

**SEDIMENT WATER OXYGEN AND NUTRIENT EXCHANGES AT
SHOAL AND CHANNEL STATIONS IN THE UPPER BAY**

Final Report

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INTRODUCTION

As a part of the environmental evaluation of Pooles Island and other dredged material placement sites in the northern portion of Chesapeake Bay, measurements of sediment oxygen consumption and sediment releases of important nutrients (nitrogen, phosphorus and silica compounds) have been made since 1993. Sediment oxygen consumption (SOC) can be an important sink for oxygen in estuarine environments and sediment nutrient releases can be a very large source of both nitrogen and phosphorus to the water column (Boynton et al., 1991a). Both of the latter compounds are essential for phytoplankton growth, which can become excessive when nutrient supplies are large. Thus, sediment processes can play an important role in determining water quality conditions by lowering oxygen levels and promoting excessive algal growth.

Since 1993, summer sediment-water oxygen and nutrient exchanges have been measured in the vicinity of Pooles Island and more recently at Site 104 located just north of the Bay Bridge at Annapolis, MD. Prior to 1993, sediment-water oxygen and nutrient exchanges were also measured at several other locations in the upper Chesapeake Bay, most notably at a site adjacent to Still Pond Neck. Available data from the upper bay from the pre-1993 period have been summarized in Boynton et al. (1992a). Based on all these measurements several general patterns have emerged and include the following:

- 1) It appears that sediment processes are more active in the Pooles Island area than at the more northern site near Still Pond Neck; natural gradients exist in the magnitude of sediment-water oxygen and nutrient exchanges within the upper bay portion of the Chesapeake just as there are gradients along the entire length of the Bay system (Cowan and Boynton, 1996).
- 2) Summer sediment-nutrient exchanges are larger in areas having low dissolved oxygen in bottom water than in areas with well oxygenated bottom water; sediment-water exchanges were considerably higher at Site 104 than at the shallower and better oxygenated stations in the vicinity of Pooles Island.
- 3) It appears that sediment-water oxygen and nutrient exchanges are enhanced at relatively shallow water sites (<10 m) which have recently received dredged material and that controlled bottom placement of material produces larger sediment-water exchanges than does hydraulic placement; these enhanced exchanges appear to last for about one year (i.e. if placement occurred during winter months, sediment-water exchanges were enhanced during the following summer but returned to pre-placement rates by the next summer; Boynton et al. 1992a).

The first part of this shoal and channel study characterizes sediment-water exchanges of oxygen and nutrients and measures surficial nutrient concentrations during one summer period (August, 1997) when sediment processes are most active and important relative to overall water quality conditions. The second part characterizes the pore water and solid phase composition of these sediments. Such measurements of vertical biogeochemical profiles can be used to identify some of the factors which control the sediment-water exchange of nutrients.

Measurements of sediment releases of important nutrients (nitrogen, phosphorus and silica compounds) were measured in August 1997, at five paired stations wherein one site of each pair

was located in a shipping channel and the other at an adjacent non-dredged site. Measurements at two stations made during August, 1997 as part of other sampling programs were included as part of this study (Pooles Island Reference Station [PLIS] and Fairfield Outfall. Combined with measurements of pore water and solid phase nutrients, iron and sulfur, a general comparison of biogeochemical processes can be made.

Acquisition and Analysis of Shoal and Channel Sediment Oxygen/Nutrient Flux and Associated Data

Location of Stations

During August, 1997, standard Sediment Oxygen and Nutrient Exchange (SONE) measurements were taken at two stations (Pooles Island Reference Station [PLIS] and Fairfield Outfall [FFOF]) and abbreviated measurements (MINISONE) were taken at 3 paired (shoal and channel) locations and at 2 channel sites near PLIS and FFOF. There were a total of ten stations.

Table 3-1 summarizes station names, station abbreviations, latitude and longitude derived from the on board differential global positioning system (DGPS), and sampling date information. Figure 3-1 shows the location of 5 paired stations.

Station Location Justification

Single sediment core samples were collected during August 1997 at eight sites in the upper bay (Figure 3-1). The sites were located along a eutrophication gradient (from the Baltimore Harbor Fort McHenry Channel out to the mainstem of the upper Bay along the Brewerton Channel) and in relatively high (Lower Craighill Channel) and low (Pooles Island Reference Station [PLIS]) salinity areas.

