 1992 (due to point source nutrient load reductions and lower than normal diffuse source nutrient load) and subsequent reduced deposition of organic matter to the sediment surface was the cause. Under conditions of reduced diffuse source loading, nitrate plus nitrite (NO_2^- + NO_3^-) fluxes from water to sediments would be reduced because nitrate plus nitrite (NO_2^- + NO_3^-) concentrations in bottom waters would be reduced. It has been shown that nitrate plus nitrite (NO_2^- + NO_3^-) fluxes from water to sediments were proportional to nitrate plus nitrite (NO_2^- + NO_3^-) concentrations in overlying waters (Boynton *et al.*, 1990). In addition, when organic matter deposition rates are sufficiently reduced so that hypoxic conditions do not occur in deep waters, nitrification of ammonium can occur and at times nitrate plus nitrite (NO_2^- + NO_3^-) escapes from sediments and is recorded as a flux from sediments to overlying waters. While nitrate plus nitrite (NO_2^- + NO_3^-) was not released from sediments at all stations (*e.g.*, Ragged Point [RGPT]), there were more instances of this occurring in 1992 than in the past several years and this is an indication of improved water and sediment quality conditions.

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

The overwhelming trend indicated a net flux of dissolved inorganic phosphorus (PO_4^-) from sediments to the overlying waters (Figure 6-2.1d). During the course of the EPC Program monitoring, average monthly values ranged from -3.53 μMP m^{-2} hr^{-1} at Point No Point [PNPT] to 90.52 μMP m^{-2} hr^{-1} at Buena Vista (BUVA). 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. It has been suggested that the high PO_4^- fluxes observed at Buena Vista (BUVA) were caused, at least in part, by the burrowing and irrigation activities of the large benthic macrofaunal community present at this location rather than iron-sulphur (Fe-S) reactions which are probably responsible for high fluxes elsewhere under low dissolved oxygen conditions (Krom and Berner, 1980).

Data collected during 1992 generally followed well established temporal trends with highest fluxes occurring during summer months (June-September). However, at most stations there was a marked reduction in the magnitude of PO_4^- fluxes. Fluxes at R-64 during 1992 were only about 40% of the seven year (1985-1991) mean. Similar reductions were observed at all other stations except in the lower Patuxent River (St Leonard Creek [STLC]) upstream of other stations. The slightly enhanced oxygen conditions (Figure 6-3.1) and more positive sediment Eh values (Figure 6-3.3.) generally existing during summer of 1992 were probably responsible for these reduced fluxes. Under oxidized conditions PO_4^- can form insoluble iron-manganese phosphate complexes or sorb to oxy-hydroxides (Krom and Berner, 1980). Both of these processes would effectively reduce sediment-water exchanges. In any case, PO_4^- fluxes were lower in 1992 than in the preceding several years. The rapid decrease in fluxes during 1992 further suggests that sediment-water exchanges are responsive to changes in water quality conditions on seasonal-annual time scales rather than to longer time scales (Boynton *et al.*, 1991).

6.2.6 Dissolved Silicate Fluxes

Monthly average silicate fluxes ranged between 102.28 μMSi m^{-2} hr^{-1} at R-64 and 883.57 μMSi m^{-2} hr^{-1} at Buena Vista (BUVA)(Figure 6-2.1e) during the course of the EPC

Program monitoring. 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 at most stations. For example, while such flux variables as NH_4^+ and PO_4^- exhibited higher values during the summer, this was not consistently true for silicate even though at times values for the months of June or July were slightly higher than in adjacent months, May and August.

The 1992 data were similar to the long-term seven year (1985-1991) average at some stations (Broomes Island [BRIS] and R-64 [R-64]), generally lower than this average at St Leonard Creek (STLC), Point No Point (PNPT), and Horn Point (HNPT), but higher during some months at two stations, Buena Vista [BUVA] and Ragged Point[RGPT].

6.3 Sediment-water Fluxes and *in situ* Environmental Conditions

6.3.1 Overview and Approach

In this section the observed magnitude of sediment-water exchanges is examined for relationships to *in situ* environmental conditions as a step towards building better understanding of factors regulating these fluxes. In earlier reports (Boynton *et al.*, 1987) results of extensive correlation analyses were reported. While a number of significant correlations were found between specific sediment-water fluxes (*e.g.*, PO_4^- fluxes) and environmental variables (*e.g.*, bottom water dissolved oxygen levels, or sediment characteristics), the r^2 values were generally low indicating non significant relationships and a lack of predictive power. These earlier evaluations were primarily used to establish which of the suspected relationships or trends were worth continued investigation.

There were some interesting changes in the magnitude of sediment-water exchanges observed during 1992 (Section 6.2). In order to explore the possible reasons for these changes environmental data collected in the EPC Program between 1985 and 1991 were organized and compared with data collected during 1992.

6.3.2 Bottom Water and Sediment Conditions

During 1992 river flows to all of the portions of the Maryland bay which are monitored in the Chesapeake Bay Program were lower than the long term fifteen year average (Figure 6-1.1). River flow, as an index of above fall line nutrient loading rates (Summers, 1989), indicates that loading during 1992 was also lower than normal. In addition in the Patuxent River point source nitrogen loads were further reduced because of sewage treatment operations at Western Branch Sewage Treatment Plant, river mile 35, upstream of all SONE stations. The conceptual model used to guide the EPC Program indicates that nutrient loading stimulates phytoplankton production which leads to deposition of organic matter to deep waters and sediments. As this material decomposes, oxygen is consumed and nutrients are released from sediments, stimulating further phytoplanktonic production of organic matter and continued low dissolved oxygen conditions. In this scenario, all of these events are ultimately tied to nutrient loading rates and hence reduction in loading rates is of key importance in improving water and sediment quality conditions.

This scenario is the basis for testing the hypothesis that during 1992 dissolved oxygen concentrations in deep waters should be somewhat elevated, chlorophyll-a mass in surficial sediments reduced and sediment Eh values more positive. The seven year average (1985-

1991) monthly bottom water dissolved oxygen concentrations at each SONE station are shown as a series of bar graphs in Figure 6-3.1 and data from 1992 are superimposed as bold dots. In two of the tributary rivers, Patuxent and Choptank Rivers, dissolved oxygen concentrations were slightly higher than this average value in 1992. Of particular importance was the slightly elevated concentrations during the summer months, June through August. The elevation in dissolved oxygen concentrations were not as evident in the mainstem bay and lower Potomac River, but even at these sites concentrations were higher than normal during May and June and hypoxic conditions were not as severe later in summer as in most years. These conditions are consistent with the lower sediment nutrient releases observed during 1992 at SONE stations. The mechanisms responsible most probably involved conversion of ammonium to nitrate (nitrification) and the trapping of phosphate in insoluble forms in more oxidized sediments.

Both the Potomac and Patuxent River flows for January through March 1992 were about 60% of the average, but the Patuxent River exhibited a greater elevation of summer dissolved oxygen (DO) relative to the average than did the Potomac River. The difference in summer dissolved oxygen (DO) values (relative to average values) could be attributed to the change in nitrogen point source loading in the Patuxent River due to improvements at Western Branch Sewage Treatment Plant, river mile 35, upstream of all SONE stations.

Surficial sediment total chlorophyll-a mass is shown for all SONE stations in Figure 6-3.2. The expected reduction due to lower levels of algal biomass accumulation and deposition at reduced nutrient loading rates, was less consistent than that observed for dissolved oxygen but there were still some changes observed during 1992. In the Patuxent River (Figure 6-3.2a-d) there was a marked reduction in sediment chlorophyll-a values at several stations during summer and fall. A similar pattern was observed in the Lower Choptank and Potomac Rivers. For some unknown reason there were some very high values observed in the mainstem bay during late summer and fall of 1992 (Figure 6-3.2h) although this index of labile sediment organic matter did not lead to high rates of sediment nutrient releases during fall 1992 (Figure 6-2.1a and b).

Sediment Eh values measured at the sediment-water interface at all SONE stations are shown as a series of bar graphs in Figure 6-3.3. There is considerable scatter among 1992 values, but there are instances in which Eh was more positive (or less negative) in 1992 than the long term seven year (1985-1991) average. In the Patuxent River values were elevated (or less negative) at most stations during July and August. The single negative value (-212 mV) at Marsh Point (MRPT) in September remains without a simple explanation. Likewise, Eh values in the mainstem (R-64 and PNPT) were elevated during spring and early summer and again in fall. These more positive Eh values result from the aerobic nature of sediments and the consequent reduction in the amount of chemically reduced compounds (*e.g.*, solid phase sulfur) accumulating in sediments. Under these conditions, nitrification (probably coupled to denitrification in deeper anaerobic sediments) and sequestering of phosphorus in insoluble phases are probably active and responsible for the reduced fluxes of NH_4^+ and PO_4^- seen at many SONE sites during 1992.

6.3.3. Inter-annual Regulation of Sediment-Water Nutrient Exchanges

Seasonal variation in the magnitude of sediment-water nutrient and oxygen fluxes is modified by such factors as temperature, benthic infaunal activity, and nitrification/denitrification rates, but is ultimately controlled by the magnitude of labile organic matter deposition to the sediment surface (Kelly and Nixon 1984; Jensen *et al.*, 1990). It is also thought that differences in the amount and quality of labile organic deposition between sites determines the spatial variability observed in fluxes.

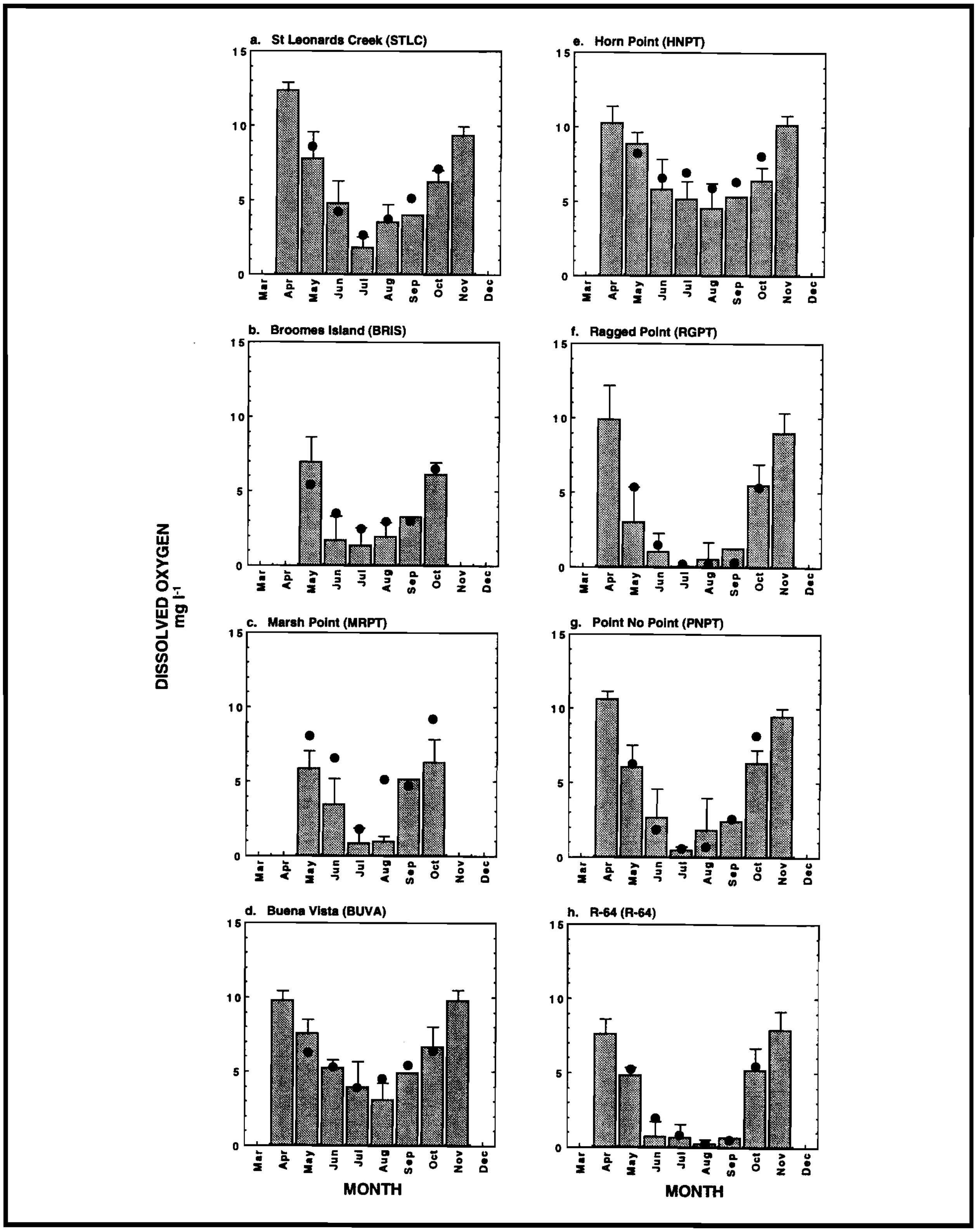


Figure 6-3.1 Monthly bottom water dissolved oxygen concentrations (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.
Monthly means and standard deviations were calculated using all data available for a specific month at each station. In general there was one value available for each month for 1985 through 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991. The bold dots indicate average monthly values for 1992. Station locations are shown in Figure 3-1.

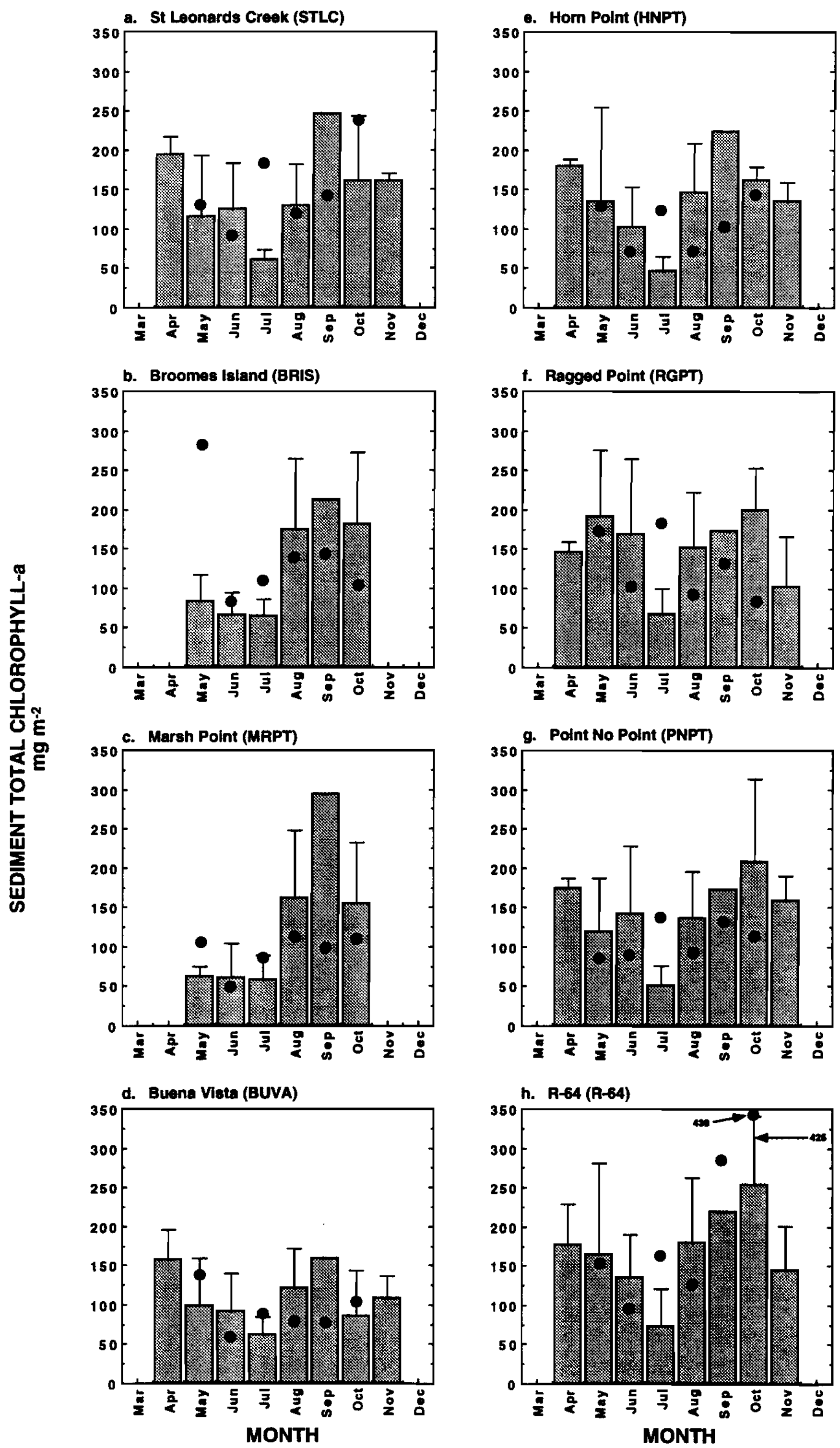


Figure 6-3.2 Monthly sediment total chlorophyll-a concentrations (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.
Monthly means and standard deviations were calculated using all data available for a specific month at each station. In general there was one value available for each month for 1985 through 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991. The bold dots indicate average monthly values for 1992. Station locations are shown in Figure 3-1.

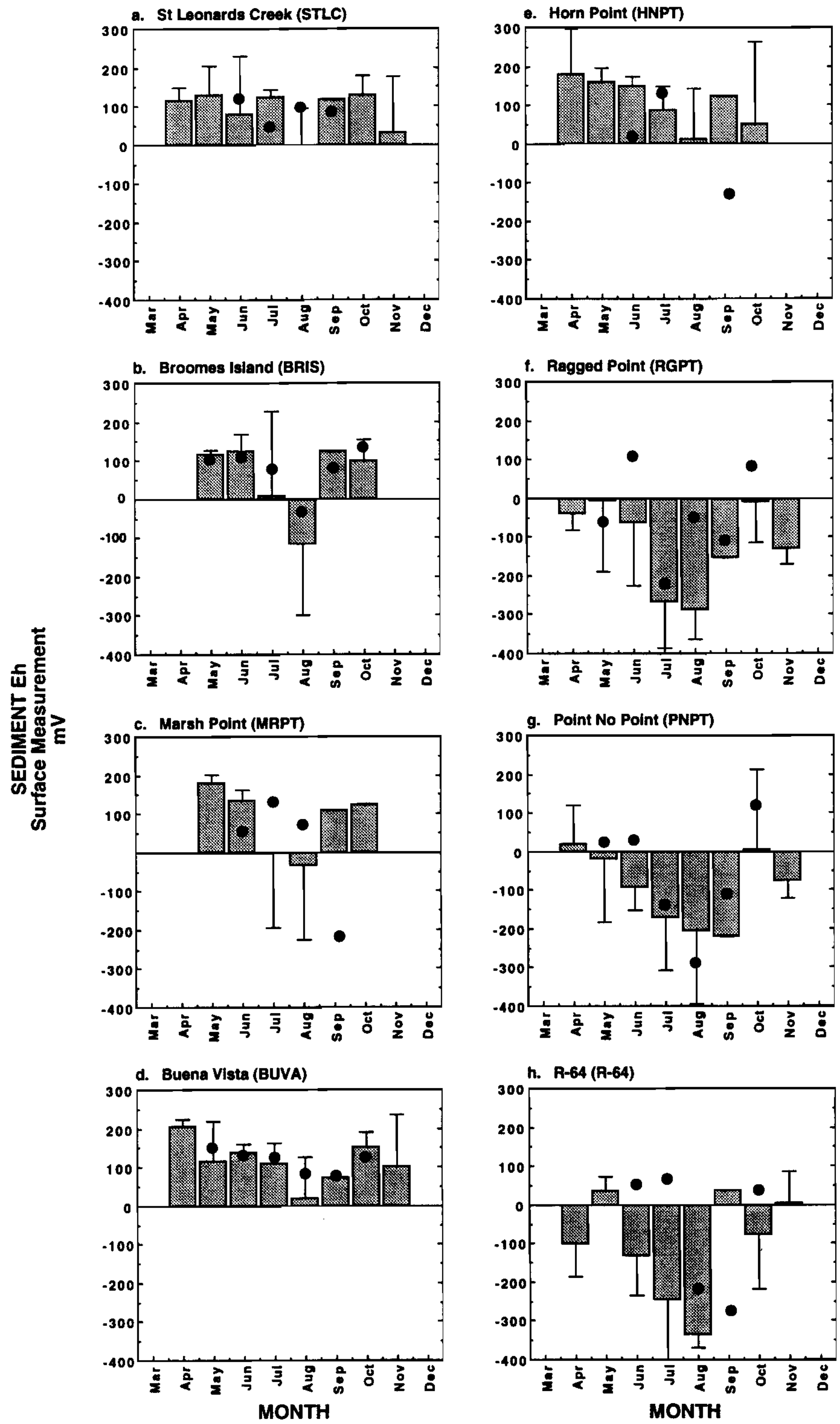


Figure 6-3.3 Monthly surficial (sediment-water interface, sediment depth = 0 cm) sediment Eh values (April to November) at eight SONE stations located in the Maryland portion of Chesapeake Bay.
Monthly means and standard deviations were calculated using all data available for a specific month at each station. In general there was one value available for each month for 1985 through 1991. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 1991. The bold dots indicate average monthly values for 1992. Station locations are shown in Figure 3-1.