Sampling Frequency

The sampling frequency for the shoal and channel 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, 1981; Boynton et al., 1982; and Boynton and Kemp, 1985). These studies indicated that fluxes are generally highest during warm periods of the year (June through September). Accordingly, many sediment-water surveys are conducted with monthly measurements during the summer period. However, since the shoal-channel activity was a preliminary survey, one set of measurements, in August 1997, was completed at 5 paired sampling sites.

Field Methods for Shoal and Channel Stations

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). .

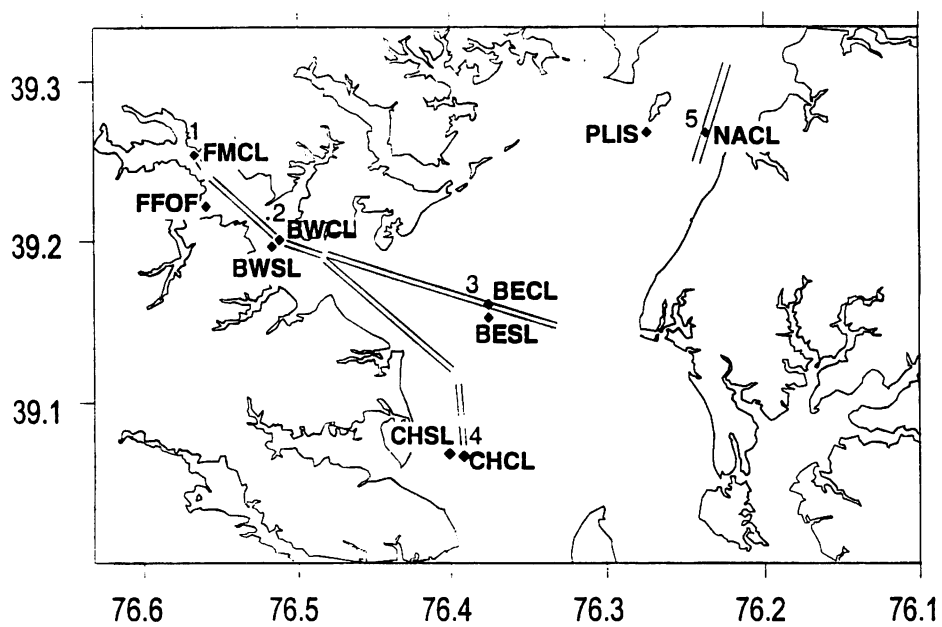


Figure 3. Location of Shoal and Channel stations in the Upper Bay area.

Table 1. Station Names, Location and Dates Sampled at the Shoal and Channel stations in the Upper Chesapeake Bay. The station labelled Brewerton Channel EAST sites corresponds to the Brewerton Channel Eastern Extension and the Brewerton Channel WEST is the Brewerton Channel proper.

Station Name	Station Abbrev.	Station Depth (m)	Latitude/ Longitude DGPS *	Year and Month Sampled
Brewerton Channel EAST	BECL	11.8 m	39° 09.585' 76° 22.344'	1997: August
Brewerton Shoal EAST	BESL	5.7 m	39° 09.724' 76° 22.261'	1997: August
Brewerton Channel WEST	BWCL	17.0 m	39° 11.457' 76° 28.597'	1997: August
Brewerton Shoal WEST	BWSL	6.0 m	39° 11.632' 76° 28.512'	1997: August
Craighill Channel	CHCL	16.1 m	39° 03.463' 76° 23.384'	1997: August
Craighill Shoal	CHSL	10.6 m	39° 03.510' 76° 23.206'	1997: August
Fort McHenry Channel	FMCL	16.4 m	39° 14.219' 76° 32.977'	1997: August
Fairfield Outfall	FFOF	6.0 m	39° 14.017' 76° 33.250'	1997: August
No. Approach Channel	NACL	18.4 m	39° 15.877' 76° 14.176'	1997: August
Pooles Island Reference Station	PLIS	3.9 m	39° 16.280' 76° 17.347'	1997: August

* Latitude and longitude is a calculated value based on Differential Global Positioning System values.

Water Column Profiles

At each of the shoal and channel stations, vertical water column (surface to bottom) profiles of temperature, salinity and dissolved oxygen were measured at 2 meter intervals immediately after obtaining intact sediment cores for incubation. The turbidity of surface waters is measured using a Secchi disc.

Water Column Nutrients

Near-bottom (0.5 - 1.0 meters) water samples were collected using a high volume submersible pump system. Samples were filtered, where appropriate, using 0.7 μm GF/F filter pads, and immediately frozen. Samples were analyzed by Nutrient Analytical Services Laboratory (NASL) for the following dissolved nutrients: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($\text{NO}_2^- + \text{NO}_3^-$), dissolved inorganic phosphorus corrected for salinity (DIP or PO_4^{3-}), and silicate ($\text{Si}(\text{OH})_4$)

Sediment-Water Exchange Studies

Sediment Profiles

At each station, a modified Bouma box corer was deployed to obtain several sediment cores. At the two standard (SONE) stations an intact sediment core is used to measure the redox potential, (Eh, in units of mV) of sediments at 1 cm intervals to about 10 cm of sediment depth. At each of the eight abbreviated (MINISONE type) stations, Eh is measured every centimeter to 2 cm depth, then every other cm thereafter.

Sub-cores of sediment are removed to a depth of 1 cm and immediately frozen for later analysis of particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active sediment chlorophyll-a. Surface sediment characterization which includes particulate nutrient and chlorophyll-a measurements and Eh profiling is used in the interpretation of oxygen and nutrient fluxes between sediment and overlying waters.

Sediment Cores

Both the standard (SONE type) measurements and the abbreviated (MINISONE type) program elements rely on the same field and laboratory techniques to estimate sediment-water oxygen and nutrient fluxes. At eight stations abbreviated protocols (relative to SONE) were used. Three replicated cores and a blank to estimate sediment-water flux were collected at stations using standard techniques whereas at stations where abbreviated techniques were used only a single sediment core was collected (no blank was used). Other minor differences between the standard and abbreviated measurements are noted below where applicable. In each case, intact sediment cores constitute a benthic microcosm where changes in oxygen and nutrient concentrations are determined. An overview of the measurement technique follows and the details of the techniques are provided in Boynton and Rohland (1990).