The differences in rates of organic matter deposition that determine spatial and seasonal variability in any one year also The differences in rates of organic matter deposition that determine spatial and seasonal variability in any one year also determine the inter-annual variability in the magnitude of sediment nutrient and oxygen (SONE) fluxes. During the course of the Chesapeake Bay monitoring program large inter-annual differences in nutrient loading rates (Summers, 1989) and algal biomass accumulation have been noted (Magnien *et al.*, 1990). Large differences in organic matter deposition rates to sediments have also been observed at one location, station R-64, in the mainstem bay.

The spring bloom event generally supplies the largest amount of organic material to the sediment surface during any one year (Boynton *et al.*, 1990). The bloom occurs when temperatures are low and water column microbial activity and zooplankton populations are reduced, so relatively little phytoplanktonic material is recycled within the water column. In addition, the spring bloom population is largely composed of diatoms that sink quickly once dead, while summer blooms are largely composed of dinoflagellates that sink slowly and so have a greater chance of being consumed in the water column before reaching the sediments (Smith, 1992). Finally, the summer pycnocline may be strong enough to prevent sinking of lighter particulates to deep waters and sediments.

There may be an opportunity to investigate inter-annual variation in sediment-water nutrient exchanges by comparing annual nutrient fluxes in different areas of the bay with some index of organic matter supply to sediments. The EPC Program routinely monitors total chlorophyll-a in surficial sediments during SONE cruises. In addition, another program (the Land Margin Ecosystem Research Program funded in Chesapeake Bay by the National Science Foundation (NSF) also measured sediment chlorophyll-a concentrations and nutrient fluxes at several locations in the bay with special emphasis during the spring bloom period of the year. These data bases have been combined and a search for relationships between organic matter supply and sediment-water nutrient exchanges was initiated.

Initially, direct correlations between a specific nutrient flux and sediment chlorophyll-a measurement at a station or group of stations for a season or series of years was completed. While a few significant correlations emerged, most either lacked predictive power or were statistically non-significant. Accordingly, sediment chlorophyll-a data were averaged at each site for which data were available over the spring-early summer period (days 80 - 220). Nutrient fluxes were averaged for each site and year for a shorter period of the year that encompassed the period when large nutrient fluxes occurred (days 120 - 220). Altogether, there were three sites and four different years for which adequate data were available. Results of regression analyses where sediment chlorophyll-a mass was used to predict sediment-water nutrient fluxes is shown in Figure 6-4. The key to the success of these analyses was the lag of one month when averaging the chlorophyll-a and flux data. This temporal lag accounts for slower microbial degradation of the deposited spring bloom material in the colder months during and immediately following the spring bloom. These analyses indicate that it is the spring bloom deposition which supports nutrient fluxes later in the year. Similar analyses using particulate carbon (PC) or particulate nitrogen (PN) as the independent variables produced similar results although not as statistically significant. Results were not statistically significant using sediment particulate phosphorus (PP) as the independent variable.

The lack of significant particulate phosphorus (PP) relationships does not necessarily indicate that phosphorus is unimportant in regulating spring phytoplankton blooms in the bay. The particulate phosphorus (PP) measurements available in the monitoring program include both particulate inorganic as well as particulate organic phosphorus compounds. Recent analysis of sediment particulate phosphorus (PP) indicate that most of the sediment particulate phosphorus (PP) is inorganic and possibly not related in any direct way to phytoplankton dynamics and organic matter deposition (C.W. Keefe, *pers. comm.*). It is conceivable that flux versus sediment particulate phosphorus (PP) concentrations would be significant if organic particulate phosphorus (PP) data were available.

These results suggest a strong case for organic matter deposition as the "master" variable regulating sediment-water nutrient exchanges along the mainstem of the bay on an annual basis. The possibility of making routine early spring measurements of sediment chlorophyll-a at all or some SONE stations is worth careful consideration. These data could then be compared to sediment-water nutrient and oxygen fluxes during the warmer periods of the year at SONE stations. If similar relationships emerge, a more quantitative assessment of organic matter loading-sediment nutrient release rates at all SONE stations could be determined. Ultimately, measurements of surficial sediment total chlorophyll-a might be used as a simple and inexpensive monitoring tool which could also be used to provide far better spatial coverage than direct measurements of nutrient fluxes.

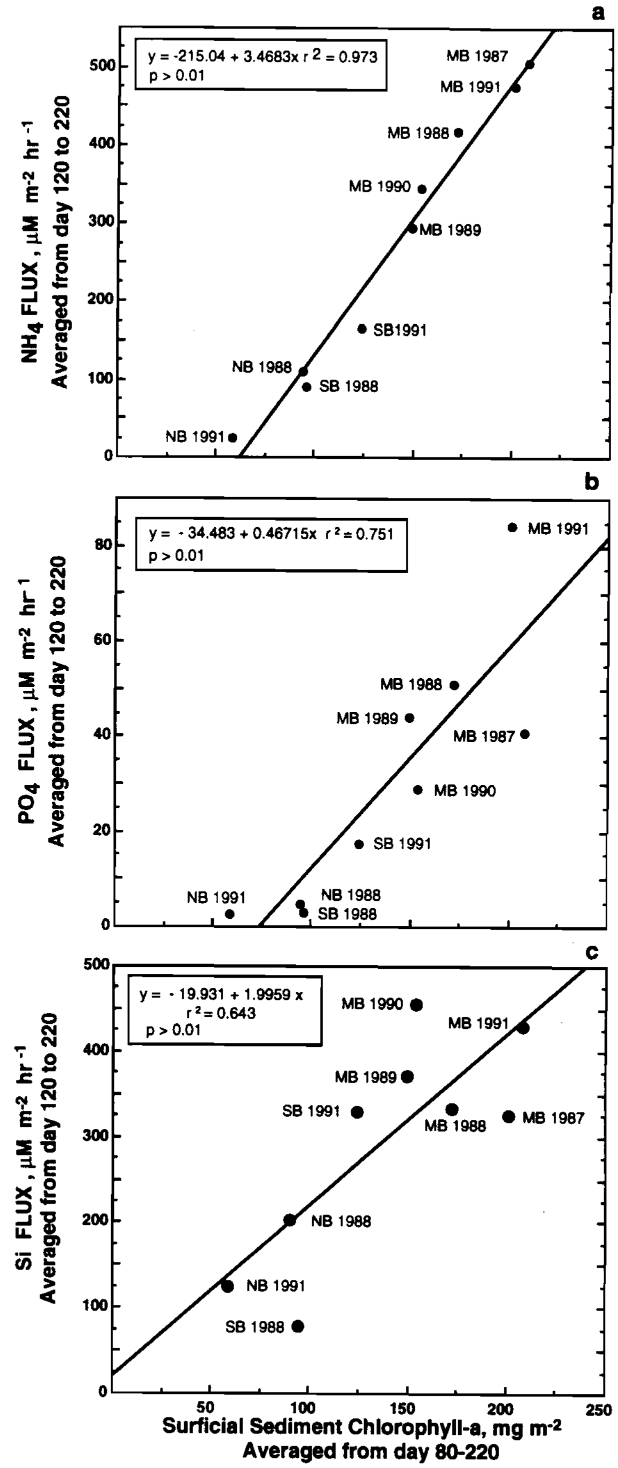


Figure 6-4. Scatter plots of surficial sediment total chlorophyll-a mass versus NH_4^+, PO_4^- and Si fluxes at three locations along the longitudinal axis of Chesapeake Bay.
Surficial sediment chlorophyll-a data at each station were averaged between day 80-220 for each year of measurement. Sediment nutrient fluxes measured at each station were averaged between days 120-220 for each year of measurement. Station designations and locations are as follow: NB = North Bay (located at the earlier SONE site at Still Pond [SLPD]); MB = Mid Bay (located at SONE station R-64); SB = South Bay (located adjacent to York Spit near the mouth of the York River, VA).

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. The first is that the upper bounds of algal biomass levels 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 and that these processes have quantitative impacts on the water column.

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 occurs 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 rate 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. This indicates 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, Level One, Number 9 (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 spring period of 1992 at station R-64 in the mainstem bay follows. Deposition patterns for the entire period of monitoring (1985-1992) are also presented, as are the results of regression analyses relating organic matter deposition rates to nutrient loading rates. Routine monitoring of organic matter deposition at R-64 was discontinued after June 3, 1992 due to budgetary limitations. However, a modified deposition monitoring program is scheduled for the spring of 1993 supported by Maryland Sea Grant Funds.

7.2 Particulate Carbon and Total Chlorophyll-a Concentrations at R-64, 1992

Particulate organic carbon and total chlorophyll-a concentrations were measured in surface and mid-depth waters at station R-64 during the first six months of 1992 (Figure 7-1.). Particulate carbon concentrations ranged from 0.55 to 1.25 mg l^{-1} in surface waters and from 0.38 to 1.42 mg l^{-1} in mid-depth waters. Except for the last three sampling periods there was good correspondence in temporal concentration patterns between surface and mid-depth samples. Some large differences in the magnitude of concentrations and the degree to which these changed over time were also recorded. Both surface and mid-depth samples showed a spike in concentration on day 75 but the magnitude of the spike was much greater in mid-depth than surface samples, while on day 140 the larger spike occurred in surface samples. These spikes and the lack of correspondence between surface and mid-depth samples probably resulted from sampling of various phases of the spring algal bloom.

Total chlorophyll-a concentrations ranged from 4 to 15 $\mu g\ l^{-1}$ and 2 to 13 $\mu g\ l^{-1}$ in surface and mid-depth samples, respectively (Figure 7-1.). From day 30 through 70, there was a noticeable correspondence in concentration patterns at surface and mid-depth samples. After this time, correspondence was not as pronounced with both surface and mid-depth concentrations alternating being higher than the other. In general chlorophyll-a concentrations were much lower (2x) than in other years (Boynton *et al.*, 1990).

7.3 Particulate Carbon and Total Chlorophyll-a Deposition Rates, 1992

Particulate carbon and total chlorophyll-a deposition rates measured during the spring of 1992 from surface and mid-depth collecting cups (deployed at depths of 5 and 9 meters from the surface) are shown in Figure 7-2. These deposition rates have not been corrected for resuspension effects. However, total chlorophyll-a is not particularly prone to interference from resuspension because of the naturally rapid decay of this compound.

Particulate carbon deposition rates ranged from 500 to 1700 and from 750 to 3800 mg C m^{-2} day^{-1} in surface and mid-depth collections, respectively. There were two unusual features of particulate carbon deposition rates during spring of 1992. First, there was one very large deposition event at the beginning of February, 3754 mg C m^{-2} day^{-1}. In fact, this was the highest winter rate observed to date and the single highest rate observed in surface and mid-water collections since 1985. Deposition rates in surface waters were lower than during most years for the rest of the spring and there was little indication of deposition of the spring bloom typical of this season (Figure 7-3.1.). Mid-water collections were somewhat higher than surface water collections as expected because of the larger water column above these cups. There was another burst in deposition around day 90 in the mid-depth cups which was almost as intense as the early peak in February. The event did not occur in the surface cups and there was no indication of a similar peak in the chlorophyll-a collections which suggests that the day 90 peak was the result of a local resuspension-deposition event.

Total chlorophyll-a deposition rates exhibited the same peak in mid-depth cup values, 22.85 mg m^{-2} day^{-1}, as did particulate carbon collections in February. Following this event, deposition rates at both surface and mid-depths were low (relative to most other years) and fairly constant for the rest of the spring period (Figure 7-3.2.).

7.4 Particulate Carbon and Total Chlorophyll-a Deposition Rates, 1985-1992

The complete data set of deposition rate measurements for particulate carbon, total chlorophyll-a and "calculated" particulate carbon for the period March, 1985 through June, 1992 are presented as a series of bar graphs (Figure 7-3.1 - 7-3.3). In these figures 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 particles. Zero (0.0) values (or the

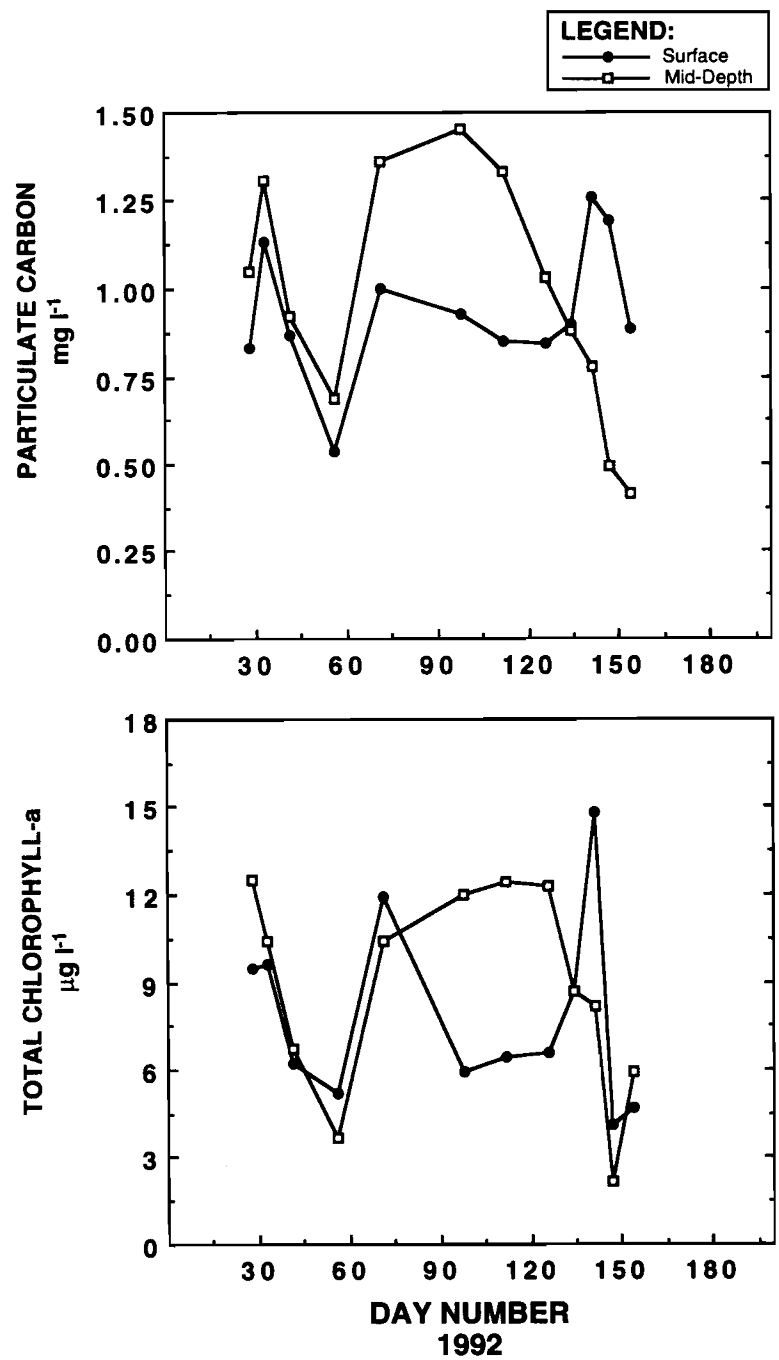


Figure 7-1. Plots of surface and mid-depth concentrations of particulate organic carbon and total chlorophyll-a from station R-64 collected during 1992.

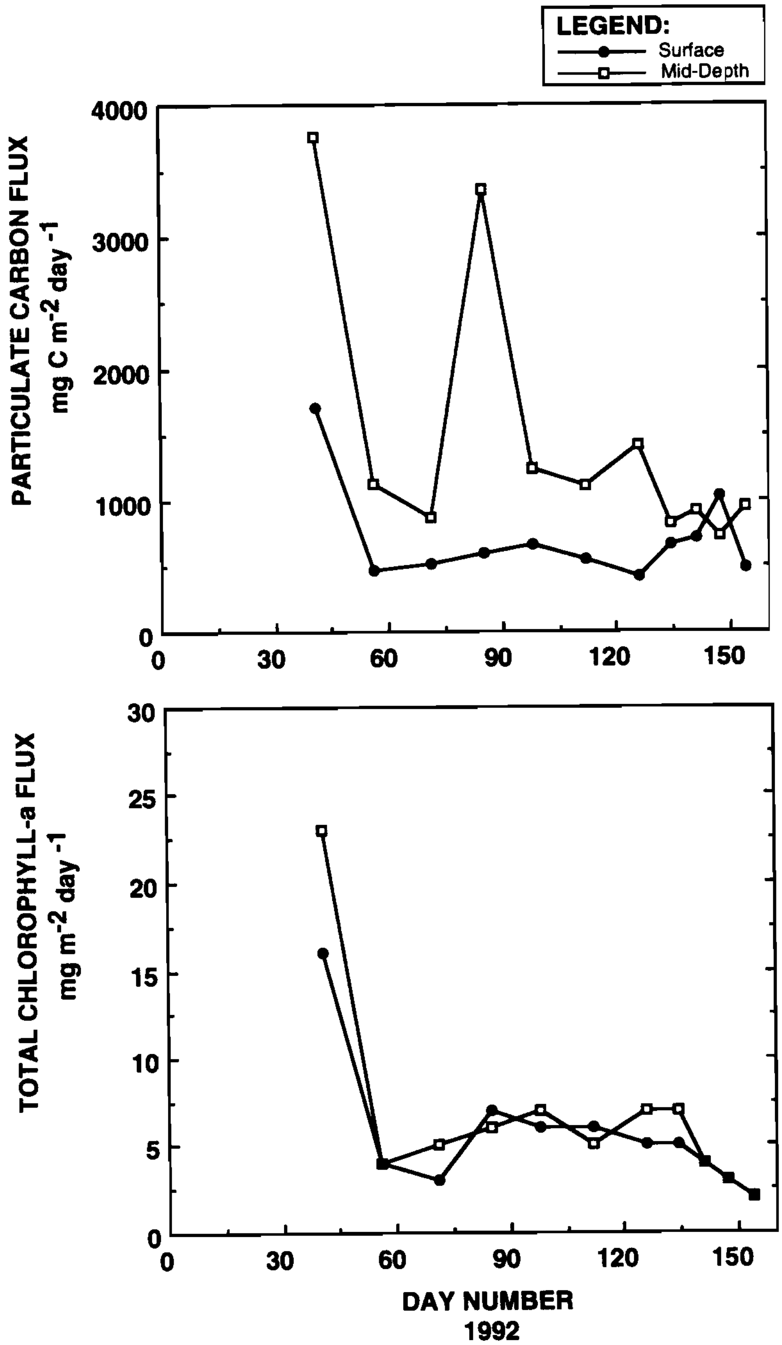


Figure 7-2. Plots of surface and mid-depth deposition rates of particulate organic carbon and total chlorophyll-a from station R-64 collected during 1992.

absence of bars) indicate periods when traps were not deployed rather than periods of time characterized by non-detectable deposition rates.

Particulate carbon deposition rates estimated from surface collections made in during these years varied between 350 and 1005 mg m^{-2} d^{-1} in 1985 (Figure 7-3.1); 280 and 1200 mg m^{-2} d^{-1} in 1986; 220 and 1205 mg m^{-2} d^{-1} in 1987; 205 and 1075 mg m^{-2} d^{-1} in 1988; 300 and 1200 mg m^{-2} d^{-1} in 1989, 220 and 1005 mg m^{-2} d^{-1} in 1990 and 220 and 1050 mg m^{-2} d^{-1} in 1991. Deposition rate measurements were made only until May, 1992 and the range in collecting rates during this interval was 500-1700 mg m^{-2} d^{-1} . In most years, 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 day^{-1}) were recorded during the summer, between the end of June and the middle of August (circa day 181 - 227). Finally, in 1985, 1987, 1989, 1990 and 1991 deposition rates increased sharply for a brief period in the fall, presumably in response to the deposition of the fall diatom bloom.