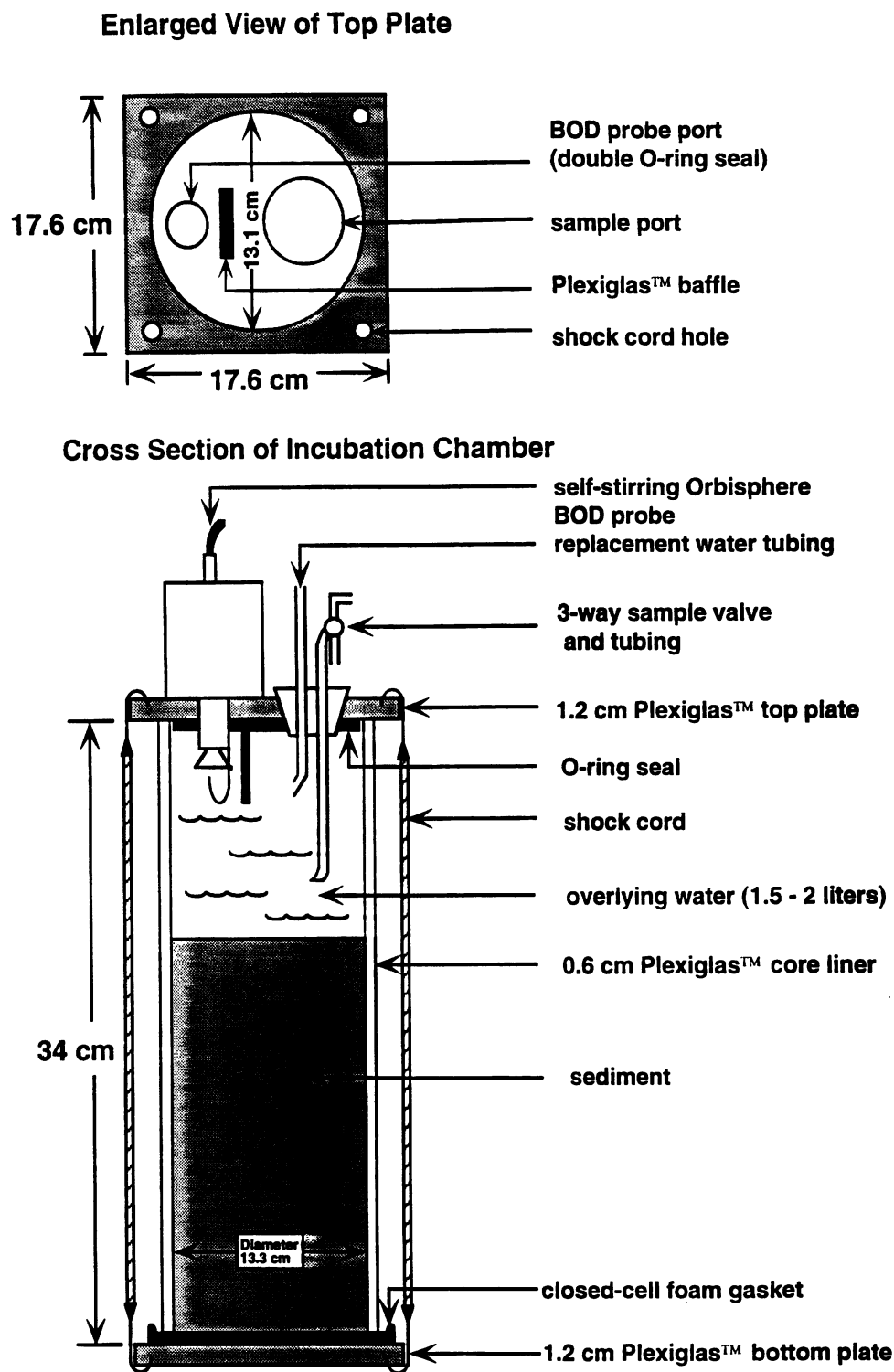
Sediment cores are collected at each station using a modified Bouma box corer. These cores are then transferred to a Plexiglass cylinder (15 cm diameter x 30 cm length) and inspected for disturbances such as large macrofauna or cracks in the sediment surface. If the sample is satisfactory, the core is fitted with an O-ring sealed top containing various sampling ports, and a gasket sealed bottom (Figure 3-2). The core is then placed in a darkened, temperature controlled holding tank where overlying water in the core is slowly replaced by ambient bottom water to ensure that water quality conditions in the core closely approximate in situ conditions. For the standard stations, water is also exchanged in the blank core.

During the period in which the flux measurements are taken, the cores are placed in a darkened temperature controlled bath to maintain ambient temperature conditions. The overlying water is gently circulated with no induction of sediment resuspension via stirring devices attached to the oxygen probes. Temperature and oxygen concentrations are recorded and overlying water samples (35 ml) are extracted from each core every 60 minutes during the incubation period. Standard stations are incubated for 4 hours so a total of 5 measurements, while abbreviated stations are incubated for 3 hours with a total of 4 measurements made. As a water sample is extracted from a core, an equal amount of ambient bottom water is added to replace the lost volume. Water samples are filtered and immediately frozen for later analysis for ammonium, nitrite, nitrite plus nitrate, dissolved inorganic phosphorous (DIP or PO_4^{3-}) and silicate (Si(OH)_4). 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.

Chemical Analyses

Standard oceanographic and estuarine methods of chemical analysis are used for all determinations of dissolved and particulate materials. Detailed reference material pertaining to all chemical analyses used is to be found in the EPC Data Dictionary (Boynton and Rohland, 1990) and Nutrient Analytical Services Laboratory: Standard Operating Procedures (D'Elia et al., 1997).

In brief, methods for the determinations of dissolved and particulate nutrients are as follows: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($\text{NO}_2^- + \text{NO}_3^-$), dissolved inorganic phosphorus (DIP) and silicate (Si(OH)_4) are measured using the automated method of EPA (1979); 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.



Data management and Quality Assurance and Quality Control (QA/QC) Checking

Shoal and Channel Data Files

Appendix I of this report contains data tables listing variables measured during August 1997. 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 month and year of collection. Within each file the stations are arranged in alphabetical order.

The data collected at each shoal or channel station are organized into five tables in the appendix:

WATER COLUMN PROFILES contain temperature, salinity and dissolved oxygen data measured at two meter intervals in the water column.

WATER COLUMN NUTRIENTS report bottom water dissolved nutrient concentrations.

SEDIMENT PROFILES include redox potential and selected sediment measurements of particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), total and active chlorophyll-a concentrations.

CORE DATA lists dissolved oxygen and nutrient measurements in shoal and channel sediment-water flux chambers.

SEDIMENT-WATER FLUX is a summary table providing oxygen and nutrient flux data.

Incorporation of Error Codes in Data Tables

In order to eliminate blank spaces in the data tables presented in Appendix I, a one or two letter alpha code (Table 2) is used to describe the problems associated with questionable parameter values. Valid entries from the Sediment Data Management Plan (EPA, 1989) are used.

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, 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.

Table 3-2. 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
DA	Damaged epiphyte array
DS	Damaged epiphyte strip
EE	Foil pouch very wet when received from field, therefore poor replication between pads, mean reported
FF	Poor replication between pads: mean reported
HD	Particulate and chlorophyll-a samples only taken at -1.0 cm of the Eh profile
HH	Sample not taken
JJ	Amount filtered not recorded (Calculation could not be done)
LA	Lost epiphyte array
LL	Mislabeled
LS	Lost epiphyte strip
NI	Data for this variable are considered to be non-interpretable
NN	Particulates found in filtered sample
NR	No replicate analyzed for epiphyte strip chlorophyll-a concentration
PA	Propagule trap added during cruise on June 5th, 1997
PF	Propagule trap not found in field
PG	Propagules weighed as a group, individual weights not recorded
PP	Assumed sample volume (pouch volume differs from data sheet volume: pouch volume used)
PU	Propagule trap found, but turned upside down
QQ	Although value exceeds a theoretically equivalent or greater value (e.g., $PO_4F > TDP$), the excess is within precision of analytical techniques and therefore not statistically significant
RR	No sample received
SD	All sampling at station discontinued for one or more sampling periods
SS	Sample contaminated in field
SW	Shallow water, light flux measured at two points only
TF	Dissolved oxygen probe failure
TL	Instrument failure in research laboratory
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
YB	No blank measured for MINI-SONE fluxes
YY	Data not recorded

Quality Assurance/Quality Control (QA/QC) Checking

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. The fourth international inter-comparison report was published in 1991 (Kirkwood, Aminot and Pertilä, 1991).
- Comparisons of dissolved nutrient analyses conducted at Horn Point Environmental Laboratory, Bigelow Laboratory, the University of Delaware and the University of New Hampshire.
- Quarterly cross calibration exercises with Virginia Institute of Marine Science (VIMS) and Old Dominion University (ODU). The most recent inter-comparison (December 1997) 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 procedures include inorganic nitrogen (ammonium, nitrite, nitrite plus nitrate) and dissolved inorganic phosphorus 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 Dr Boynton. This procedure is also carried out for other parameters performed by the laboratory. Precision and limits of detection for the variables measured are provided in the Data Dictionary (Boynton and Rohland, 1990).

Pore Water and Solid Phase Analyses

Sediments were collected by CBL personnel at the time they collected cores for sediment-water exchange studies. Sediments were collected by subcoreing the box corer with 7 cm id acrylic tubing.

All sediment extrusion and sectioning was carried out in nitrogen-filled glove bags to minimize oxidation artifacts (Bray et al. 1973). The sediments were sectioned in 0.5 cm intervals in the top 1 cm, with 1 and 2 cm sections deeper within the core (0.0-0.5, 0.5-1.0, 1-2, 2-3, 3-5, 5-7, 9-11, 16-18 cm intervals). Sediment was sectioned into 50 mL centrifuge tubes and centrifuged for 20 minutes at 4000 rpm. The water was filtered through a 0.4 μ m syringe filter. The pore water sample was divided into separate vials for each analysis immediately after filtration.

Pore water analysis was carried out using standard methodologies used in the HPL biogeochemistry laboratory for the last 5 years. These procedures are listed in Table 3.