The seasonal pattern of particulate carbon deposition rates to a depth of 9 meters (mid-depth collecting cups), was much stronger than in surface collections, and values were generally greater than in surface collections, often by a factor of two or more (Figure 7-3.1.). In part these differences were due to the fact that mid-depth cups were closer to the sediment surface and more prone to collect resuspended material than were surface cups. The tops of the mid-depth collecting cups were always above or in the pycnocline and because of this the effects of collecting locally resuspended material were probably small. It is possible that the mid-depth cup collections were larger due to exposure to a longer water column from which new material may be collected. Additionally, a 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 1180 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, 320 to 1510 mg m^{-2} d^{-1} in 1990 and 300 to 1650 mg m^{-2} d^{-1} in 1991. Deposition rate measurements were made only until May, 1992 and the range in collecting rates during this interval was 750-3800 mg m^{-2} d^{-1}, the highest rates on record during the monitoring period. The spring bloom, circa day 50 - 150, was clearly seen in all years, but varied widely (> 2x) in magnitude (Figure 7-4.1; Table 7-1.). During four years (1987, 1989, 1990 and 1991) there was also a strong peak in deposition rates during the fall period, circa day 275 - 325. Values obtained during the summer months did not show any striking trends but there were brief periods when rates were substantial.

Data collected during the monitoring period 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 7-3.2. Total chlorophyll-a values have not been corrected for resuspension effects. A correction factor if applied would be small because chlorophyll-a is labile and 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 deposition rate 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 present a clearer picture of deposition rates of "new material" than uncorrected estimates based on particulate organic carbon, nitrogen or phosphorus because in the case of chlorophyll-a resuspension effects are probably minimal. The magnitude of total chlorophyll-a deposition rates in the surface layer varied from 1.5 to 25.5 mg m^{-2} d^{-1} (Figure 7-3.2) during the monitoring period. If chlorophyll-a deposition rates are converted to carbon [using a carbon : chlorophyll-a ratio of 50, (Day *et al.*, 1989)], 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 (until circa day 100; Figure 7-3.2), 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.

Estimates of total chlorophyll-a deposition based on mid-depth cup collections ranged from 2.4 to 26.0 mg m^{-2} d^{-1} during the monitoring period (Figure 7-3.2) and 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 slighter larger than surface collection rates. As was indicated 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 at mid-depth was very similar to that observed in surface waters but was more distinct. Additionally, inter-annual differences were more apparent at mid-depths. There was an indication of a slight spring bloom in 1989, as noted in other portions of the monitoring program (Magnien *et al.*, 1990; Sellner, 1989), but in most other years the bloom signals are well developed. A strong and repeatable pattern of deposition has been detected which appears to be related to inter-annual variations in nutrient loading and plankton dynamics.

In an earlier Ecosystem Processes Component (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 alternate deposition rates were calculated as the difference between water column production and water column consumption rates (referred to as net community production). The logic of this approach is that only that material which is not consumed in the upper portion of the water column is available for deposition to deep waters and the sediment surface. During late winter and spring, phytoplankton production rates are modest but water column respiration rates are small (possibly because of cool temperatures) and deposition rates in spring have often been large. Water column production rates are greatest in the summer but so too are respiration rates and much of the material produced in the water column is consumed before being deposited. Deposition rates are therefore generally lower in summer than in spring. In fact the occasional large, but brief, deposition events that do occur during summer may be the result of a small temporal mis-match between water column production and consumption rates (Smith, 1992).

While there seems to be a reasonable case for using total chlorophyll-a as an indicator of "new deposition", chlorophyll-a based deposition measurements themselves are not useful as measures of organic matter deposition. Organic matter or particulate organic carbon measurements are a better representation of the total amount of material available for oxidation. Chlorophyll-a represents only a small fraction of the total weight of water column organic stocks. This problem can be partly corrected by converting total chlorophyll-a deposition rates to estimates of particulate carbon deposition. In this approach a chlorophyll-a deposition rate measurement is multiplied by the average particulate carbon : total chlorophyll-a ratio found in the water column at the same depth as the collection cup. This ratio is calculated using water column data collected at the beginning and end of a deployment period and an average value derived which is used in converting total chlorophyll-a deposition to particulate carbon deposition. The correction factor is applied to the entire monitoring data set. The results are shown in Figure 7-3.3.

In general, the calculated particulate carbon deposition rates exhibit the same temporal patterns as the direct measurements of particulate carbon deposition. Calculated rates on average are slightly lower than direct measurements (Figure 7-3.3.) but calculated rates do show occasional large peaks which are not present in the direct measurement data set. The exact reason for this apparent amplification of some values is not clear. However, if a particulate carbon : total chlorophyll-a ratio is high (due to a local resuspension event, for example), then the calculated particulate carbon rate will also be high. While this conversion makes chlorophyll-a deposition rate measurements more useful, it does not completely remove the possibility for effects of resuspension events from entering the measurement.

7.5 Relationships between Nutrient Loading and Deposition Rates in the Mainstem Bay

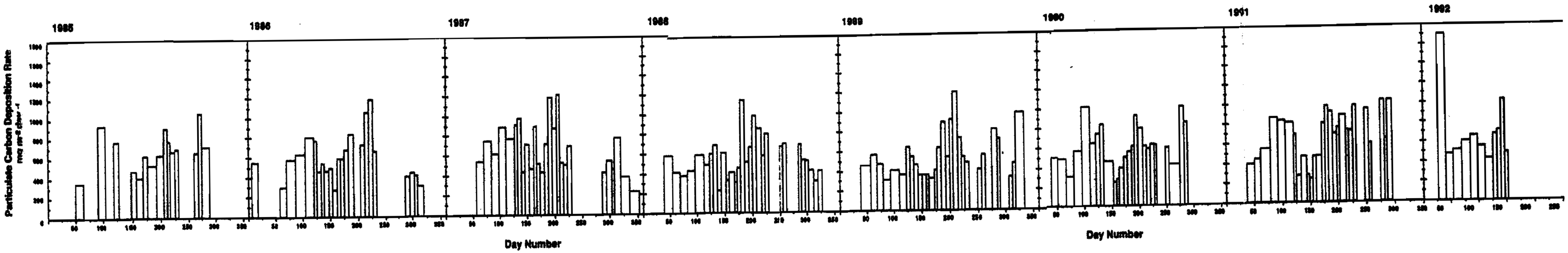
7.5.1 Overview and Approach

The conceptual model used as a guide in the Ecosystem Processes Component (EPC) Program indicates that nutrients from all sources promote the growth of phytoplankton. A portion of the phytoplankton sinks from the surface mixed layer to deeper waters and some smaller portion of this material reaches the sediment surface where it continues to decompose. The purpose of this section is to examine EPC Program data for inter-relationships or causal linkages suggested by the conceptual model. Specifically, inter-annual differences in spring phytoplankton bloom deposition rates are described and then related to nutrient loading rates. Nutrient loading rates to the mainstem bay are not available for all years, especially recent years, so in this analysis river flow from the Susquehanna (which is correlated with nutrient loading rates) is used as a substitute variable.

7.5.2 Spring Bloom Characteristics, 1985-1992

Estimates of the magnitude of deposition resulting from the spring phytoplankton bloom for 1985 through 1992 are shown in Table 7-1. These data were developed using total chlorophyll-a collections from mid-water collecting cups. Within each year, individual observations of deposition rates were time weighted for the period of the spring bloom deposition event which typically lasts from mid-February through most of May (days 50 - 150). Total deposition of total chlorophyll-a from mid-depth collection cups between days 50 - 150 ranged from about 541 mg m^{-2} in 1989 to 1190 mg m^{-2} in 1990. Estimates of spring bloom depositions reported here follow qualitative trends detected by EPC and other portions of the monitoring program (Magnien *et al.*, 1990). For example, 1989 and 1991 deposition rates were low which is consistent with observations of the diatom blooms in those years. Deposition rates in 1988 and 1990 were large, again consistent with spring bloom characteristics for those years. Natural variability has produced inter-annual spring

PARTICULATE CARBON DEPOSITION RATES
a. Surface Cup Collections, 1985 - 1992



PARTICULATE CARBON DEPOSITION RATES
b. Mid - depth Cup Collections, 1985 - 1992

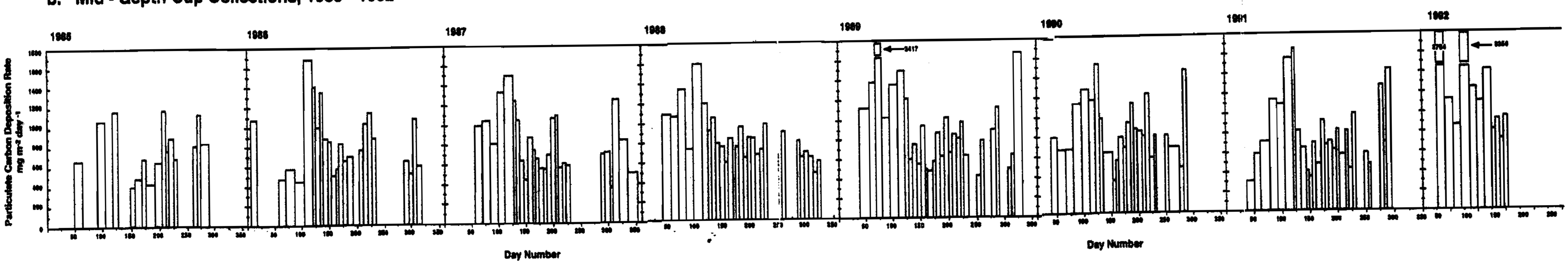
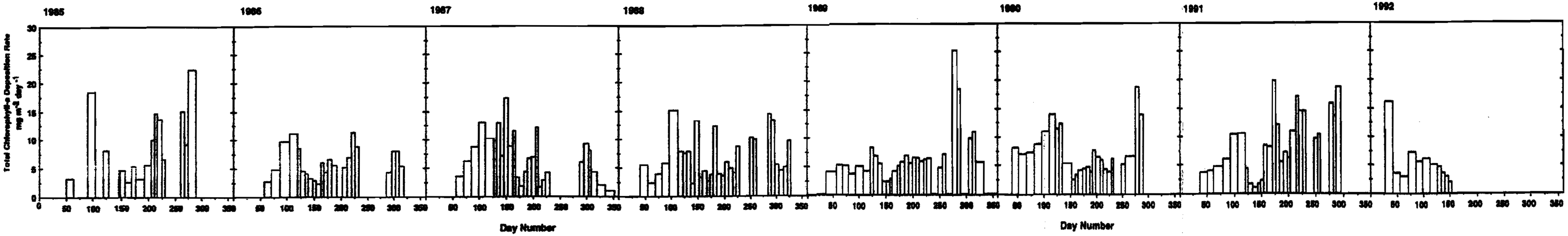


Figure 7-3.1. Bar graphs showing estimated particulate organic carbon deposition rates for the period 1985-1992 based on data collected from surface water collecting cups (5 meter depth) and mid-depth collecting cups (9 meter depth) at station R-64 in the mid Chesapeake Bay.

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.

TOTAL CHLOROPHYLL-a DEPOSITION RATES
a. Surface Cup Collections, 1985 - 1990



TOTAL CHLOROPHYLL-a DEPOSITION RATES
b. Mid-depth Cup Collections, 1985 - 1990

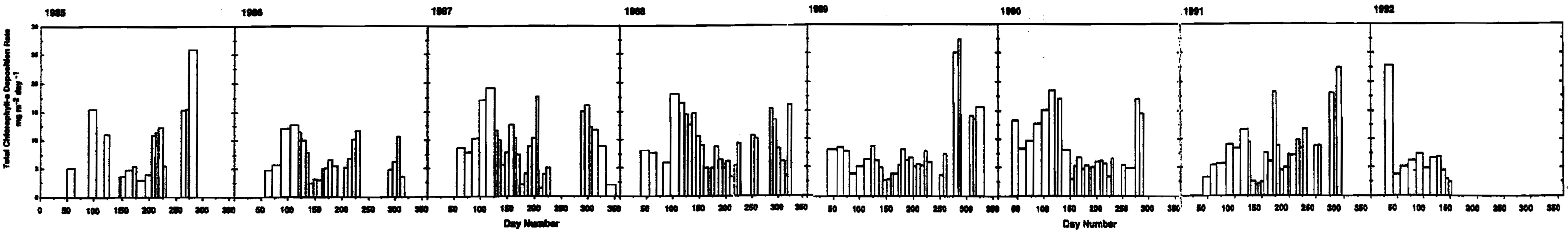
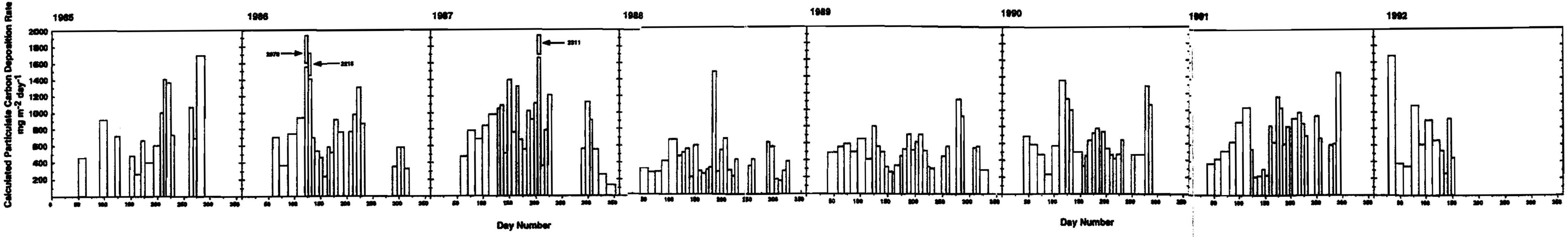


Figure 7-3.2. Bar graphs showing estimated total chlorophyll-a deposition rates for the period 1985-1992 based on data collected from surface water collecting cups (5 meters) and deep water collecting cups (9 meter depth) at station R-64 in the mid Chesapeake Bay.

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.

Calculated Particulate Carbon Deposition Rate
a. Surface Cup collections, 1985-1992



Calculated Particulate Carbopn Deposition Rate
b. Mid-depth Cup Collections, 1985-1992

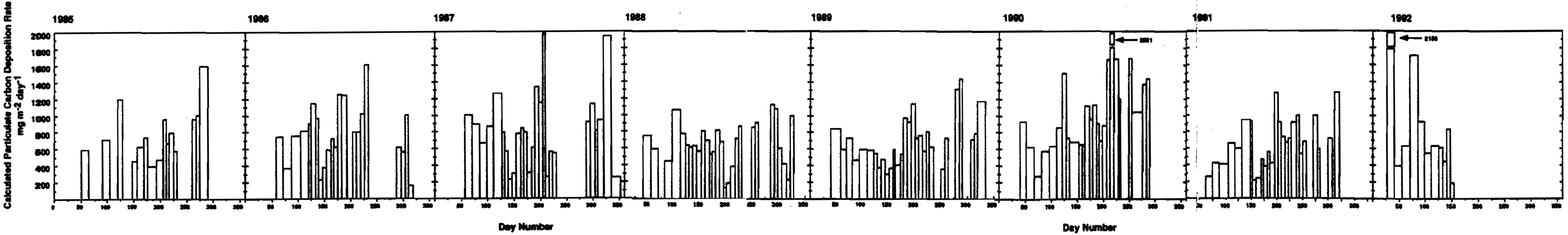


Figure 7-3.3. Bar graphs showing calculated particulate carbon deposition rates for the period 1985-1992 based on data collected from surface water collecting cups (5 meters) and deep water collecting cups (9 meter depth) at station R-64 in the mid Chesapeake Bay.

Values are corrected for resuspension based on conversion of total chlorophyll-a deposition rates to particulate carbon deposition rates using particulate carbon : total chlorophyll-a ratios of material suspended in the water column. The height of each bar indicates the estimated rate of deposition of particulate carbon while bar widths represent the time interval the collecting cups were deployed.

Table 7-1. Estimates of total chlorophyll-a deposition (mg m^{-2}) to mid-depth cups during spring bloom periods (days 50 - 150) in 1985 - 1992.

YEAR	TOTAL CHLOROPHYLL-a DEPOSITION (mg m^{-2})
1985	832
1986	795
1987	999
1988	1155
1989	541
1990	1190
1991	625
1992	645

Table 7-2. Monthly average river flow from the Susquehanna River measured at Conowingo, MD from October, 1984 through June 1992.

The flows shown as bold numbers were used in developing regressions relating river flow to spring deposition. Units of flow are cubic feet per second (cfs). Flow data are from the United States Geological Survey (U.S.G.S.) 1984 through 1992. The data for 1992 are incomplete at this time.

	YEAR							
Month	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92
Oct	7983	14280	16590	18160	7750	27080	75000	6370
Nov	15180	53240	50720	25090	28400	34010	50000	11100
Dec	**55010**	**53970**	**65420**	**43030**	**16700**	**14630**	**80000**	**26100**
Jan	**29820**	**31890**	**29510**	**23500**	**22800**	**40830**	**70300**	**26600**
Feb	**36590**	**66090**	**22680**	**55030**	**26600**	**89820**	**52500**	**22600**
Mar	56200	101700	57630	48890	40000	38960	73500	63100
Apr	52150	60910	90980	36670	62000	54970	53800	67500
May	24480	27740	28200	61950	107000	57510	31000	34200
Jun	16880	30920	16010	15570	68000	29320	8580	25900

deposition rates which differ by about a factor of two.

7.5.3 Spring Deposition Responses to Nutrient Loading Rates (as indexed by river flow)

One of the main goals of the Chesapeake Bay nutrient control program is to reduce nutrient loads to a point where oxygen depletion of deep waters does not occur or is substantially lessened in intensity. The loss of an adequate oxygen supply to deep waters is, in part, a result of density stratification of the water column through much of the year, which retards mixing and reaeration of these waters (Boicourt, 1992). Another feature which promotes chronic hypoxic/anoxic conditions is the decomposition of organic matter in deep water which is the ultimate source of deep-water oxygen demand. Thus, it is deposition of organic matter which links phytoplankton-nutrient processes in the surface layer with the oxygen-consuming decomposition process in deep waters (Kemp and Boynton, 1992). Given this conceptual relationship, it would be useful to be able to quantitatively link nutrient loading rates to deposition rates and to further establish a connection between deposition rates and oxygen conditions in deep waters. This section presents progress made to date on the former of these linkages.

Estimates of the magnitude of spring bloom deposition for the years 1985 through 1992 were presented in the preceding section and they are used as the dependent variable in the following analyses. Susquehanna River flows were used as an index of nutrient loading rates for the periods 1985 through 1992. These flows were used as the independent variable in these analyses. Preliminary analyses examining possible relationships between river flow and spring deposition data indicated that spring deposition was not well correlated with average annual or water year (October 1 through September 30) river flows (Boynton *et al.*, 1990). In this analysis, a number of river flow averages were developed for different time periods preceding the spring bloom period (March through May) to determine if any particular temporal pattern and magnitude of flow influences spring bloom size. Specifically, river flows were calculated for the following time intervals; October-June, November-May, December-April, December-March, December-February, January-May, January-April, January-March, February-May, February-April and February-March. Monthly average river flows measured at Conowingo, MD are given in Table 7-2. and the months immediately preceding the spring bloom period are shown in bold type.

Simple linear regression analyses were conducted to establish whether or not a consistent relationship existed between river flow in a given time period (independent variable) and spring deposition rates (dependent variable). A total of 14 regression analyses were performed. Some of these results were statistically significant (positive relationship) while others only suggested a positive relationship (*i.e.*, increased deposition with increased flow) but were not statistically significant. A single strong departure from a general trend was sufficient to render these regressions non-significant. This is related, in part, to the small number of observations ($n = 8$) available for use. The strongest relationship developed to date is shown in Figure 7-4 which uses mean river flow for the December through March period of each year as the independent variable.