Hydrogen sulfide and pH analyses were carried out immediately while most of the other analyses were completed within two weeks. Nitrate and silicate analyses were carried out in the HPL Analytical Services Laboratory. This suite of analyses allowed an assessment of sulfur-iron-phosphorus chemical cycling as well as information on nitrogen cycling. Concentrations of nutrients in sediments are generally 1-3 orders of magnitude higher than those in the water column. Dilution was used to put these analytes on scale for routine methodologies and to provide sufficient volume so that eight solutes could be analyzed on less than 10 milliliters of water.

Table 3. Pore Water Analyses

Analyte	Reference	Description
Soluble reactive phosphorus (SRP)	Parsons et al 1984 EPA 365.2	Manual colorimetric analysis
NH ₄ ⁺	Parsons et al. 1984	Phenol/hypochlorite colorimetry
NO ₃ ⁻	EPA 353.2	Automated colorimetric analysis
SO ₄ , Cl ⁻	EPA 300.0	Ion chromatography
Fe	Gibb 1979	Ferrozine colorimetry
H ₂ S	Cline 1969; EPA 376.2	Colorimetric analysis

We used dried sediment for the chemical analysis of most solid phase components. Acid volatile sulfide (AVS), consisting primarily of iron monosulfide (FeS), was measured on frozen mud samples from the pore water centrifugation. Chromium reducible sulfur (CRS) is the sum of AVS, pyrite-S and elemental S; in most Chesapeake Bay sediments, pyrite is the predominant form (Cornwell and Sampou, 1996). Organic carbon is determined as the total carbon from elemental carbon and nitrogen analysis. The HCl-Fe analysis is used as a measure of iron in the form of oxides and monosulfides (Leventhal and Taylor, 1990). Combined with the CRS analyses, the iron is partitioned into several important species. The form of the iron affects the ultimate fate of inorganic phosphorus in these estuarine sediments; the conversion of iron oxides into iron sulfide minerals may be a key determinant in phosphorus fluxes from Chesapeake Bay

sediments.

Table 4. Solid Phase Analyses

Analyte	Reference	Description
Total C, N		Control Instruments Elemental Analyzer
Total P	Aspila et al. 1976	HCl extraction of ashed sediment, colorimetry
Inorganic P	Aspila et al. 1976	HCl extraction of unashed sediment, colorimetry
HCl-Fe	Leventhal 1990	Analysis of 1.0 N HCL extract by flame AAS
CRS	Cornwell and Morse 1987	Cr(II) digestion, distillation, sulfide electrode
AVS	Cornwell and Morse 1987	Acidification, volatilization, sulfide electrode

INTERPRETATION OF DATA AND DISCUSSION

One of the continuing objectives of this program is to explore monitoring data, as well as other data sources, for relationships between nutrient loading (e.g., point, non-point and atmospheric sources, releases caused by dredging activities) and responses of sediment processes. 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 regulated by rates of external nutrient supplies. Freshwater input to the bay and tributary rivers is an important external forcing on bay ecology, largely determining salinity patterns, buoyancy and processes such as those mentioned above. Moreover, both the magnitude and timing of freshwater flow events have been shown to influence bay water quality (Boicourt, 1992). River flow has been shown to be a good first approximation of nutrient loading rates for many areas of Chesapeake Bay, including the upper bay, and this approximation is used in this report. The purpose of reporting these data in this report is to indicate the relative degree of nutrient loading experienced by the upper bay during monitoring activities of 1997.

Water Quality Conditions

Total (cumulative) river flow from the Susquehanna River for water years (October - September) 1968 - 1997 is shown in Figure 3. During this period, flows varied by about a factor of two and exhibited substantial year to year variation. For example, during the last four years, 1994 and 1996 had very high flows, 1995 had especially low flows and 1997 flows were closer to the long-term average.

Annual monthly flows (preliminary values released by the U.S.G.S. for 1997) for the Susquehanna River for the period 1993 through December, 1997 are shown in Figure 3. This provides details of freshwater input patterns experienced in the upper Bay. Average monthly flows in this system were high in April, 1993 (250,100 cfs), in March and April, 1994 (147,800 cfs) and in January - May, 1996 (117,800 cfs, 68,200 cfs, 74,800 cfs, 75,800 cfs and 84,600 cfs, respectively) and December, 1996 (115,900 cfs; Figure 3.). In contrast, 1995 was a notable low flow year, while 1997 was characterized by relatively low winter and spring flows but these flows were higher than the exceptionally low flows of 1995.

Bottom water temperatures at shoal stations ranged from 25.2°C to 26.5°C and were only very slightly lower at channel stations ranging from 23.5°C to 25.0°C. Bottom water temperature at the Pooles Island Reference Station (PLIS) was 20.6°C in June, 1997, 20.7°C in July and August, 1997 (Boynton et al., 1998). A summary of the bottom water conditions at the shoal and channel stations is presented in table 5. Figure 4 presents the bottom water conditions at the paired shoal and channel stations.

Bottom water salinity in 1997 ranged between 7.3 and 11.7 ppt at shoal stations and from 10.6 to 14.3 at channel stations. Bottom water salinity at Pooles Island Reference station was 1.6 ppt in June 1997, 4.6 ppt in July 1997 and 7.3 ppt in August, 1997 (Boynton et al., 1998)

Dissolved oxygen (DO) concentrations at shoal stations ranged from 2.6 mg L⁻¹ to 6.5 mg L⁻¹ and at channel stations from 0.1 mg L⁻¹ to 1.9 mg L⁻¹. Oxygen concentrations in bottom waters at Pooles Island Reference Station (PLIS) was 8.38 mg L⁻¹ in June, 1997, 6.54 mg L⁻¹ in July, 1997 and 6.53 mg L⁻¹ in August, 1997 (Boynton et al., 1998). Low DO values observed in channels in August may be the result of up bay advection of water from deeper areas of the Chesapeake Bay.

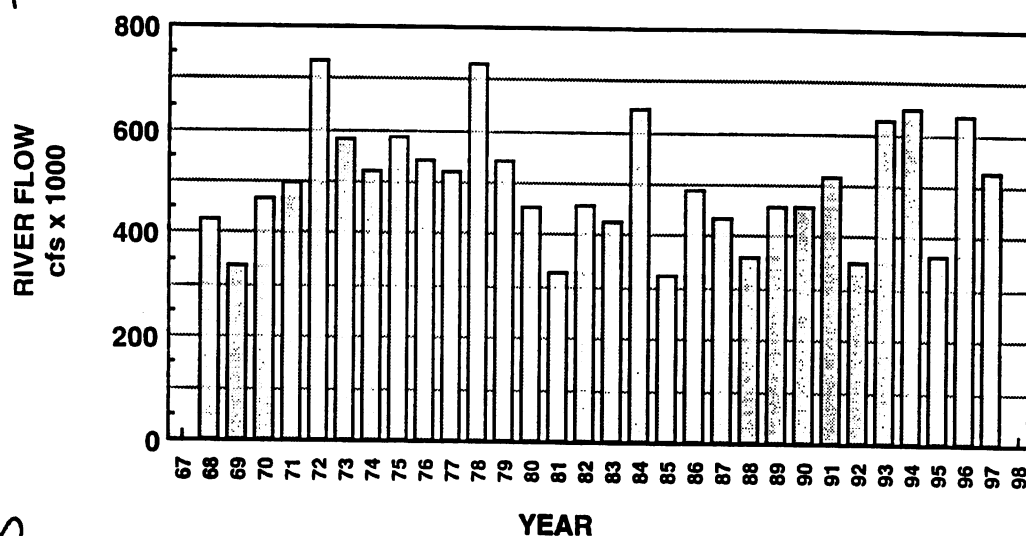
Ammonium concentrations ranged from 16.9 to 35.5 μmol N L⁻¹ at channel stations and from 8.3 to 18.7 μMN (Appendix I) at shoal stations. Ammonium concentrations recorded in 1997 at Pooles Island Reference Station (PLIS) ranged from 1.0 to 8.9 μmol N L⁻¹ (Boynton et al., 1998).

Nitrite plus nitrate concentrations ranged from 0.09 to 3.34 μmol N L⁻¹ at channel stations and from 0.91 to 11.00 μmol N L⁻¹ at shoal stations (Appendix I). Nitrite plus nitrate concentrations recorded in 1997 at Pooles Island Reference Station (PLIS) ranged from 11.0 to 40.0 μmol N L⁻¹ (Boynton et al., 1998).