Several preliminary conclusions can be drawn from these analyses:

(1) It appears that river flows (*i.e.*, nutrient loads) averaged for substantial periods of time (*e.g.*, October through May) prior to a spring bloom are not correlated with the magnitude of a spring bloom. Large flows prior to December, which occasionally occur during fall months, also seemed to have no noticeable effects on the size of spring deposition. Maximum monthly

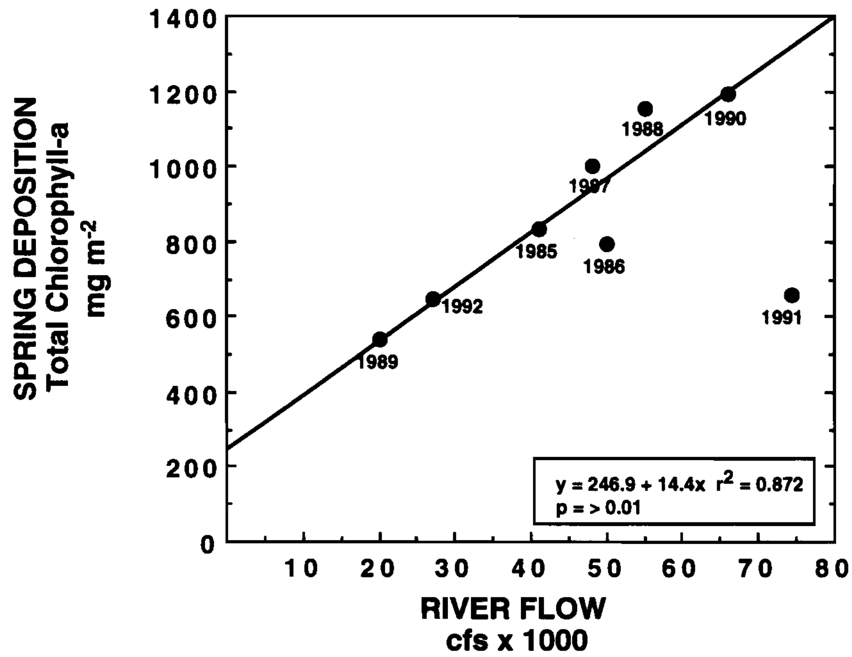


Figure 7-4. Scatter plot of river flow (x-variable) from the Susquehanna River (average flows from the December - February period) versus deposition rates of total chlorophyll-a during the spring bloom period. Data from 1985-1992 are included in the analysis.

flows were not generally correlated with deposition rates. Spring bloom deposition therefore, is not simply a response to extreme, relatively rare events. It appears that river flows which occur closer in time to the spring bloom have the most influence on the magnitude of the subsequent deposition rates.

(2) Low river flows (< 30,000 cfs) during the months of December through February were always associated with small spring deposition events (*e.g.*, 1989 and 1992; Tables 7-1. and 7-2.).

(3) Relatively small deposition events (*e.g.*, 1991 and to a lesser extent 1986) are associated with very high and sustained flows that begin in the fall and continue throughout the winter. This does not mean that a large spring bloom and subsequent deposition event did not occur but rather that it did not occur in the area of the bay where the sediment trap was deployed. In these years the bloom may have occurred further down the bay. Examination of water column data from the Chesapeake Bay Water Quality Monitoring Program might provide some clarification.

(4) The largest deposition events (*e.g.*, 1987, 1988 and 1990) were all associated with river flow patterns which featured a *distinct pulse in flow during one or two months during December through February*. The flows which are associated with the magnitude of spring deposition events are shown in bold print in Table 7-2.

It appears that considerable work has yet to be done in order to understand the relationship between loading and deposition. These analyses show some strong correlations between these variables. The departures of expected patterns in load-deposition relationships in some years may be due to numerous other factors that operate to either produce or consume organic matter in the water column and sediments. The complex transport patterns which are operational in the bay probably serve to further complicate the picture. The challenge is to continue to examine these and other data, looking for inter-annual differences in loads and other *in situ* environmental conditions which would provide new clues as to the nature of this relationship.

7.6 Spring Deposition and Hypoxia in the Mainstem Bay

In a previous Interpretive Report, Level One #8, (Boynton *et al.*, 1991) water column and deposition rate data for the spring period (January - May) of 1985 though 1991 were examined for indications of biological influences on initiation of hypoxic conditions in the mainstem region of the bay. This analysis is extended to include data collected during the spring period of 1992.

One of the main water quality problems prevalent in the bay is the yearly development of zones of hypoxic or anoxic water in deep areas during summer months, June through September. 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 how much nutrient loads need to be reduced to alleviate low oxygen conditions.

Establishing 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 (Boicourt, 1992; Kemp and Boynton, 1992).

Ecosystem Processes Component (EPC) data are not adequate to entirely resolve this problem but it is possible to determine relationships between deep water oxygen characteristics and organic matter deposition rates for one region of the mainstem bay where seasonal oxygen problems are chronic. Data collected by the EPC program, and other components of the monitoring program (Magnien *et al.*, 1990), exhibited deep water oxygen characteristics in the mainstem bay which indicated that deposition-oxygen status relationships might exist:

(1) 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. There is more organic matter being produced in the system than oxygen available to oxidize this material during summer periods.

(2) 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.

(3) In 1992 the spring freshet was very small throughout the winter-spring period. Spring chlorophyll-a concentrations ($< 20\ \mu g\ l^{-1}$) and deposition rates (<25 mg m^{-2} day^{-1}) were among the lowest on record and dissolved oxygen concentrations at R-64 remained relatively high (> 4.0 ml l^{-1}), at least through the beginning of June. During 1992 dissolved oxygen concentrations in deep water at this station (R-64) were still about 1 mg l^{-1} in mid-July.

These results suggest that deep water oxygen conditions during the first half of 1992 were regulated, at least in part, by the amount of organic matter deposited during spring. Vertical mixing of oxygen from the surface to deep waters, which is influenced by the degree of water column stratification, is also involved. Resolving the effects of biological and physical processes is one of the most difficult aspects of this problem. Finally, since it appears that the system usually receives enough organic matter to produce hypoxic or anoxic conditions, the inter-annual pattern of oxygen decline may largely be 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 may be responsible for *maintaining* them.

Bottom water oxygen concentrations were routinely measured, on a biweekly or weekly basis, at the VFX site located adjacent to R-64 in the mainstem bay. Water depth at this site is about 17 meters and vertical stratification characteristics are typical for this region of the bay. The daily rate of change of oxygen concentration (dO_2/dt) was calculated using data measured during the spring (April through June), for 1985 through 1992. The time period over which rates of change were calculated varied slightly among years but in most cases included the period from the beginning of March through the middle of May. The criterion used to determine the starting point was that the first observation should not be followed by any oxygen measurements of higher concentrations. Typically, during late winter and early spring, deep water oxygen concentrations exhibit both small increases and decreases over time but are usually close to saturation (*i.e.*, within 10% of saturated conditions). 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 1992 calculated from these data were linear (r^2 values associated with linear regressions of time versus dilssolved oxygen (DO) concentration >0.92) and differed appreciably among years (0.082 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 probably caused by early deposition events rather than events that occurred in late 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 suspension. In addition, chlorophyll-a more closely approximates labile organic matter stocks than does a measure of total particulate carbon. Chlorophyll-a deposition rates (x-variable) were regressed against the rate of dissolved oxygen (y-variable) decline derived from regressions of time vs dissolved oxygen concentration (dO^2/dt). The results are shown in Figure 7-5. Less significant relationships were also found between measures of dissolved oxygen decline and maximum deposition rates during the same time period. Average deposition rates which included 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 point to a strong influence of sediment and water column respiration biological processes on oxygen decline and relate such declines to nutrient 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 regime. Oxygen decline would be more rapid in warm years than in cold years simply because of the influence of temperature on respiration rates. In this scenario, organic matter needed to support respiration is not 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 (Boynton *et al.*,1992b). Additionally, for the most part warm and cool springs were not correlated with high and low rates of oxygen decline. The second hypothesis is 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 occurs and rates of oxygen decline are greater. Stratification certainly plays a major role in determining deep water oxygen characteristics. However, the case for stratification being a dominant factor in causing inter-annual differences in oxygen decline rates is weak because the years of high and low stratification do not correspond to years of high and low rates of oxygen decline, as would be true if stratification were a prime factor causing these differences. Although the existing data are not sufficient to resolve all of the factors involved, the data do support the relationships between nutrient load and the duration and extent of hypoxia/anoxia in the deeper areas of the Bay.

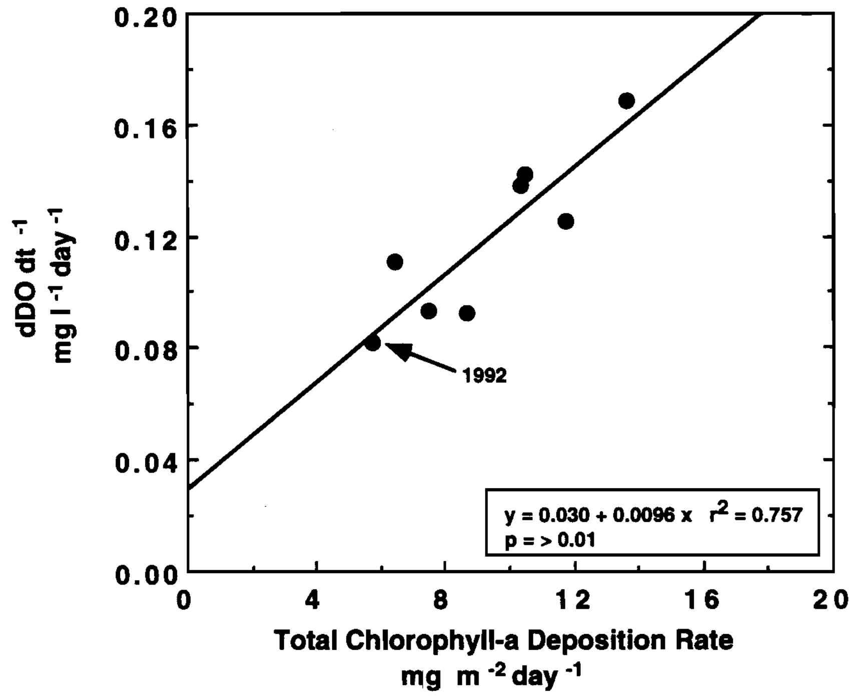


Figure 7-5. A scatter plot of dissolved oxygen time rate of change (dO_2/dt; mg l^{-1} day $^{-1}$) versus total chlorophyll-a deposition rates (mg m^{-2} day^{-1}) at mid-depth in the water column. Data were collected at station R-64 in the mesohaline region of the mainstem Chesapeake Bay during spring periods between 1985 and 1992.

8. STATISTICAL EXAMINATION OF SEDIMENT-WATER FLUXES FOR LONG TERM TRENDS

8.1 Introduction

Developing management actions to implement the 40% nutrient load reduction strategy is the major thrust of the Chesapeake Bay Water Quality Monitoring Program during its third phase beginning in 1991. Prior to this, the Chesapeake Bay Water Quality Monitoring Program developed a data base containing data related to the water quality conditions throughout the bay system. These data were used to describe conditions in the bay system and identify areas of poor water quality. The Ecosystem Processes Component (EPC) Program has been a part of this effort since 1984 and has now accumulated 8 complete years of monitoring data. This data set was determined to be sufficient for statistical analyses designed to detect temporal trends in sediment-water flux data (Sediment Oxygen and Nutrient Eppyxchanges [SONE]) which may have resulted from either natural processes or management induced nutrient load reduction or some combination of both. Specifically, regression coefficients for five sediment oxygen and nutrient exchanges (SONE) variables regressed on year were analyzed by analysis of variance to test for temporal and spatial trends present in the data. Additionally, power analysis was used to determine the sensitivity of flux measurements (*i.e.*, smallest change that could be detected) within the limits of the present program design.

8.2 Selection of data for use in Statistical Analyses

8.2.1 Rivers

The four rivers sampled during the SONE program are each assigned an alphabetic code; four letters in the case of the Choptank River (**CHOP**), and three letters each in the case of the Potomac River (**POT**), the Patuxent River (**PTX**) and the Susquehanna River (Chesapeake Mainstem [**SUS**]). This variable was used in stage 3, the analysis of variance.

8.2.2 Stations

Location (Figure 3-1) of the SONE stations in each of the four rivers were selected to have depth and sediment characteristics representative of the estuarine zone being monitored (Section 3.1.1). A preliminary analysis of the data indicated that in order for a station to be included in the analysis it should meet the criterion of having been sampled at least 3 months per year for at least 3 years. Six stations had 8 months of data per year and 2 stations, Marsh Point (MRPT) and Broomes Island (BRIS), had 6 months of data per year. Five stations (Maryland Point [MDPT], Thomas Point (TMPT), Buoy R-78 (R-78), Still Pond [SLPD] and Windy Hill [WDHL]) at which data were collected for a shorter period of time and for which limited data were available, were excluded from the analysis.

The 8 stations used in the analyses are as follows:

Patuxent River
4 stations: Buena Vista (BUVA), Marsh Point (MRPT), St Leonard Creek (STLC) and Broomes Island (BRIS)

Choptank River:
1 station: Horn Point (HNPT)

Potomac River:
1 station: Ragged Point (RGPT)

Susquehanna River (Chesapeake Mainstem):
2 stations: Point No Point (PNPT) and R-64

8.2.3 Months

Data for 7 months, April, May, June, July, August, October and November, were used in the analyses. The years included are 1985 through 1991. Data collected during 1984 were excluded from the analyses due to the limited reliability of some data collected during the early stages of the EPC Program when sampling techniques were being developed. The criterion of inclusion for a station was at least three months of measurements per year for three years. This criterion was used to minimize potential problems associated with the inclusion of stations with very limited amounts of data. Changing the criterion for station inclusion to require more monthly measurements per year would result in a greater amount of data loss.

8.2.4 Flux Variables

Five flux variables were used in the analyses:

1. sediment oxygen consumption (SOC),
2. ammonium (NH_4^+),
3. nitrite plus nitrate (NO_2^- + NO_3^-),
4. dissolved inorganic phosphorus (DIP or PO_4^-) and
5. silicious acid ($Si(OH)_4$) fluxes.

Nitrite (NO_2^-) is included in nitrite plus nitrate (NO_2^- + NO_3^-) fluxes because (NO_2^-) fluxes were so small.

8.3. Statistical Approach

The raw flux data set (Appendix B, Tables B-6.1 through B-6.28, Boynton *et al.*, 1990 and Boynton *et al.*, 1992b) was used in stage 1 when outliers were determined. Variables used are: number of observations, sone number, river, station abbreviation, core number, month, year and flux value. A second (corrected) data set in which outliers and missing values are eliminated was used in stage 2 when weighted regression coefficients for the model flux = year were calculated for each month/station combination. The third data set used in the analysis of variance was created at the end of stage 2 and included number of observations, river, station abbreviation, month, number of observations per month and a weighted estimate of the rate of change in flux per year.

A copy of each of the Statistical Analysis System (SAS) programs used in the various stages of this analysis is provided in Appendix D. Detailed explanations of the use of the various SAS procedures together with useful statistical information may be found in the SAS User's Guide: Statistics (1985) and SAS System for Regression (Freund and Littell, 1985). The three stages comprising the analysis are as follows:

8.3.1. Stage 1: *Influence Diagnostics* - Determination of Outliers

Outlier analysis is a valuable tool providing the researcher with indications of the need for reinvestigating data points for accuracy (Myers, 1990). Suspect data points in error at the data entry level can be corrected and remaining highly influential data points can be examined and considered for elimination from the analysis. At times the outliers may point to serious model deficiencies making the resulting analysis less useful.

Influence statistics are calculated to determine the potential of a particular observation to influence the regression line due to leverage (Myers, 1990). These statistics were computed by examining the changes in various regression statistics when each observation is omitted from the analysis (one at a time) as compared to the analysis with all observations present. The model used for the stage 1 analysis was flux regressed on year at each river, station and month combination using ordinary least squares (OLS). This should not be confused with stage 2 which used weighted least square (WLS) to generate the rate of change in flux across years. Once a high leverage value has been identified a decision has to be made with regard to the inclusion or exclusion of the associated data point.

The procedure REG with /INFLUENCE selected provides the following set of influence statistics associated with the generation of the regression coefficients across time. They are defined and their use is discussed in Freund and Littell (1986):

1. studentized residuals
2. Hat Diag H
3. covariance ratio statistic
4. Dffits and
5. Dfbetas.

In this stage of the analysis data for each variable at each station for each month for which there were 4 or more years and 4 or more months data were included. In those cases where significance was indicated in three of the five tests described above, the original data sheets were consulted and a decision made as to whether or not to delete the observation from the data set used in subsequent analyses. The outliers detected in this study were single data points which had a large impact on the slope of the subsequent regression analysis. In most cases where data were discarded the sample was associated with either (1) the presence of a large organism in one of the triplicate sediment cores or (2) abnormally high concentrations of a dissolved compound in overlying waters in one of the triplicate set of sediment cores. The former was primarily associated with ammonium fluxes (*i.e.*, one core of the triplicate sediment core set having a very high flux value) and the latter with phosphate fluxes (*i.e.*, one core of a set of triplicate sediment core set having a very low [or negative] value).

The number of observations available for inclusion in the analyses ranged from 555 for dissolved organic phosphorus (DIP) to 597 for nitrite + nitrate (NO_2^- + NO_3^-)(Table 8-1). The percentage of outliers discarded was low in the order of 1%, however for phosphate, where small negative values were eliminated due to overlying water anamolies, the value was as high as 2.5% (Table 8-1).

8.3.2 Stage 2: *Iteritively Reweighted Least Squares Estimation of Yearly Rates of Change in Sediment-water Fluxes*

Linear regression techniques (SAS, REG procedure) were used to estimate the rates of change in flux/year for each river, station and month combination. The model was a simple linear regression of flux on years. The regression procedure used was iteratively reweighted

Table 8-1. Number of observations (1985-1991) included in the statistical analyses.

VARIABLE	ABBREVIATION	NUMBER OBSERVATIONS USED	% OUTLIERS
Sediment Oxygen Consumption	SOC	596	1.0
Ammonium	NH_4^+	583	1.7
Nitrite + Nitrate	$NO_2^- + NO_3^-$	597	0.0
Dissolved Inorganic Phosphorus	DIP	555	2.5
Silicate	DSI	598	0.7

least squares. Ordinary least squares was used to fit the initial model. Weights were computed for each observation based on the influence statistic dffits. The weights were computed such that observations with large influence (large dffits) were assigned a weight less than one depending on the magnitude of the dffits statistic (minimum weight was 0.01). While observations with small influence (small dffits) were assigned the maximum weight of one these weights are used with the same model to solve a weighted regression. From this analysis new weights were computed from the new dffits and the weighted regression model was fitted again. This procedure was repeated until the estimated regression coefficients (yearly rate of change in flux) stabilized. This procedure results in more robust estimate of the regression coefficients than would ordinary least squares when outliers are a potential problem.

8.3.3 Stage 3: *Analysis of Variance - Test of hypotheses*

Estimates of the rates of change in flux/year for each river, station, and month from stage 2 were analyzed by analysis of variance (ANOVA) techniques (SAS, GLM procedure). Since the estimates from stage 2 were computed from varying amounts of data, the ANOVA was weighted for the number of observations used to compute the rate of change in flux/year. The ANOVA model included the sources of variation for river (4), station (8) within river, month (7) and the river by month interaction. In addition to the four ANOVA hypotheses, pairwise contrast (t test using the MSE) were used to test for differences between rivers, stations with rivers (Patuxent [PTX] and Susquehanna [SUS] Rivers only), between rivers within month (or between months within river). Tests were also done to determine if the change in flux/year was significantly different from zero overall or for any level of aggregation of river, station and month (t test using MSE).

8.3.4 Stage 4: *Power Analysis*

Power analysis is used (1) either *a priori* when the sampling procedure is being designed or (2) *a posteriori* during the interpretation of the results. Power curves were constructed to examine the relationship between power and change/year in flux associated with the increase in data through continued sampling to year 2000 (Gerrodette, 1987). Power analysis is as an important tool for the decision maker in management situations where detecting trends in resource parameters is important (Peterman, 1990a, 1990b).

The standard formulas for calculating power and detectable-effect size are discussed in Dixon and Massey (1969), Pearson and Hartley (1976) and Cohen (1988).

A comprehensive analysis of the Chesapeake Bay Program Monitoring design for detecting water quality and living resource trends has been completed by Alden, Siebel and Jones (1990). The study was designed to assess the ability of the Chesapeake Bay monitoring program to detect true trends ('power' assessment) and the robustness of the analytical approach.

For each flux rate, information derived from the analysis of variance analysis for each variable was used to construct power curves. These include the desired level of type I error, (in this case 0.05), the standard error of the change per year (seb) computed by the analysis of variance in stage 3, the error degrees of freedom (dfe) from the analysis of variance in stage 3 and the sample size (determined by the final year of sampling [yr]). Power testing indicates whether or not the number of samples used is sensitive enough to detect a given yearly rate of change in flux values.

8.4. Results

8.4.1 Results from the *Analysis of Variance*

The results from stage 3: *Analysis of Variance* are presented as a series of tables (Tables 8-2, 8-3 and 8-4).

Table 8-2 contains the mean square values for change in flux/year with significance indicated for the sources of variation. In only one case, (nitrate plus nitrite; $NO_2^- + NO_3^-$ flux), was a significant interaction found for river by month indicating that rivers are responding differently with respect to this variable.

Table 8-3 summarizes the means for the months April through November (with the exception of September) for each of the rivers and for each SONE flux variable. The last column contains the least mean square values for rivers summed over all months. This value represents the average change in flux within a river averaged for all months (April through November). The values have letters indicating the significant differences among the mean values.

i. Sediment Oxygen Consumption (SOC) fluxes

Table 8.3 indicated that there were no significant trends for sediment oxygen consumption (SOC) flux for any month in the Potomac River and Maryland Mainstem Bay (Susquehanna River). In the Choptank River there was a definite sign of increasing sediment oxygen consumption (SOC) during June and a smaller statistically significant ($p = 0.10$) decrease during July. The only other trend was a decrease in sediment oxygen consumption (SOC) in the Patuxent River during November. The statistically significant changes are of ecological importance i.e. a change of this magnitude would impact dissolved oxygen (DO) conditions. When data for all months was analyzed, the Patuxent River was not seen to be different from the Choptank River but the trend was not the same as the Potomac and Susquehanna Rivers. The Potomac River showed a significant increasing trend ($p = 0.05$) for sediment oxygen consumption (SOC).

ii. Ammonium (NH_4^+)

Two ecologically significant trends were evident for ammonium (NH_4^+) in the Potomac River. A highly significant ($p = 0.001$) decreasing trend in ammonium was detected during July and a less significant ($p = 0.05$) decrease during August. Again, decreases of this magnitude are of ecological importance. The Potomac River showed a significant decreasing trend ($p = 0.001$) for ammonium (NH_4^+) when all the data for all months is included and was significantly different from the others.

iii. Nitrite and Nitrate ($NO_2^- + NO_3^-$)

No significant trends for nitrite and nitrate ($NO_2^- + NO_3^-$) were detected in the Maryland Mainstem Bay (Susquehanna River). Two highly significant ($p = 0.001$) trends were found, one in the Choptank River during June and the other in the Patuxent River during August. Three less significant trends were also detected; two for the month of April in the Potomac River ($p = 0.01$) and Patuxent River ($p = 0.05$), and the other for the month of June in the Patuxent River ($p = 0.05$). The Patuxent River showed a decreasing trend ($p = 0.05$) for nitrite and nitrate ($NO_2^- + NO_3^-$) when data for all months is used, and was different than the other three rivers.

iv. Dissolved Inorganic Phosphorus (PO_4^- or DIP)

Two significant decreasing trends of ecological importance were indicated for dissolved inorganic phosphorus (PO_4^-), one in the Potomac River ($p = 0.01$) for the month of July and for the month of June in the Susquehanna River ($p = 0.05$). No difference was found between rivers for dissolved inorganic phosphorus (PO_4^-) when data for all months is used.

v. Silicate (Si)

Only one value showed an increasing trend ($p = 0.05$) for the Patuxent River during July. No significant difference was found between rivers for silicate (Si) when data for all months is used.

In general these results indicated that there is greater similarity among mean values than significant differences for the different months, suggesting that seasonality does not appear to have a marked influence on the flux trends, with the exception of the month of June and August.

The Patuxent and Susquehanna Rivers seem to respond similarily across months (Table 8-3), while the Choptank and Potomac Rivers respond differently from each other and from the Patuxent and the Susquehanna Rivers. Significant values were found for sediment oxygen consumption (SOC) and ammonium for rivers (Table 8-3) indicating a difference between the four rivers in the study. Increases in sediment oxygen consumption (SOC) flux was observed for the Potomac and Susquehanna Rivers while there was a decrease for the Patuxent River. The Potomac River exhibited a significant decrease in ammonium (NH_4^+) flux compared to the other rivers. Significant values for ammonium (NH_4^+) and nitrate plus nitrite ($NO_2^- + NO_3^-$) were found for stations within rivers.

Table 8-4 has the least mean square values for each of the five SONE variables at six of the eight stations. There were more similarities among the stations than there were differences. Two stations in the Patuxent River had significant differences; Buena Vista (BUVA) had significant values for nitrate plus nitrite ($NO_2^- + NO_3^-$) and silicate ($Si(OH)_4$) while Marsh Point (MRPT) had significant differences for ammonium (NH_4^+) and nitrate plus nitrite ($NO_2^- + NO_3^-$). In the mainstem bay, R-64 had a significant mean square value for dissolved inorganic phosphorus (DIP).

TABLE 8-2. Table of mean square values for flux rates from Stage 3: *Analysis of Variance*.

Dependent: Change in flux/year ($\mu M\ m^{-2}\ hr^{2}\ yr^{-1}$; $gO_2\ m^{-2}\ day^{-1}\ yr^{-1}$ for SOC)

	MEAN SQUARE							
	df	SOC	NH_4^+	$NO_2^- + NO_3^-$	df	DIP	df	SI
River	3	0.784*	97310**	770	3	325	3	45419
Station/river	4	0.087	29414+	3274 *	4	752	4	72077
Month	6	0.532+	5501	3772 *	6	969	6	42131
River x Month	18	0.288	16430	1999	18	369	18	17947
Error	16	0.243	14762	993	15	706	16	50176

+ $p = 0.10$
* $p = 0.05$
** $p = 0.01$
*** $p = 0.001$

Table 8-3. Table of Least Square Means by River for Change in Flux/Year for five SONE variables.

RIVER ------------------------------LEAST SQUARE MEANS ($\mu M\ m^{-2}\ hr^{-1}\ yr^{-1}$)------------------------------

i. Sediment Oxygen Consumption ($g\ O_2\ m^{-2}\ day^{-1}\ yr^{-1}$)

RIVER	April	May	June	July	August	October	November	River[1]
CHOP	0.226	-0.100	0.373**	-0.301+	0.025	-0.039	-0.015	0.024[ab]
POT	0.091	0.210	0.182	0.063	0.161	0.013	0.102	0.117*[a]
PTX	0.180	-0.112	0.009	-0.124	-0.052	-0.039	-0.412**	-0.079[b]
SUS	0.056	0.018	0.074	0.089	0.134	0.066	0.093	0.076[a]
Month	0.138+	0.004	0.159*	-0.068	0.067*	0.000*	-0.058	0.035

ii. Ammonium

RIVER	April	May	June	July	August	October	November	River[1]
CHOP	-3	7	-23	54	7	-29	1	2[a]
POT	-40	-37	-44	-177***	-70*	-29	-35	-62***[b]
PTX	-15	29	8	38+	25	-1	12	14[a]
SUS	21	-10	-36+	22	-19	-14	34	-0[a]
Month	-9	-3	-24	-15	-14	-18	3	-11

iii. Nitrite + Nitrate

RIVER	April	May	June	July	August	October	November	River[1]
CHOP	5.5	-14.0	-28.8***	6.4	-3.2	-0.7	-3.6	-4.5[a]
POT	-34.1**	-5.9	0.0	1.2	3.5	-2.0	-6.9	-6.9[a]
PTX	-16.8*	-1.4	-17.3*	14.3	-25.2***	4.1	-5.0	-6.7*[a]
SUS	0.2	2.6	-3.5	2.4	-7.4	0.5	-6.8	-1.7[a]
Month	-11.3	-4.7	-15.2***	5.8	-8.6*	1.8	-2.6	-5.0**

iv. Dissolved Inorganic Phosphorus

RIVER	April	May	June	July	August	October	November	River[1]
CHOP	-0.8	-0.6	0.2	-8.9	0.8	-4.1	-0.7	-2.0[a]
POT	1.1	-2.1	-2.5	-25.7**	0.9	0.1	-1.2	-4.2[a]
PTX	-2.1	-0.3	-2.4	1.6	6.4+	-0.4	2.7	-1.6[a]
SUS	-0.2	0.4	-10.7*	-5.4	2.1	-0.5	2.7	-1.6[a]
Month	-0.5	-0.5	-3.8	-9.6*	2.5	-1.2	0.2	-1.8

Table 8-3. Table of Least Square Means by River for Change in Flux/Year for five SONE variables (Continued).

RIVER	LEAST SQUARE MEANS ($\mu M\ m^{-2}\ hr^{-1}\ yr^{-1}$)							
	v. Silicate							
	April	May	June	July	August	October	November	River[1]
CHOP	-17	-23	-24	-87	25	-8	-18	-22[a]
POT	-40	-58	-19	34	20	-25	-39	-18[a]
PTX	-75	-1	38	96*	56	0	28	20[a]
SUS	-36	-16	-64	27	6	-41	-10	-19[a]
Month	-42	-24	-17	17	27	-18	-10	-10

+	p = 0.10	
*	p = 0.05	Test of no significant change
**	p = 0.01	in flux across years
***	p = 0.001	
abc	Any means with an identical letter are not significantly different from each other at the 10% level	
1	t-tests were used to detect differences among rivers across all months.	

NOTE: Circled values are ecologically important

Table 8-4. Least Square Mean values for change in flux per year for six stations and five SONE variables from Stage 3: *Analysis of Variance*.

Station	River	Sediment Oxygen Consumption (SOC)[1]	Ammonium (NH_4^+)	Nitrite + Nitrate ($NO_2^- + NO_3^-$)	Dissolved Inorganic Phosphorus (PO_4^-)	Silicate (Si)
		Least Sqaure Means ($\mu M\ m^{-2}\ hr^{-1}\ yr^{-1}$)				
PATUXENT RIVER:						
BRIS	PTX	-0.1363	-12.47	3.48	-3.32	57.92
BUVA	PTX	-0.1032+	11.66	-8.15*	1.87	56.78*
MRPT	PTX	-0.0305	60.25*	-22.35***	3.49	-24.88
STLC	PTX	-0.0443	-3.61	0.09	-0.16	-8.45
MARYLAND MAINSTEM BAY (SUSQUEHANNA RIVER):						
PNPT	SUS	0.0907+	12.01	-1.29	2.17	-13.96
R-64	SUS	0.0604	-12.87	-2.16	-5.46+	-23.73

+ $p = 0.10$ | Test of no significant change in flux between stations in two rivers
* $p = 0.05$
** $p = 0.01$
*** $p = 0.001$

1 Sediment Oxygen Consumption (SOC) units = $g\ O_2\ m^{-2}\ day^{-1}\ yr^{-1}$

8.4.2 Results from the *Power Analysis*

Table 8-5 summarizes the magnitude of the change in fluxes which can be detected. Values are derived from power curves using current levels of detection based on actual data covering the period 1985 through 1991 and additional levels of detection which are predicted values based on projections using additional sampling for the years 1994, 1996 and 2000. Power curves for one variable, ammonium (NH_4^+), are presented in Figure 8-2. It should be noted that as increasing numbers of samples are added (in future years), the tail of the curve becomes noticeably flatter.

By way of example, the 1991 curve in Figure 8-1. indicates that there is a 60% probability of detecting a 12 unit change (*i.e.*, 12 μMN m^{-2} hr^{-1} yr^{-1}) in ammonium flux based on the present data set (1985 through 1991). Similarly, there is a 95% probability of detecting a change of approximately 25 μMN m^{-2} hr^{-1} yr^{-1} using the same data. As the graphs in Figure 8-2 indicate, the probabilities of detecting smaller rates of changes increase as the sampling period progresses.

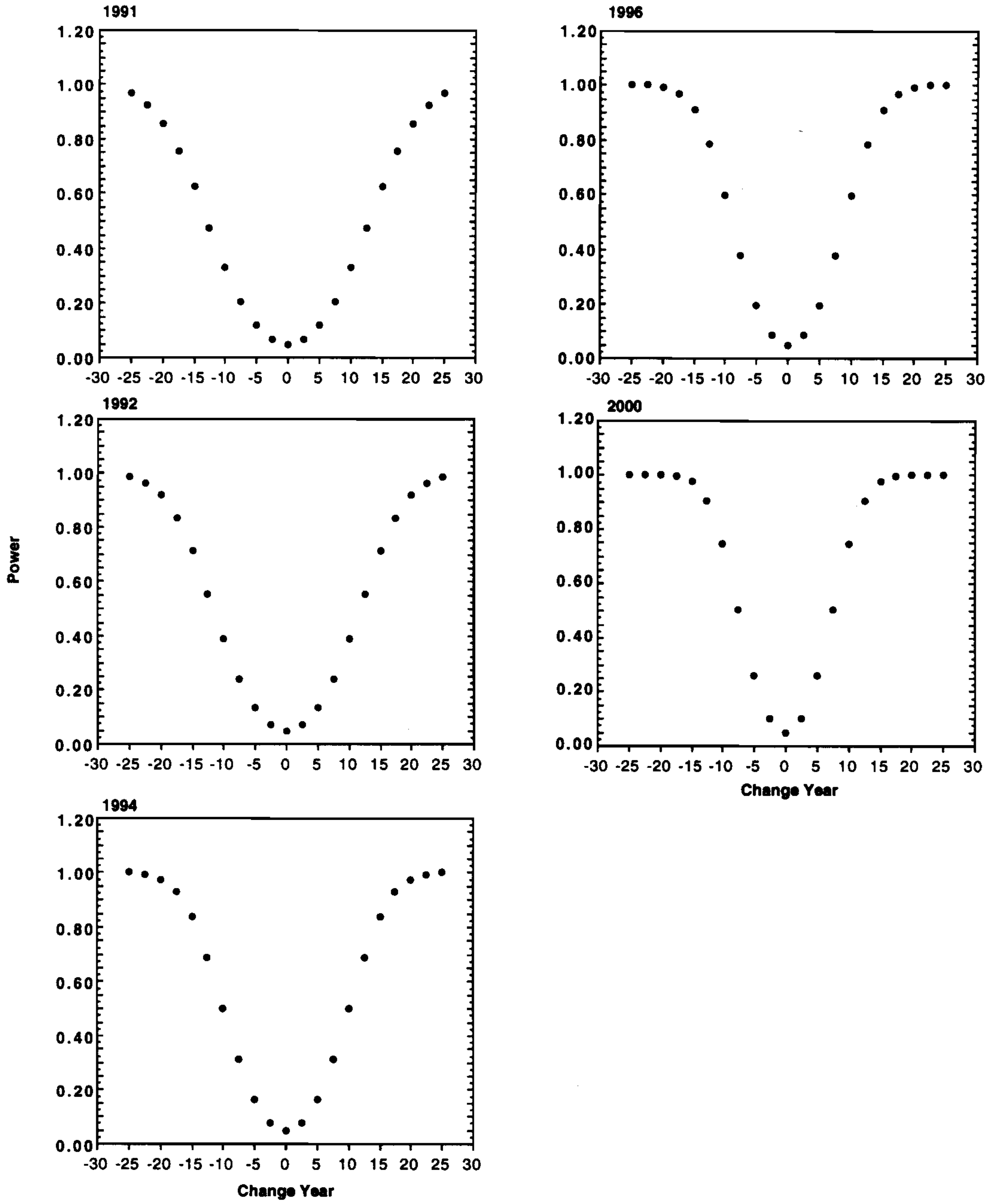


Figure 8-1. Power curves for ammonium (NH_4^+) for the years 1991, 1992, 1994, 1996 and 2000. The power values for 1991 are based on the data set available for 1985 through 1991 while all of the other graphs reflect predicted values which would be associated with increased sample size from continued sampling.

Table 8-5. A summary of the detection limits ($p > 0.95$) of changes in sediment-water fluxes estimated from the power analyses.

Years indicated the year up to which flux data are included (*i.e.*, 1991 included flux data from 1985 through 1991). Later years (*i.e.*, 1992 through 2000) are projections of results based on the inclusion of additional years of data having the same characteristics as the data set collected between 1985 and 1991. Units for data in the table are $\mu M\ m^{-2}\ hr^{-1}\ yr^{-1}$ except for sediment oxygen consumption (SOC) where the units are $g\ O_2\ m^{-2}\ day^{-1}\ yr^{-1}$.

FLUX VARIABLE	YEAR				
	1991	1992	1994	1996	2000
Sediment Oxygen Consumption (SOC)	0.08	0.08	0.08	0.07	0.06
Ammonium (NH^{4+})	23.8	20.5	17.0	16.0	14.9
Nitrate + Nitrite ($NO_2^- + NO_3^-$)	6.0	5.5	4.8	4.0	3.5
Dissolved Inorganic Phosphate (DIP)	5.1	4.6	4.0	3.5	2.8
Silicate ($Si(OH)_4$)	40.0	36.3	30.0	27.5	22.5

8.5. Discussion of Results

8.5.1 Trend Analyses

Relatively few significant trends were detected in the Ecosystem Processes Component (EPC) Program sediment-water flux data. It might be concluded that there were no trends in these data that emerged based on a linear model (*i.e.*, either increasing or decreasing trends that could be best fitted with a straight line). In this case, there may have been "trends" in the data but these were other than linear. Alternatively, it could be argued that trends were imbedded in the data set but that the variability associated with the data was sufficiently large so that the trends could not be detected. In other words, the level of detection was not sufficiently sensitive to detect these trends.

At this point it seems far more likely that the lack of temporal trend was related to the former as opposed to the latter explanations given above. In earlier reports (Boynton *et al.*, 1990) it was shown that there were substantial inter-annual differences in the magnitude of specific fluxes at various stations. However, these inter-annual differences generally did not proceed in either an increasing or decreasing pattern. Rather, it appeared that fluxes were related to the magnitude of nutrient loading rates which at most sites has not simply increased or decreased during the monitoring period, except in the Potomac River where a general (although not completely consistent) declining flow was evident (Figure 6.1.1). Additionally, very strong statistical and experimental relationships have been observed between the magnitude of sediment-water fluxes and the amount of labile organic matter on the sediment surface resulting from the deposition of the spring bloom. Spring bloom deposition, in turn, has been related to nutrient loading rates (Figure 7.5.1). Thus, it appears that the natural inter-annual variability in nutrient loading rates (due to wet and dry years) is providing a larger signal than the nutrient reductions achieved by the management program to date. In this regard, future measurements in the Patuxent River will be of particular interest because substantial phosphorus reductions have been achieved and nitrogen reductions began during the fall of 1991.

If these reductions are large enough to dominate the natural variations due to inter-annual weather changes temporal trends in sediment-water fluxes should become evident. In fact a few are evident already. The station in the lower Potomac River (RGPT) exhibited significant increases in sediment oxygen consumption (SOC) rates and significant decreases in ammonia (NH_4^+), phosphorus (PO_4^-) and nitrate plus nitrite (NO_2^- + NO_3^-) fluxes (Table 8-4). These changes in flux are consistent with predictions associated with lower nutrient loading conditions which has been the case in the Potomac River (Figure 6-1.1). Its important to note that in all the other river systems there has been at least one cycle in high-low river flow during the monitoring period, except in the Potomac River where flows have been generally below the fifteen year average and steadily decreasing during the last four years. As the relationships between flow (*i.e.*, nutrient loading rates) and ecosystem responses (*e.g.*, sediment-water exchanges) becomes clearer it may be possible to better account for inter-annual variations in flux attributable to natural as opposed to anthropogenic causes. This in turn would further improve the ability to detect trends in these data sets.

8.5.2 Power Analyses

In the preceding section it was suggested that the lack of trend detection was due to the lack of linear increase or decrease in flux rate rather than an inability to detect trends. The power analysis conducted indicates this is the case because the differences in fluxes which can be detected with the present sampling scheme are quite small and in all cases are also small in terms of general ecological impact.

Limits of detection for the changes in flux rates provided in Table 8-2 are all small relative to the average fluxes observed at SONE stations and are very small relative to average fluxes observed during summer periods when fluxes are typically highest (Figures 6-2.1a - 6-2.1e). Sediment oxygen consumption (SOC) fluxes at SONE stations range between 0.5 and 2.5 g O_2 m^{-2} day^{-1} during spring and early summer. An annual change of about 0.08 g O_2 m^{-2} day^{-1} represents an ability to detect a change of between 3 and 16 percent per year. Similar results emerge for other fluxes as well, suggesting that the current sampling regime is adequate.

Another way to evaluate the effectiveness of sampling is to compare the level of change in flux which can be detected with some change in another environmental variable of management interest. In this case ammonium fluxes provide a good example. During summer periods it appears that nitrogen limits primary production in the mesohaline regions of the bay. During this period of the year sediments are an important source of nitrogen (as well as Si and PO_4^-) which supports primary production rates. Summer sediment release rates of ammonium are in the range of 250-300 μMN m^{-2} hr^{-1} which is an amount capable of supporting primary production rates of about 0.6 g C m^{-2} day^{-1}. Total production rates are about 1-2 g C m^{-2} day^{-1} so it is clear that sediment nutrient supplies are important. It appears that we can detect ammonium flux changes of about 24 μMN m^{-2} hr^{-1} yr^{-1}. This level of detection is equivalent to an 8% change in primary production rate, a very small change. Similar results are obtained when other nutrient fluxes are considered in this same context. It would seem that the level of detection, which will continue to improve gradually over the next few years, is adequate for the variables measured in the SONE portion of the EPC Program.

REFERENCES

Alden R.W. III, J.C. Siebel and C.M. Jones. 1990. Analysis of the Chesapeake Bay Program Monitoring Design for detecting Water Quality and Living Resource trends. AMRL Technical Report No.747. Applied Marine Research Laboratory, College of Science, Norfolk, VA 23529-0456. *Draft Manuscript.*

Aspila, I., H. Agemian, and A.S.Y. Chau. 1976. A semi-automated method for the determination of inorganic, organic and total phosphate in sediments. Analyst 101:187-197.

Boicourt, W. 1992. Influences of Circulation Processes on Dissolved Oxygen in the Chesapeake Bay. In: D.E. Smith, M. Leffler and G. Mackiernan [Eds.], Oxygen Dynamics in the Chesapeake Bay: A synthesis of Recent Research, Maryland Sea Grant Book, College Park, MD, p. 7-59.

Boynton, W.R. and W.M. Kemp. 1985. Nutrient regeneration and oxygen consumption by sediments along an estuarine salinity gradient. Mar. Ecol. Prog. Ser. 23:45-55.

Boynton, W.R., W.M. Kemp and J.M. Barnes. 1985a. Ecosystem Processes Component Level I Data Report No. 2. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES]CBL Ref. No. 85-121.

Boynton, W.R., W.M. Kemp and C.W. Keefe. 1982a. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production, p. 69-90. In: V.S. Kennedy, [Ed.], Estuarine Comparisons, Academic Press, NY.

Boynton, W.R., W.M. Kemp and C.G. Osborne. 1980. Nutrient fluxes across the sediment-water interface in the turbid zone of a coastal plain estuary, p. 93-109. In: V.S. Kennedy, [Ed.], Estuarine Perspectives, Academic Press, NY.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1991. Ecosystem Processes Component Level 1 Interpretive Report No. 8. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 91-110.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S.E. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1992b. Ecosystem Processes Component Level 1 Interpretive Report No 9. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 92-042.

Boynton, W.R., W.M. Kemp, J.H. Garber and J.M. Barnes. 1986. Ecosystem Processes Component Level 1 Interpretive Report No. 3. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 86-56b.

Boynton, W.R., W.M. Kemp, J.H. Garber, J.M. Barnes, L.L. Robertson and J.L. Watts. 1987. Ecosystem Processes Component Level 1 Interpretive Report No. 4. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 88-06.

Boynton, W.R., W.M. Kemp, J.H. Garber, J.M. Barnes, L.L. Robertson and J.L. Watts. 1988. Ecosystem Processes Component Level 1 Interpretive Report No. 5. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 88-69.

Boynton, W.R., W.M. Kemp, L. Lubbers, K.V. Wood and C.W. Keefe. 1985b. Ecosystem Processes Component. Pilot Study, June-July 1984. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 85-3.

Boynton, W.R., W.M. Kemp, C.G. Osborne, E. Spalding, C.W. Keefe and K.V. Wood. 1982b. Estuarine community dynamics in relation to power plant operations. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 82-78.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn and F.M. Rohland. 1990. Ecosystem Processes Component Level 1 Interpretive Report No. 7. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 90-062.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, J.L. Watts., S. Stammerjohn and L.L. Matteson. 1989. Ecosystem Processes Component Level 1 Interpretive Report No. 6. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 89-080.

Boynton, W.R., J.H. Garber, W.M. Kemp, and R. Summers. 1992a. Input, Storage, Recycling and Fate of Nitrogen and Phosphorus in Chesapeake Bay and Selected Tributaries. Draft Report to Maryland Department of the Environment, 2500 Broening Highway, Baltimore, MD 21224.

Boynton, W.R. and F.M. Rohland. 1990. Ecosystem Processes Component (EPC) Data Dictionary. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 90-029.

Boynton, W.R., F.M. Rohland and L.L. Matteson. 1992. Update Pages (Volumes I and II). Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 92-105.

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Science. Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey.

Day, J.W. Jr., C.A.S. Hall, W.M. Kemp and A. Yanez-Arancibia. 1989. Estuarine Ecology. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, Singapore.

Dixon, W.J. and F.J. Massey, Jr. 1969 Introduction to statistical analysis. 3rd ed. McGraw Hill Book Co., New York. 638p.

D'Elia, C.F., D.M. Nelson, and W.R. Boynton. 1983. Chesapeake Bay nutrient and plankton dynamics: III. The annual cycle of dissolved silicon. Geochim. Cosmochim. Acta 14:1945-1955.

Environmental Protection Agency (EPA). 1979. Methods for Chemical Analysis of Water and Wastes. USEPA-6000/4-79-020. Environmental Monitoring and Support Laboratory, Cincinnati, OH.

Environmental Protection Agency (EPA). 1989. Sediment data management plan. Chesapeake Bay Program. CBP/TRS 29/89.

Freund, R.J. and R.C. Littell. 1986. SAS System for Regression. SAS Series in Statistical Applications, SAS Institute Inc., SAS Circle Box 8000, Cary, NC 27512-8000.

Garber, J.H., W.R. Boynton, and W.M. Kemp. 1987. Ecosystem processes component-study plan and budget for FY88. Maryland Office of Environmental Programs. Maryland Chesapeake Bay Water Quality Monitoring Program. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 87-50.

Garber, J.H., W.R. Boynton, J.M. Barnes., L.L. Matteson, L.L. Robertson, A.D. Ward and J.L. Watts. 1989. Ecosystem Processes Component and Benthic Exchange and Sediment Transformations. Final Data Report. Maryland Department of the Environment. Maryland Chesapeake Bay Water Quality Monitoring Program. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 89-075.

Gerrodette, T. 1987. A Power Analysis for Detecting Trends. Ecology 68(5): 1364 - 1372.

James, R.W., Jr., J.F. Horlein, B.F. Strain and M.J. Smigaj. 1990. Water Resources Data Maryland and Delaware Water Year 1990. 1. Atlantic Slope Basins, Delaware River through Patuxent River. U.S. Geological Survey Water-Data Report MD-DE-90-1.

Jensen, M.H., E. Lomstein and J. Sorensen. 1990. Bethic NH_4 and NO_3 flux following sedimentation of a spring phytoplankton bloom in Aarhus Bight, Denmark. Mar. Ecol. Prog. Ser. 61:87-96.

Kelly, J.R. and S.W. Nixon. 1984. Experimental studies of the effect of organic deposition on the metabolism of a coastal marine bottom community. Mar Ecol. Prog. Ser. 17:157-169.

Kemp, W.M. and W.R. Boynton. 1980. Influence of biological and physical factors on dissolved oxygen dynamics in an estuarine system: implications for measurement of community metabolism. Estuar. Coast. Mar. Sci. 11:407-431.

Kemp, W.M. and W.R. Boynton. 1981. External and internal factors regulating metabolic rates of an estuarine benthic community. Oecologia 51:19-27.

Kemp, W.M. and W.R. Boynton. 1984. Spatial and temporal coupling of nutrient inputs to estuarine primary production: the role of particulate transport and decomposition. Bull. Mar. Sci. 35:522-535.

Kemp, W.M. and W.R. Boynton. 1992. Benthic-Pelagic Interactions: Nutrient and Oxygen Dynamics. In: D.E. Smith, M. Leffler and G. Mackiernan [Eds.], Oxygen Dynamics in the Chesapeake Bay: A synthesis of Recent Research, Maryland Sea Grant Book, College Park, MD, p. 149-221.

Kemp, W.M., W.R. Boynton, J.C. Stevenson, R.W. Twilley and J.C. Means. 1983. The decline of submerged vascular plants in Chesapeake Bay: summary of results concerning possible causes. Mar. Tech. Soc. J. 17(2):78-89.

Krom, M.D. and R.A. Berner. 1980. The diffusion coefficients of sulfate, ammonium and phosphate ions in anoxic marine sediments. Limnol. Oceanogr. 25: 327 - 337.

Magnien R.E. *et al.* 1987. Monitoring for management actions. First Biennial Report. The Maryland Office of Environmental Programs, Chesapeake Bay, Water Quality Monitoring Program, Baltimore, MD.

Magnien, R.E., D.K. Austin and B.D. Michael. 1990. Chemical/Physical Properties Component: Level I Data report. Chesapeake Bay Projects Division, Chesapeake Bay and Special Projects Program, Water Management Administration, 2500 Broening Highway, Baltimore, MD 21224.

Malone, T.C. 1992. Effects of Water Column Processes on Dissolved Oxygen Nutrients, Phytoplankton and Zooplankton. In: D.E. Smith, M. Leffler and G. Mackiernan [Eds.], Oxygen Dynamics in the Chesapeake Bay: A synthesis of Recent Research, Maryland Sea Grant Book, College Park, MD, p. 149-221.

Myers, R.H. 1990. Classical and Modern Regression with Applications. The Duxbury Advanced Series in Statistics and Decision Sciences, PWS-Kent Publishing Company, Boston.

Nixon, S.W. 1981. Remineralization and nutrient cycling in coastal marine ecosystems, p. 111-138. In: B.J. Neilson and L.E. Cronin [Eds.], Estuaries and Nutrients, Humana Press, Clifton, NJ.

Nixon, S.W. 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol. Oceanogr., 33 (4, part 2), 1005-1025.

Paashe, E. 1973. The influence of cell size on growth rate, silica content, and some other properties of four marine diatom species. Norw. J. Bot. 20:197-204.

Pearson, E.S. and H.O. Hartley (ed). 1976. Biometrika tables for statisticians. Vol.2. Charles Griffin and Company Ltd. Buckinghamshire, England. 385 p.

Peterman, R.M. 1990a The Importance of Reporting Statistical Power: The Forest decline and acidic deposition example. Ecology 71(5), 2024 - 2027.

Peterman, R.M. 1990b. Statistical Power Analysis can Improve Fisheries Research and Management. Can J. Fish. Aquat. Sci. 47:2-15.

Progress Report of the Baywide Nutrient Reduction Reevaluation, Chesapeake Bay Program. 1992. U.S. Environmental Protection Agency for the Chesapeake Bay Program [CSC.LR18.12/91].

Roden, E.E. 1990. Sediment sulfur cycling and its relationship with carbon cycling and oxygen balance in the Chesapeake Bay. Ph. D. Thesis. MEES Program, University of Maryland. 256 p.

SAS User's Guide: Statistics. 1985. Version 5 Edition. SAS Institute Inc., Box 8000, Cary, North Carolina 27511-8000.

Sellner, K. 1989. Long term phytoplankton monitoring and assessment program. Maryland Chesapeake Bay Water Quality Monitoring Program. Benedict Estuarine Research Laboratory, Benedict, MD.

Shoaf, W.T. and B.W. Lium. 1976. Improved extraction of chlorophyll a and b from algae using dimethyl sulfoxide. Limnol. Oceanogr. 21:926-928.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fish. Res. Bd. Can. Bull. 167 (second edition).

Smith, E. 1992. Seasonal and longitudinal patterns of planktonic community production and respiration. M. Sc. Thesis. Marine Environmental and Estuarine Studies Program. University of Maryland System, Horn Point Environmental Laboratories, Cambridge, MD.

Summers, R.M. 1989. Point and Non-point Source Nitrogen and Phosphorus loading to the Northern Chesapeake Bay. Maryland Department of the Environment, Water Management Administration, Chesapeake Bay and Special Projects Program. Technical Report, Baltimore MD.

Technicon Industrial Systems. 1977. Silicates in water and seawater. Industrial Method No. 186-72W/B. Technicon Industrial Systems, Terrytown, NY.

APPENDIX A

ECOSYSTEM PROCESSES COMPONENT SONE AND VFX PARAMETER LIST

INTRODUCTION

Appendix A contains Table A-1 part of the Ecosystem Processes Component Data Dictionary. The data dictionary is an extensive reference document providing a listing and description of all variables used by the Maryland Department of the Environment, Ecosystem Processes Component (MDE/EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program.

Table A-1 lists all variables used in both the sediment oxygen and nutrient exchanges (SONE) and vertical flux (VFX) programs. The variables are sorted in alphabetical order using the MDE/EPC table name (Table A-1). This is followed by the one to eight character CHESSEE variable name as a cross reference since the data from this component is to be incorporated into the Chesapeake Bay Program (CBP) data base (CHESSEE). Table A-1 contains a parameter description, the MDE/EPC unit of measure and the unit abbreviation used in all MDE/EPC data tables.

Table A-1. SONE and VFX Variable and Parameter List

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
AA VIAL NO	SAMPLEID	Basic identification number for water samples.	Number	
BASIN	BASIN	Name of basin: Chesapeake Bay.	Alpha	
BLANK SLOPE DIP	BS_DIP	Time rate of change of phosphorus concentration in SONE blank chamber.	Micromoles per liter per minute	$\mu M/(l \bullet min)$
BLANK SLOPE DO	BS_DO	Time rate of change of dissolved oxygen concentration in SONE blank chamber.	Milligrams per liter per minute	$mg/(l \bullet min)$
BLANK SLOPE H2S	BS_H2S	Time rate of change of hyrodgen sulfide concentration in SONE blank chamber.	Nanomoles per liter per minute	$nM/(l \bullet min)$
BLANK SLOPE NH4	BS_NH4	Time rate of change of ammonium concentration in SONE blank chamber.	Micromoles per liter per minute	$\mu M/(l \bullet min)$
BLANK SLOPE NO23	BS_NO23	Time rate of change of nitrite plus nitrate concentration in SONE blank chamber.	Micromoles per liter per minute	$\mu M/(l \bullet min)$
BLANK SLOPE Si(OH)4	BS_DSI	Time rate of change of siliceous acid concentration in SONE blank chamber.	Micromoles per liter per minute	$\mu M/(l \bullet min)$
B Si	BIO_SI	Particulate biogenic silica (amorphous opal) concentration in water sample.	Micrograms per liter	$\mu g/l$
CHLa ACTIVE	CHL_A	The total chlorophyll-a of a water sample is acidified and measured fluorometrically. Active chlorophyll-a is then determined by subtracting the value obtained following acidification from the total chlorophyll-a value.	Micrograms per liter	$\mu g/l$
CHLa TOTAL	CHL_T	The total chlorophyll-a concentration of a water sample determined by extraction in 90% acetone and measured fluorometrically. This value includes active chlorophyll-a and some undefined chlorophyll-a degredation products.	Micrograms per liter	$\mu g/l$
COND	COND	Conductivity of water.	Millimhos per centimeter	mmho/cm
CORE DEPTH	CORE_Z	Depth either above or beneath (negative values) the sediment water interface at which measurement was taken; a core depth of zero represents the sediment water interface.	Centimeters	cm
CORE H_2O DEPTH	COREWATZ	Height of water above the sediment surface in SONE chamber.	Meters	m
CORE H_2O VOL	CORE_WAT	Total volume of water overlying SONE sediment core in a SONE chamber.	Milliliters	ml

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
CORE NO	CORE_NO	SONE chamber replicate identifier.	Alpha or numeric	
CORR DIP	DIP_CORR	Dissolved inorganic phosphorus concentration of a filtered water sample which has been corrected for salinity effects.	Micromolar	μM
CRUISE	CRUISE	SONE cruise identifier.	See Appendix B Table B-2	
CUP DEPTH	CUP_DPTH	Depth of water from water surface to the top of the sediment trap cup.	Meters	m
DATE	DATE	Date of sample collection or measurement, alphanumeric.	Day, Month, Year	DDMMMYY
DATE DEP	DATE_DEP	Date on which VFX sediment trap was set out, alphanumeric.	Day, Month, Year	DDMMMYY
DATE RET	DATE_RET	Date on which VFX sediment trap was retreived, alpha-numeric.	Day, Month, Year	DDMMMYY
DILU VOL	DILU_VOL	Total volume, in liters, in which VFX sediment trap contents are suspended for sub-sampling.	Liters	l
DIP	DIP_MOL	Dissolved inorganic phosphorus concentration of a filtered water sample.	Micromolar	μM
DIP FLUX	DIP_FLUX	Net flux of dissolved inorganic phosphorus across sediment water interface.	Micromolar phosphorus per square meter per hour	μMP/(m^2 • hr)
DIP FLUX MEAN	DIP_MFLX	Average of triplicate dissolved inorganic phosphorus flux determinations at a SONE station.	Micromolar phosphorus per square meter per hour	μMP/(m^2 • hr)
DIP SLOPE	DIP_SLP	Time rate of change of dissolved inorganic phosphorus concentration in overlying waters of a SONE chamber.	Micromolar phosphorus per liter per minute	μMP/(l • min)
DO	DISOXY	Dissolved oxygen concentration.	Milligrams per liter	mg/l
DO FLUX	DO_FLUX	Net flux of dissolved oxygen across sediment-water interface. DO flux is synonomous with sediment oxygen consumption (SOC).	Grams oxygen per square meter per day	$gO_2/(m^2 \cdot day)$

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
DO FLUX MEAN	DO_MFLX	Average of triplicate dissolved oxygen flux determinations at a SONE station.	Grams oxygen per square meter per day	$gO_2/(m^2 \cdot day)$
DO SAT	DOSAT	Measured oxygen concentration relative to oxygen saturation concentration at sample temperature and salinity.	Percentage	%
DO SLOPE	DO_SLP	Time rate of change of dissolved oxygen concentration in over-lying waters of a SONE chamber.	Milligrams O_2 per liter per minute	$mg/(l \cdot min)$
Eh CORR	EH_CORR	Eh corrected = Eh measured + 244mV. This gives Eh relative to the hydrogen electrode.	Millivolts	mV
Eh MEAS	ORP	A measure of the chemical environment (oxidizing or reducing) at a specific depth in the sediment column measured relative to a calomel electrode.	Millivolts	mV
FLUX BSi	BSI_VFX	The calculated flux of biogenic silica to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX CHLa ACTIVE	CHLA_VFX	The calculated flux of active chlorophyll-a to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX CHLa TOTAL	CHLT_VFX	The calculated flux of total chlorophyll-a to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX PC	PC_VFX	The calculated flux of particulate organic carbon to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX PN	PN_VFX	The calculated flux of particulate organic nitrogen to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX PP	PP_VFX	The calculated flux of particulate phosphorus to the depth of the opening of the VFX sediment trap cup.	Milligrams per square meter per day	$mg/(m^2 \cdot day)$
FLUX SESTON	SEST_VFX	The calculated flux of total particulates to the depth of the opening of the VFX sediment trap cup.	Grams per square meter per day	$g/(m^2 \cdot day)$

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
GEAR CODE	GEAR	Sampling Gear Code.	See Appendix B Table B-8	
H2O %	H2O_SED	The percentage (by weight) of water loss by drying for a specified section of the sediment column.	Grams of water per 100 grams of wet sediment	%
H2S	H2S_MOL	Hydrogen sulfide concentration of a filtered water sample.	Micromolar	μM
H2S FLUX	H2S_FLUX	Net flux of dissolved hydrogen sulfide across sediment water interface.	Micromolar sulfur per square meter per hour	$\mu MS/(m^2 \bullet hr)$
H2S FLUX MEAN	H2S_MFLX	Average of triplicate hydrogen sulfide flux determinations at a SONE station.	Micromolar sulfur per square meter per hour	$\mu MS/(m^2 \bullet hr)$
H2S SLOPE	H2S_SLP	Time rate of change of hydrogen sulfide concentration in overlying waters of a SONE chamber.	Micromolar sulfur per liter per minute	$\mu MS/(1 \bullet min)$
LAT	LAT	Latitude.	Decimal degrees and minutes	
LONG	LONG	Longitude.	Decimal degrees and minutes	
NH4	NH4_MOL	Ammonium concentration of a filtered water sample.	Micromolar	μM
NH4FLUX	NH4_FLUX	Net flux of dissolved ammonium across sediment water interface.	Micromolar nitrogen per square meter per hour	$\mu MN/(m^2 \bullet hr)$
NH4 FLUX MEAN	NH4MFLX	Average of triplicate ammonium flux determinations at a SONE station	Micromolar nitrogen per square meter per hour	$\mu MN/(m^2 \bullet hr)$

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
NH_4 SLOPE	NH4_SLP	Time rate of change of ammonium	Micromolar per minute	μM/min
NH4 SLOPE	NH4_SLP	Time rate of change of ammonium concentration in overlying waters of a SONE chamber.	Micromoles nitrogen per liter per minute	μMN/(l • min)
NO2	NO2_MOL	Nitrite concentration of a filtered water sample.	Micromolar	μM
NO2 FLUX	NO2_FLUX	Net flux of dissolved nitrite across sediment water interface.	Micromolar nitrogen per square meter per hour	μMN/(m^2 • hr)
NO2FLUX MEAN	NO2_MFLX	Average of triplicate nitrite flux determinations at a SONE station.	Micromolar nitrogen per square meter per hour	μMN/(m^2 • hr)
NO2SLOPE	NO2_SLP	Time rate of change of nitrite concentration in overlying waters of a SONE chamber.	Micromolar nitrogen per liter per minute	μMN/(l • hr)
NO2+NO3	NO23_MOL	Nitrite + nitrate concentration of a filtered water sample.	Micromolar	μM
NO2+NO3 FLUX	NO23FLUX	Net flux of dissolved nitrite + nitrate across sediment water interface.	Micromolar nitrogen per square meter per hour	μMN/(m^2 • hr)
NO2+NO3 FLUX MEAN	NO23MFLX	Average of triplicate nitrite + nitrate flux determinations at a SONE station.	Micromolar nitrogen per square meter per hour	μMN/(m^2 • hr)
NO2+NO3 SLOPE	NO23_SLP	Time rate of change of nitrite + nitrate concetration in overlying waters of a SONE chamber.	Micromolar nitrogen per liter per minute	μMN/(l • min)

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
PC	PC_WAT	Particulate organic carbon concentration of a water sample.	Micrograms per liter	$\mu g/l$
PN	PN_WAT	Particulate organic nitrogen concentration of a water sample.	Micrograms per liter	$\mu g/l$
PP	PP_WAT	Particulate phosphorus concentration of a water sample.	Micrograms per liter	$\mu g/l$
SALIN	SALIN	Salinity of water at sample depth.	Parts per thousand	ppt
SALZONE	SALZONE	Basic description of salinity regime at a SONE or VFX sampling station.	See Appendix B Table B-7	
SAMPLE DEPTH	SDEPTH	Sample depth from surface of water.	Meters	m
SECCHI DEPTH	SECCHI	Depth from water surface to which Secchi disk can be seen.	Meters	m
SECTION MIDPOINT	SECMPT	The midpoint of a sediment section as measured from the sediment surface e.g. a sediment slice from 2-3 cm depth would have a sediment midpoint of 2.5 cm.	Centimeters	cm
SED CHLa ACTIVE	CHLA_SED	The total chlorophyll-a sediment section sample is acidified and measured fluorometrically. Active chlorophyll-a is then determined by subtracting the value obtained following acidification from the total chlorophyll-a value.	Milligrams per square meter	mg/m^2
SED CHLa TOTAL	CHLT_SED	The total chlorophyll-a concentration of a sediment section sample determined by extraction in 90% acetone and measured fluorometrically. This value includes active chlorophyll-a and some undefined chlorophyll-a degredation products.	Milligrams per square meter	mg/m^2
SED PC	PC_SED	Percentage by dry weight of particulate organic carbon for a specified section of the sediment column.	Grams carbon per 100 grams of dry sediment	% (wt)
SED PN	PN_SED	Percentage by dry weight of particulate organic nitrogen for a specified section of the sediment column.	Grams nitrogen per 100 grams of dry sediment	% (wt)
SED PP	PP_SED	Percentage by dry weight of particulate phosphorus for a specified section of the sediment column.	Grams phosphorus per 100 grams of dry sediment	% (wt)

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
SEGMENT	SEGMENT	Chesapeake Bay Program segment designation.	See Appendix B Table B-3	
SESTON	SES_MG	Concentration as dry weight of total particulates in a water sample (seston).	milligrams per liter	mg/l
SILICATE FLUX	DSI_FLUX	Net flux of dissolved silicate across sediment water interface.	Micromolar silicate per square meter per hour	μMSi/(m^2 • hr)
SILICATE FLUX MEAN	DSIMFLUX	Average of triplicate silicate flux determinations at a SONE station.	Micromolar silicate per square meter per hour	μMSi/(m^2 • hr)
SILICATE SLOPE	DSISLOPE	Time rate of change of silicate concentration in overlying waters of a SONE chamber.	Micromolar silicate per liter per minute	μMSi/(l • min)
Si(OH)4	DSI_MOL	Silicious acid concentration of a filtered water sample.	micromolar	μM
SOURCE	SOURCE	Data collecting agency.	See Appendix B Table B-4	
STANAME	STANAME	Nearest Maryland station.	See Appendix B Table B-5.2	
STATION	STATION	Sampling station identifier.	See Appendix B Table B-5.1	
TDN	TDN_MOL	Total dissolved nitrogen concentration of a filtered water sample.	Micromolar nitrogen per liter	μMN/l
TDP	TDP	Total dissolved phosphorus concentration of a filtered water sample.	Micromolar phosphorus per liter	μMP/l
TEMP	WTEMP	Temperature of water at sample depth.	Degrees Centigrade	C
TIME	TIME	Time of day that sample was collected using 24-hour clock.	Hours, minutes in 24-hour time	HHMM
TIME DELTA	TIME_DEL	Time difference between samples.	Minutes	MM

Table A-1. SONE and VFX Variable and Parameter List - CONT

MDE/EPC TABLE NAME	CHESSEE VARIABLE NAME	PARAMETER DESCRIPTION	MDE/EPC UNIT	UNIT ABBR
TIME DEP	TIME_DEP	Time of day at which VFX sediment trap was deployed using 24-hour clock.	Hours, minutes in 24-hour time	HHMM
TIME OF SAMPLE hr	TIME_H	Hour portion of time variable.	Hours	HH
TIME OF SAMPLE min	TIME_M	Minute portion of time variable.	Minutes	MM
TIME RET	TIME_RET	Time of day at which VFX sediment trap was retrieved, using 24-hour clock.	Hours, minutes in 24-hour time	HHMM
TIME SUM	TIME_SUM	Summation of the time elapsed from beginning of incubation of a SONE chamber.	Minutes	MM
TIME TOTAL	TIME_TOT	Total number of deployment days of VFX sediment trap.	Decimal days	Days
TOTAL DEPTH	TDEPTH	Total depth of water column at station.	Meters	m
TOTAL DEPTH AVG	TDEP_AVG	Average of water depth measured when VFX sediment trap was deployed and water depth measured when VFX sediment trap was retrieved.	Meters	m
[UMCEES] CBL REF. NO.	DOC_ID	Documentation identification.	Alpha-numeric	

DATE: NOVEMBER 1990

APPENDIX D

STATISTICAL ANALYSIS SYSTEM (SAS) PROGRAMS

STAGE 1: INFLUENCE DIAGNOSTICS

PROGRAMS: RGPTNH4.sas
REG.sas

```
***            STAGE 1: PLOTS AND SLOPE CALCULATIONS OF FLUX DATA
***            Programmer: Frances Rohland
***            Date: June 1991


***            Program Name: RGPTNH4.SAS ;


OPTIONS PS=52 ls= 80 PAGENO=1 ;

LIBNAME SONE 'E:\riverf\' ;

data ALL;
  set SONE.SWFLUX;
  if station in ('RGPT') ;
  FLUX = NH4_FLUX ;
run;

title1 'STATION IS RAGGED POINT, POTOMAC RIVER' ;

data FLUX ;
SET ALL ;
  if station in ('RGPT') ;
  month = month(date) ;
  year  = year(date) ;
  keep sone station core_no month year flux;
run;

TITLE2 'VARIABLE IS AMMONIUM (NH4) ' ;

PROC SORT DATA=FLUX;
  BY FLUX ;
  QUIT;

PROC PRINT DATA=FLUX ;
  VAR STATION SONE CORE_NO MONTH YEAR FLUX;
  QUIT;

DATA FLUX;
SET FLUX ;
  IF FLUX=. THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;


***          APRIL ;
DATA BAPR;
SET FLUX ;
  IF MONTH NOT = 4 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;


proc sort data=BAPR ;
```

```
  by YEAR;
  quit;

DATA BAPR;
  SET BAPR;
TITLE3 ' MONTH IS APRIL (4) ' ;

proc print data=BAPR ;
  var station sone core_no month year flux ;

PROC MEANS PRINT DATA=BAPR ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BAPR ;
  BY YEAR ;
VAR FLUX;

QUIT;

*** FIND THE LINEAR REGRESSION EQUATIONS ;
PROC REG DATA=BAPR;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = APRIL (4) ' ;
  RUN ;


***          MAY ;

DATA BMAY;
SET FLUX ;
  IF MONTH NOT = 5 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;

proc sort data=BMAY ;
  by year;
  quit;


DATA BMAY;
  SET BMAY;
TITLE3 ' MONTH IS MAY (5) ' ;

proc print data=BMAY ;
  var station sone core_no month year flux ;
```

```
PROC MEANS PRINT DATA=BMAY ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BMAY ;
  BY YEAR ;
VAR FLUX;
QUIT;

* FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BMAY;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = MAY (5) ' ;
  RUN ;


***        JUNE ;
DATA BJUN;
SET FLUX ;
  IF MONTH NOT = 6 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;

proc sort data=BJUN ;
  by year;
  quit;


DATA BJUN ;
  SET BJUN;
TITLE3 ' MONTH IS JUNE (6) ' ;


proc print data=BJUN ;
  var station sone core_no month year flux ;


PROC MEANS PRINT DATA=BJUN ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BJUN ;
  BY YEAR ;
VAR FLUX;
QUIT;
```

```
* FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BJUN;

MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = JUNE (6) ' ;
  RUN ;


***          JULY ;

DATA BJUL;
SET FLUX ;
  IF MONTH NOT = 7 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;

proc sort data=BJUL ;
  by year;
  quit;

DATA BJUL ;
  SET BJUL;
TITLE3 ' MONTH IS JULY (7) ' ;

proc print data=BJUL ;
  var station sone core_no month year flux ;

PROC MEANS PRINT DATA=BJUL ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BJUL ;
  BY YEAR ;
VAR FLUX;
QUIT;


*** FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BJUL;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
```

```
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = JULY (7) ' ;
  RUN ;


***        AUGUST ;

DATA BAUG;
SET FLUX ;
  IF MONTH NOT = 8 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;

proc sort data=BAUG ;
  by year;
  quit;

DATA BAUG ;
  SET BAUG;
TITLE3 ' MONTH IS AUGUST (8) ' ;

proc print data=BAUG ;
  var station sone core_no month year flux ;

PROC MEANS PRINT DATA = BAUG ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BAUG ;
  BY YEAR ;
VAR FLUX;
QUIT;

*** FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BAUG;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = AUGUST (8) ' ;
  RUN ;

***        OCTOBER ;

DATA BOCT;
SET FLUX ;
  IF MONTH NOT = 10 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
```

```
RUN;

proc sort data=BOCT ;
  by Year;
  quit;

DATA BOCT ;
  SET BOCT;
TITLE3 ' MONTH IS OCTOBER (10) ' ;

proc print data=BOCT ;
  var station sone core_no month year flux ;

PROC MEANS PRINT DATA=BOCT ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BOCT ;
  BY YEAR ;
VAR FLUX;
QUIT;

* FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BOCT;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = OCTOBER (10) ' ;
  RUN ;


***        NOVEMBER ;

DATA BNOV;
SET FLUX ;
  IF MONTH NOT = 11 THEN DELETE ;
  KEEP SONE STATION CORE_NO MONTH YEAR FLUX ;
RUN;

proc sort data=BNOV ;
  by year;
  quit;

DATA BNOV ;
  SET BNOV;
TITLE3 ' MONTH IS NOVEMBER (11) ' ;

proc print data=BNOV ;
```

```
  var station sone core_no month year flux ;

PROC MEANS PRINT DATA=BNOV ;
  BY MONTH;
VAR FLUX;
QUIT;

PROC MEANS PRINT DATA=BNOV ;
  BY YEAR ;
VAR FLUX;
QUIT;

* FIND THE LINEAR REGRESSION EQUATIONS ;

PROC REG DATA=BNOV;
  MODEL FLUX = YEAR ;
  OUTPUT OUT=BNH P=PRED;
  TITLE2 ' FLUX LINEAR REGRESSION BY YEAR' ;

PROC PLOT DATA = BNH;
  PLOT FLUX*YEAR = '*' PRED*YEAR = '@'/OVERLAY BOX;
  LABEL FLUX = 'NH4 FLUX';
  TITLE2 'PLOT OF FLUX FOR RGPT, MONTH = NOVEMBER (11) ' ;
  RUN ;
```

```
***          STAGE 1: INFLUENCE DIAGNOSTICS
***          Statistician: Larry Douglass
***          Date: June 1991



***          FILENAME : REG.SSD ;


OPTIONS PAGESIZE = 70 ls = 78 PAGENO=1 ;

LIBNAME SONE 'E:\LDSSD\' ;

data ALL ;

      set SONE.SWFLUX ;
      if station in
   ('BRIS','BUVA','MRPT','STLC','R-64','PNPT','HNPT','RGPT');
      FLUX = NH4_FLUX ;

run;


title1 ' Dependent Variable is NH4 FLUX' ;
***    Deletes lines where FLUX is missing  ***  ;

data FLUX;
SET ALL;

   if station in('BUVA','STLC','R-64','PNPT','HNPT','RGPT');
   if FLUX=. then delete ;

   month = month(date) ;
   year = year(date) ;
   KEEP SONE STATION CORE_NO MONTH YEAR FLUX;

run ;

proc sort data = FLUX;
   by station month year ;

quit ;


***          The following two PROCS count the number    ***;
***          of available years in the data set     ***;

proc means noprint data = FLUX;
    by station month year ;
    var flux ;
    output out = no_yr mean = flux ;
quit ;


```

```
proc means noprint data = NO_YR ;
   by station month ;
   var FLUX ;
   output out = NO_YR n=no_yr ;
quit ;

title 2 'Analysis using 4 or more years and 4 or more months' ;
***    adds NO_YR to the flux data set, ;
***    sets the minimum no of years required for analysis, ;
***    and computes a centered year linear and quadratic terms ;
***    for regression ;

data FLUX;
   merge FLUX NO_YR ;
   by station month ;
   if first.station then stat_no+1 ;
   if no_yr ge 4;
   yr_lin = year -1985 ;
   yr_quad = yr_lin**2 ;
   drop _type_ _freq_;
run ;

title3 'Print of data used for determining regression coefficients' ;
   proc print uniform data = FLUX ;
quit ;

title3 'Analysis of the quadratic regression coefficient' ;
***    creates data set of regression coefficients ;
***    for combinations of station and months ;
proc reg data = FLUX outest = BETAS ;
   by station month ;
   model flux = yr_lin yr_quad/INFLUENCE ;
   output out = RESID r=r_flux p=p_flux ;
quit ;

title3 'Residual plots' ;
proc plot data = RESID;
   plot r_flux * p_flux
   r_flux*stat_no
   r_flux*month/vref=0 ;
quit ;


title3 'Descriptive statistics and outliers for regression analysis' ;
   proc univariate normal plot data = RESID ;
   var r_flux ;
quit ;


***    The following PROC counts the ;
***    number of available months  ;
proc means data = BETAS ;
   by station ;
   var  yr_quad
```

```
    output out = NO-MO n=no_mo ;
quit ;

data NO_MO ;
set NO_MO;
    drop _type_ _freq_ ;


***   Adds the number of months to the BETAS data set *** ;
***   and sets the minimum number of months          *** ;
***   required for analysis                          *** ;
data BETAS ;
merge BETAS NO_MO ;
   by station ;
   if no_mo ge 4 ;
   mo_lin = -.5858500*(month=5)-.3254720*(month=6)
         +.1952824*(month=8)+.7160390*(month=10) ;
   mo_quad = +.4959593*(month=5) -.2806090*(month=6)
         -.6786810*(month=8) +.1503764*(month=10);
drop _type_ ;
run ;


title3 'Print of data used for analysis of variance' ;
proc print data = BETAS ;
quit ;


title3 'Full model' ;
proc glm data = BETAS ;
class station ;

      model yr_quad =
      station
      mo_lin
      mo_lin*station
      mo_quad
      mo_quad*station
     /ss4 ;
quit ;


title 'Final Model' ;
proc glm data = BETAS ;
class station ;
    model yr_quad =
    station
    month
    /ss4 ;


estimate 'mean quad' intercept 6 station 1 1 1 1 1 1
   month 43.5
   /divisor = 6 ;
```

```
lsmean station/stderr pdiff e  ;
output out= RESID r = ryr_quad p = pyr_quad ;
quit ;


title4 'Examination of Assumptions ';
data RESID;
   set RESID;
   ayr_quad = abs(ryr_quad) ;
run ;

proc plot data = RESID;
   plot ryr_quad*pyr_quad/vref=0;
quit ;


pooc corr spearman data = RESID ;
   var ayr_quad ;
   with pyr_quad ;
quit ;


proc univariate normal plot data = RESID ;
var ryr_quad ;
quit ;
```

STAGE 2: WEIGHTED LEAST MEAN SQUARE ANALYSIS

PROGRAM: NH4_FLUX.sas

```
***          STAGE 2: WEIGHTED LEAST SQUARE ANALYSIS
***          Statistician: Larry Douglass
***          Date: June 1991


title1 'BOYNTON and ROHLAND  -  SEDIMENT FLUX DATA';

***          Program Name: NH4_FLUX.SAS ***;

options ls=125 ps=45 pageno=1;


*** libname syntax for 6.06 ***;
libname ssd v604 'a:\';

*** libname syntax for 6.04 ***;
*libname ssd 'a:\';

***  reading in river flow data  ***;
data FLOW;
set SSD.RIVERFLW;
run;

proc sort data=FLOW;
by river year month;
quit;


*** libname syntax for 6.06 ***;
libname ssv v604 'a:\';

*** libname syntax for 6.04 ***;
*libname ssv 'a:\';

*** reading in sediment flux data ***;
title2 'Dependent variable is NH4 FLUX';
data ALL;
set SSV.SWFLUX;
if station in('BRIS','BUVA','MRPT','STLC','R-64','PNPT','HNPT','RGPT');
flux = nh4_flux;
keep sone station core_no date flux;
run;


***  creating a river identification variable and extracting  ***
***  a month and year code from the date                      ***;
title3 'Analysis using 3 or more years and 3 or more months';
*** Deletes lines where FLUX FLUX is missing *****;
data FLUX;
set ALL;
if station in('BRIS','BUVA','MRPT','STLC') then river='PTX ';
if station in('R-64','PNPT') then river='SUS ';
if station in('HNPT') then river='CHOP';
if station in('RGPT') then river='POT ';
```

```
if flux=. then delete;
month = month(date);
year = year(date);
keep sone river station core_no month year flux;
run;

proc sort data=FLUX;
by river year month;
quit;

*** deleting data lines when flux is missing ***;
data FLUX;
merge FLUX FLOW;
by river year month;
if flux=. then delete;
run;


proc sort data=FLUX;
by station year month core_no;
quit;

*** The following data step counts the number of months ***;
data NO_MOS;
set FLUX;
by station year month core_no;
if first.year then no_mos=0;
if first.month then no_mos+1;
if last.year then output;
keep station year no_mos;
run;


*** Adds NO_MOS to the FLUX data set, sets the minimum number ***
*** of months required for anlaysis.                         ***;
data FLUX;
merge FLUX NO_MOS;
by station year;
if no_mos ge 3;
run;


proc sort data=FLUX;
by river station month year core_no;
quit;

*** The following data step counts the number  ***
*** of observations and the number of years    ***;
data NO_YRS;
set FLUX;
by river station month year core_no;
if first.month then do;
  no_yrs=0;
  no_obs=0;
```

```
end;
no_obs+1;
if first.year then no_yrs+1;
if last.month then output;
keep river station month no_yrs no_obs;
run;


*** Adds NO_YRS to the FLUX data set, sets the minimum number ***
*** of years required for anlaysis, and defines yr=0 as 1985 ***
*** and computes log10 of yr for regression analysis.       ***;
data FLUX;
merge FLUX NO_YRS;
by river station month;
if first.station then stat_no+1;
if no_yrs ge 3;
yr = year - 1985;
log_flow=log10(flow);
run;


title4 'Print of data used for determining regression coefficients';
proc print uniform data=FLUX;
quit;


title4 'Parameter esimates for the linear regression coefficient';
title5 'Ordinary least squares';
*** Creates data set of regression coefficients ***
*** for combinations of river, station and month ***;
proc reg noprint data=FLUX outest=BETA;
by river station month;
model flux = yr;
output out=WTS r=res dffits=dffits;
quit;


title6 'Model includes yr';
proc print uniform data=BETA;
var river station month _rmse_ yr;
quit;


*** computes weights first weighted model ***:
data WTS;
set WTS;
p=2;
*** where p = # of regression parameters ***;
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
*** where 1.5 provides a bound for wts<1 ***;
kwl = k / abs(dffits);
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
```

```
res0=res;
drop res dffits;
run;
%MACRO ITER;
*** generates dffits used to weight each iteration ***;
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = yr;
output out=wts r=res dffits=dffits;
quit;
*** computes weights for each iteration
data WTS;
set WTS;
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
kwl = k / abs(dffits*(res/res0));
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
res0=res;
drop res dffits;
run;
%MEND ITER;
*** each line (%ITER) produces one iteration and the ***
*** weights for the next iteration                   ***;
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
```

```
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER


***** prints the data set used for the next to the last iteration *****;
title5 'Weighted least squares iteration #39';
title6 'Model includes yr';
proc print uniform data=BETA;
var river station month _rmse_ yr;
quit;


*** Performs the last iteration and creates a data set with ***
*** the change/yr estimates for the analysis of variance ***;
title5 'Weighted least squares iteration #40';
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = yr;
quit;


*** prints the change/year estimates to be used in the anova ***;
title6 'Model includes yr';
proc print uniform data=BETA;
var river station month _rmse_ yr;
quit;


*** prints the weights used for the last iteration *****;
title6 'Print of weights for last iteration';
proc print uniform data=WTS;
var sone river station core_no flux month year flow log_flow
   no_mos no_yrs no_obs stat_no yr wt;
quit;


data NO_OBS;
```

```
set FLUX;
by river station month;
if last.month then output;
keep river station month no_obs;
run;

*** Adds the number of observations to the BETA data set      ***
*** and the coefficients for month linear and month quadratic ***;
data YR;
merge BETA NO_OBS;
by river station month;
model='YEAR       ';
covar='NONE    ';
mo_lin  = -.5232680*(month=4) -.3640130*(month=5) -.204757*(month=6)
       -.0455020*(month=7) +.1137539*(month=8) +.432265*(month=10)
       +.5915205*(month=11);
mo_quad = +.5585835*(month=4) +.0693893*(month=5) -.2602100*(month=6)
       -.4302130*(month=7) -.4406220*(month=8) +.0173473*(month=10)
       +.4857248*(month=11);
keep river station month model covar yr mo_lin mo_quad no_obs;
run;

title4 'Parameter esimates for the linear regression coefficient';
title5 'Ordinary least squares';
*** Creates data set of regression coefficients  ***
*** for combinations of river, station and month ***;
proc reg noprint data=FLUX outest=BETA;
by river station month;
model flux = flow yr;
output out=WTS r=res dffits=dffits;
quit;

title6 'Model includes flow yr';
proc print uniform data=BETA;
var river station month _rmse_ flow yr;
quit;

data WTS;
set WTS;
p=3;
*** where p = # of regression parameters ***;
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
*** where 1.5 provides a bound for wts<1 ***;
kwl = k / abs(dffits);
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
res0=res;
drop res dffits;
run;
```

```
%MACRO ITER;
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = flow yr;
output out=wts r=res dffits=dffits;
quit;


data WTS;
set WTS;
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
kwl = k / abs(dffits*(res/res0));
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
res0=res;
drop res dffits;
run;


%MEND ITER;


%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
```

```
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER


title5 'Weighted least squares iteration #39';
title6 'Model includes flow yr';
proc print uniform data=BETA;
var river station month _rmse_ flow yr;
quit;


title5 'Weighted least squares iteration #40';
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = flow yr;
quit;


title6 'Model includes flow yr';
proc print uniform data=BETA;
var river station month _rmse_ flow yr;
quit;


title6 'Print of weights for last iteration';
proc print uniform data=WTS;
var sone river station core_no flux month year flow log_flow
   no_mos no_yrs no_obs stat_no yr wt;
quit;


data NO_OBS;
set FLUX;
by river station month;
if last.month then output;
keep river station month no_obs;
run;


*** Adds the number of observations to the BETA data set ***;
data FL_YR;
merge BETA NO_OBS;
by river station month;
model='FLOW YEAR    ';
```

```
covar='FLOW   ';
mo_lin  = -.5232680*(month=4) -.3640130*(month=5) -.204757*(month=6)
      -.0455020*(month=7) +.1137539*(month=8) +.432265*(month=10)
      +.5915205*(month=11);
mo_quad = +.5585835*(month=4) +.0693893*(month=5) -.2602100*(month=6)
      -.4302130*(month=7) -.4406220*(month=8) +.0173473*(month=10)
      +.4857248*(month=11);
keep river station month model covar yr mo_lin mo_quad no_obs;
run;


title4 'Parameter esimates for the linear regression coefficient';
title5 'Ordinary least squares';
*** Creates data set of regression coefficients  ***
*** for combinations of river, station and month ***;
proc reg noprint data=FLUX outest=BETA;
by river station month;
model flux = log_flow yr;
output out=WTS r=res dffits=dffits;
quit;


title6 'Model includes log_flow yr';
proc print uniform data=BETA;
var river station month _rmse_ log_flow yr;
quit;


data WTS;
set WTS;
p=3;
*** where p = # of regression parameters ***;
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
*** where 1.5 provides a bound for wts<1 ***;
kwl = k / abs(dffits);
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
res0=res;
drop res dffits;
run;


%MACRO ITER;
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = log_flow yr;
output out=wts r=res dffits=dffits;
quit;


data WTS;
set WTS;
```

```
k=1.5*(p**.5)*(((p-1)/no_obs)**.5);
kwl = k / abs(dffits*(res/res0));
if kwl > 1 then wt=1;
  else wt=kwl;
if wt=. then wt=.01;
res0=res;
drop res dffits;
run;


%MEND ITER;


%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
%ITER
```

```
title5 'Weighted least squares iteration #39';
title6 'Model includes log_flow yr';
proc print uniform data=BETA;
var river station month _rmse_ log_flow yr;
quit;


title5 'Weighted least squares iteration #40';
proc reg noprint data=WTS outest=BETA;
by river station month;
weight wt;
model flux = log_flow yr;
quit;


title6 'Model includes log_flow yr';
proc print uniform data=BETA;
var river station month _rmse_ log_flow yr;
quit;


title6 'Print of weights for last iteration';
proc print uniform data=WTS;
var sone river station core_no flux month year flow log_flow
   no_mos no_yrs no_obs stat_no yr wt;
quit;


data NO_OBS;
set FLUX;
by river station month;
if last.month then output;
keep river station month no_obs;
run;


*** Adds the number of observations to the BETAS data set ***;
data LF_YR;
merge BETA NO_OBS;
by river station month;
model='LOG_FLOW YEAR';
covar='LOG_FLOW';
mo_lin  = -.5232680*(month=4) -.3640130*(month=5) -.204757*(month=6)
        -.0455020*(month=7) +.1137539*(month=8) +.432265*(month=10)
        +.5915205*(month=11);
mo_quad = +.5585835*(month=4) +.0693893*(month=5) -.2602100*(month=6)
        -.4302130*(month=7) -.4406220*(month=8) +.0173473*(month=10)
        +.4857248*(month=11);
keep river station month model covar yr mo_lin mo_quad no_obs;
run;


*** libname syntax for 6.06 ***;
libname ssd v604 'a:\';
```

```
*** libname syntax for 6.04 ***;
*libname ssd 'a:\';


data SSD.NH4_FLUX;
set YR FL_YR LF_YR;
depvar='NH4 ';
run;


title6 'Print of parameter estimates for analysis of variance';
proc print uniform data=SSD.NH4_FLUX;
quit;
```

STAGE 3: ANALYSIS OF VARIANCE

PROGRAM: NH4_AOV.sas

```
***              STAGE 3: ANALYSIS OF VARIANCE
***              Statistician: Dr Larry Douglass
***              Date: July/August 1991


title1 'BOYNTON and ROHLAND  -  SEDIMENT FLUX DATA';

title2 'Dependent variable is NH4 FLUX';
title3 'Analysis using 3 or more years and 3 or more months';

***              Program Name: NH4_AOV.SAS *****;

options ls=96  ps=52 pageno=1;

*** libname syntax for 6.04 *****;
libname ssd 'b:\';

***  Data set contains flow and flux data for the eight sites, ***
***  (BRIS, BUVA, MRPT, STLC, R-64, PNPT, HNPT and RGPT).     ***;
data BETA;
set SSD.NH4FLUX;
run;

title4 'Print of linear parameter estimates for analysis of variance';
proc print uniform data=BETA;
where covar='FLOW';
var river station month no_obs depvar covar yr;
quit;

proc sort data=beta;
by depvar covar model;
quit;

***  yr is change/year  ***;
title4 'Anova where the dependent variable is change/year';
proc glm data=BETA;
by depvar covar model;
where covar='FLOW';
weight no_obs;
class river station month;
model yr=
    river
    station(river)
    month
month*river
    /ss4;
estimate 'grand lsmean' intercept 112  river 28 28 28 28
       station(river) 28 28 7 7 7 7 14 14
       month 16 16 16 16 16 16 16
       river*month  4 4 4 4 4 4 4  4 4 4 4 4 4 4
                4 4 4 4 4 4 4  4 4 4 4 4 4 4
       /divisor=112;
lsmeans river station(river) month  month*river/stderr pdiff;
output out=resid r=ryr p=pyr;
```

```
quit;

title5 'Examination of residuals';
data resid;
set resid;
wryr=ryr*no_obs**.5;
wayr=abs(wryr);
run;

proc plot data=resid;
by depvar covar model;
plot ryr*pyr
    wryr*pyr/vref=0;
quit;

proc corr spearman nosimple data=resid;
by depvar covar model;
var wayr;
with pyr;
quit;

proc univariate normal plot data=resid;
by depvar covar model;
var wryr;
quit;
```

STAGE 4: POWER ANALYSIS

PROGRAM: FLXPOWER.sas

```
***          STAGE 4:  POWER ANALYSIS
***          Statistician:  Dr Larry Douglass
***          July/August 1991


OPTIONS LS=96 PS=52 PAGENO=1;

***          Program Name:  FLXPOWER.SAS                         ***
***                                    ***
*** minchgyr, maxchgyr and interval are the min and max for    ***
***   change/year and the increment for computing and for     ***
***   the x-axis for the power curve.                  ***
*** alpha is the desired level of type I error.            ***
*** seb is the standard error of the change/year.            ***
*** dfe is the error degrees of freedom for the anova.         ***
*** yr is the final year of sampling, this is what controls     ***
***   sample size.                        ***;


%macro power(minchgyr, maxchgyr, interval, alpha, seb, dfe, yr);
data POWER;
do chg_yr = &minchgyr to &maxchgyr by &interval;
*** computes the total number of years to be sampled ***;
no_yrs  = &yr-84;
*** computes the number of years to be added to the data set ***;
add_yrs = &yr-91;
*** delta is the total change ***;
delta = chg_yr*no_yrs;
*** rseb is relative standard error of the change/year based on ***
*** the current years seb.                        ***;
rseb = &seb / ((4.5+add_yrs)/4.5)**.5;
*** stddelta is the standardized delta, change/year divided by ***
*** the relative standard error.                 ***;
stddelta= chg_yr / rseb;
*** computes the critical t value for alpha and error df.     ***;
crit=tinv(1-&alpha/2,&dfe);
*** computes power using the non-central t distribution      ***;
power=1-probt(crit,&dfe,stddelta)+probt(-crit,&dfe,stddelta);
*** the non-central generates an error message and a missing   ***
*** value for type II error, therefore power has been set to 1 ***;
if power=. then power=1;
output;
end;
run;

*** plots the power curve ***;
proc plot data=power;
plot power*chg_yr='+'/vaxis=0 to 1 by .1 vref=.05 href=0;
quit;

*** prints the data for power curve ***;
proc print;
quit;
```

```
%mend power;

*** this is the syntax for the mower macro                    ***
*** power(minchgyr, maxchgyr, interval, alpha, seb, dfe, yr) ***;

title 'Power of the test for NH4 - alpha=.05 and data thru 91';
%power (-25, +25, 2.5, .05, 6.18067115, 16, 91);

title 'Power of the test for NH4 - alpha=.05 and data thru 92';
%power (-25, +25, 2.5, .05, 6.18067115, 16, 92);

title 'Power of the test for NH4 - alpha=.05 and data thru 94';
%power (-25, +25, 2.5, .05, 6.18067115, 16, 94);

title 'Power of the test for NH4 - alpha=.05 and data thru 96';
%power (-25, +25, 2.5, .05, 6.18067115, 16, 96);

title 'Power of the test for NH4 - alpha=.05 and data thru 2000';
%power (-25, +25, 2.5, .05, 6.18067115, 16, 100);


title 'Power of the test for DO - alpha=.05 and data thru 91';
%power (-.25, +.25, .025, .05, .02444803, 16, 91);

title 'Power of the test for DO - alpha=.05 and data thru 92';
%power (-.25, +.25, .025, .05, .02444803, 16, 92);

title 'Power of the test for DO - alpha=.05 and data thru 94';
%power (-.25, +.25, .025, .05, .02444803, 16, 94);

title 'Power of the test for DO - alpha=.05 and data thru 96';
%power (-.25, +.25, .025, .05, .02444803, 16, 96);

title 'Power of the test for DO - alpha=.05 and data thru 2000';
%power (-.25, +.25, .025, .05, .02444803, 16, 100);


title 'Power of the test for NO23 - alpha=.05 and data thru 91';
%power (-10, +10, 1, .05, 1.55827033, 16, 91);

title 'Power of the test for NO23 - alpha=.05 and data thru 92';
%power (-10, +10, 1, .05, 1.55827033, 16, 92);

title 'Power of the test for NO23 - alpha=.05 and data thru 94';
%power (-10, +10, 1, .05, 1.55827033, 16, 94);

title 'Power of the test for NO23 - alpha=.05 and data thru 91';
%power (-10, +10, 1, .05, 1.55827033, 16, 96);

title 'Power of the test for NO23 - alpha=.05 and data thru 2000';
%power (-10, +10, 1, .05, 1.55827033, 16, 100);
```

```
title 'Power of the test for DSI - alpha=.05 and data thru 91';
%power (-45, +45, 2.5, .05, 11.1385596, 16, 91);

title 'Power of the test for DSI - alpha=.05 and data thru 92';
%power (-45, +45, 2.5, .05, 11.1385596, 16, 92);

title 'Power of the test for DSI - alpha=.05 and data thru 94';
%power (-45, +45, 2.5, .05, 11.1385596, 16, 94);

title 'Power of the test for DSI - alpha=.05 and data thru 96';
%power (-45, +45, 2.5, .05, 11.1385596, 16, 96);

title 'Power of the test for DSI - alpha=.05 and data thru 2000';
%power (-45, +45, 2.5, .05, 11.1385596, 16, 100);


title 'Power of the test for DIP - alpha=.05 and data thru 91';
%power (-5.5, +5.5, .25, .05, 1.39085273, 16, 91);

title 'Power of the test for DIP - alpha=.05 and data thru 92';
%power (-5.5, +5.5, .25, .05, 1.39085273, 16, 92);

title 'Power of the test for DIP - alpha=.05 and data thru 94';
%power (-5.5, +5.5, .25, .05, 1.39085273, 16, 94);

title 'Power of the test for DIP - alpha=.05 and data thru 96';
%power (-5.5, +5.5, .25, .05, 1.39085273, 16, 96);

title 'Power of the test for DIP - alpha=.05 and data thru 2000';
%power (-5.5, +5.5, .25, .05, 1.39085273, 16, 100);
```

[UMCEES]CBL Ref. No.93-030a

MARYLAND DEPARTMENT OF THE ENVIRONMENT

MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYSTEM PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT NO. 10

PART 1: INTERPRETIVE REPORT

(July 1984 - December 1992)

APPENDIX B:
(Volume III: Boynton et al., 1992: [UMCEES]CBL Ref. No. 92-042)

1992:
SEDIMENT OXYGEN AND NUTRIENT EXCHANGES (SONE)
DATA SET:
DATA FILES FOR SONE PROGRAM: CRUISES 35 - 40
(January - December 1992)

Corrected pages for March 93 Report

Ref. No 93-030A

TABLE B-1.37. MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM
ECOSYSTEM PROCESSES COMPONENT
SEDIMENT OXYGEN AND NUTRIENT EXCHANGES (SONE)
WATER COLUMN PROFILES: Vertical profiles of temperature, salinity, dissolved oxygen and other characteristics at SONE stations

SONE CRUISE: 37
FILENAME : H2OPRF37
REVISED : 11OCT94

STATION	DATE	TIME	TOTAL DEPTH (m)	SECCHI DEPTH (m)	GEAR CODE	SAMPLE DEPTH (m)	TEMP (C)	COND (mmho/cm)	SALIN (ppt)	DO (mg/l)	DO SAT (%)
STLC	17JUL92	855	6.5	1.3	WP05	0.5	27.7	24.6	14.8	5.86	81.0
						2.0	27.5	24.7	14.9	5.22	71.9
						4.0	26.6	25.4	15.3	3.24	44.0
						6.0	25.8	25.9	15.7	2.35	31.5
BRIS	13JUL92	915	15.5	1.1	WP05	0.5	27.1	23.6	14.1	6.60	89.8
						2.0	27.0	23.7	14.2	6.41	87.2
						4.0	25.9	24.5	14.7	3.95	52.9
						6.0	25.2	25.3	15.3	2.35	31.1
						8.0	25.0	25.3	15.3	2.32	30.6
						10.0	25.0	25.3	15.3	2.32	30.6
						12.0	24.9	25.4	15.3	2.35	31.0
						14.0	24.9	25.5	15.4	2.33	30.7
						15.0	24.7	25.6	15.5	2.35	30.9
MRPT	13JUL92	1600	5.5	0.8	WP05	0.5	27.3	23.2	13.9	7.77	106.1
						2.0	27.3	23.2	13.9	7.61	103.8
						3.0	27.2	23.2	13.9	7.52	102.4
						4.0	26.7	23.6	14.1	3.75	50.7
						5.0	26.0	24.1	14.5	1.79	24.0
BUVA	13JUL92	1210	5.5	0.6	WP05	0.5	28.3	20.1	11.8	6.65	91.3
						2.0	28.0	20.4	12.0	5.76	78.8
						3.0	28.0	20.4	12.0	5.08	69.4
						4.0	27.7	20.8	12.3	4.51	61.4
						5.0	27.6	21.1	12.5	3.71	50.5

TABLE B-1.37. MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM
ECOSYSTEM PROCESSES COMPONENT
SEDIMENT OXYGEN AND NUTRIENT EXCHANGES (SONE)
WATER COLUMN PROFILES: Vertical profiles of temperature, salinity, dissolved oxygen and other characteristics at SONE stations

SONE CRUISE: 37
FILENAME : H2OPRF37
REVISED : 11OCT94

STATION	DATE	TIME	TOTAL DEPTH (m)	SECCHI DEPTH (m)	GEAR CODE	SAMPLE DEPTH (m)	TEMP (C)	COND (mmho/cm)	SALIN (ppt)	DO (mg/l)	DO SAT (%)
HNPT	15JUL92	1830	7.5	YY	WP05	0.5	28.2	23.7	14.2	7.19	99.9
						2.0	28.3	23.6	14.1	7.19	99.9
						4.0	28.3	23.7	14.2	7.20	100.0
						6.0	28.3	23.7	14.2	7.12	99.0
						7.0	28.3	23.7	14.2	7.03	97.7
RGPT	16JUL92	1315	16.5	1.2	WP05	0.5	27.9	20.3	11.9	9.50	129.5
						2.0	26.7	21.1	12.5	6.83	91.5
						4.0	25.6	23.9	14.3	3.79	50.3
						6.0	24.8	26.5	16.1	2.02	26.7
						8.0	23.9	27.9	17.0	1.06	13.9
						10.0	23.8	28.0	17.1	0.85	11.1
						12.0	23.2	28.1	17.2	0.27	3.5
						14.0	22.7	28.1	17.2	0.10	1.3
						16.0	22.5	28.2	17.2	0.22	2.8
PNPT	16JUL92	955	13.5	1.7	WP05	0.5	26.9	26.9	16.4	7.93	109.0
						2.0	27.0	26.9	16.4	7.76	106.8
						4.0	27.0	27.0	16.4	7.37	101.4
						6.0	27.0	27.2	16.6	7.11	98.0
						8.0	25.9	28.1	17.2	4.44	60.2
						10.0	24.0	29.9	18.4	1.77	23.4
						12.0	23.5	32.1	19.9	0.67	8.8
						13.0	23.4	32.2	20.0	0.71	9.4
R-64	14JUL92	1115	16.0	1.7	WP05	0.2	26.7	24.1	14.5	8.61	116.7
						2.0	26.4	24.2	14.5	8.44	113.8
						4.0	26.3	24.4	14.7	7.76	104.4
						6.0	25.7	25.1	15.1	6.45	86.2
						8.0	24.6	25.9	15.7	4.43	58.2
						10.0	22.6	27.8	17.0	1.44	18.4
						12.0	22.3	28.2	17.2	0.98	12.5
						14.0	22.2	28.3	17.3	0.73	9.3
						15.5	22.2	28.4	17.4	0.71	9.0