Bottom water phosphorus (DIP) concentrations ranged from 0.64 to 2.72 μmol P L⁻¹ at channel stations and from 0.16 to 0.60 μmol P L⁻¹ at shoal stations (Appendix I). Dissolved inorganic phosphorus (DIP) concentrations recorded in 1997 at Pooles Island Reference Station (PLIS) ranged from 0.06 to 0.6 μmol P L⁻¹ (Boynton et al., 1998).

Silicate concentrations ranged from 44.7 to 47.4 μmol Si L⁻¹ at channel stations and from 38.4 to 42.0 μMSi at shoal stations Table B-2.1). Silicate concentrations recorded in 1997 at Pooles Island Reference Station (PLIS) ranged from 8.2 to 40.8 μmol Si L⁻¹ (Boynton et al., 1998).

A



B

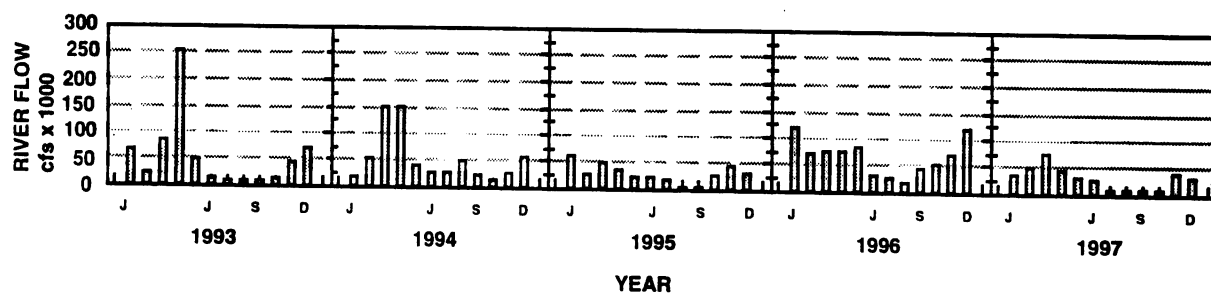


Figure 3a. Bar graphs of water year (October - September) cumulative river flow for the Susquehanna River for the period 1968 through 1997 (James et al., 1995; Monthly summaries of cumulative stream flow in Maryland, Pennsylvania and Virginia. USGS Pamphlet.). Flow was measured at Conowingo, MD Station # 01578310.

b. Bar graphs of average monthly river flow from the Susquehanna River for 1993, 1994, 1995, 1996 and 1997. Flows were measured at Conowingo, MD. Station # 01578310.

Table 5. Summary of Bottom Water Conditions at Shoal and Channel Stations: temperature, salinity and dissolved oxygen. All samples are from 1997.

Station	Date	Total Depth (m)	Secchi Depth (m)	Sample Depth (m)	Temp (C)	Cond (mmho /cm)	Salin (ppt)	DO (mg/L)	DO Sat (%)
Fairfield Outfall	Aug 12	5.7	1.3	5.0	26.0	15.6	8.9	6.4	82.3
Fort McHenry Channel	Aug 12	16.4	1.3	15.0	23.5	23.6	14.1	0.2	2.0
Brewerton Shoal West	Aug 12	6.0	0.5	5.0	25.4	16.8	9.7	2.6	34.0
Brewerton Channel West	Aug 12	16.4	0.7	16.0	23.8	23.9	14.3	0.1	1.5
Brewerton Shoal East	11 Aug	5.7	1.2	5.0	25.3	17.4	10.0	5.3	68.0
Brewerton Channel East	11 Aug	12.0	1.2	11.0	24.0	23.0	13.7	0.1	0.9
Craighill Shoal	11 Aug	10.0	1.3	9.5	25.2	20.0	11.7	4.3	55.8
Craighill Channel	11 Aug	16.0	1.4	15.0	24.1	23.8	14.3	0.1	1.0
Pooles Island Reference Station	14 Aug	3.9	1.9	3.0	26.5	13.1	7.3	6.5	84.7
Northern Approach Channel	11 Aug	13.0	1.3	12.5	25.0	18.3	10.6	1.9	25.0

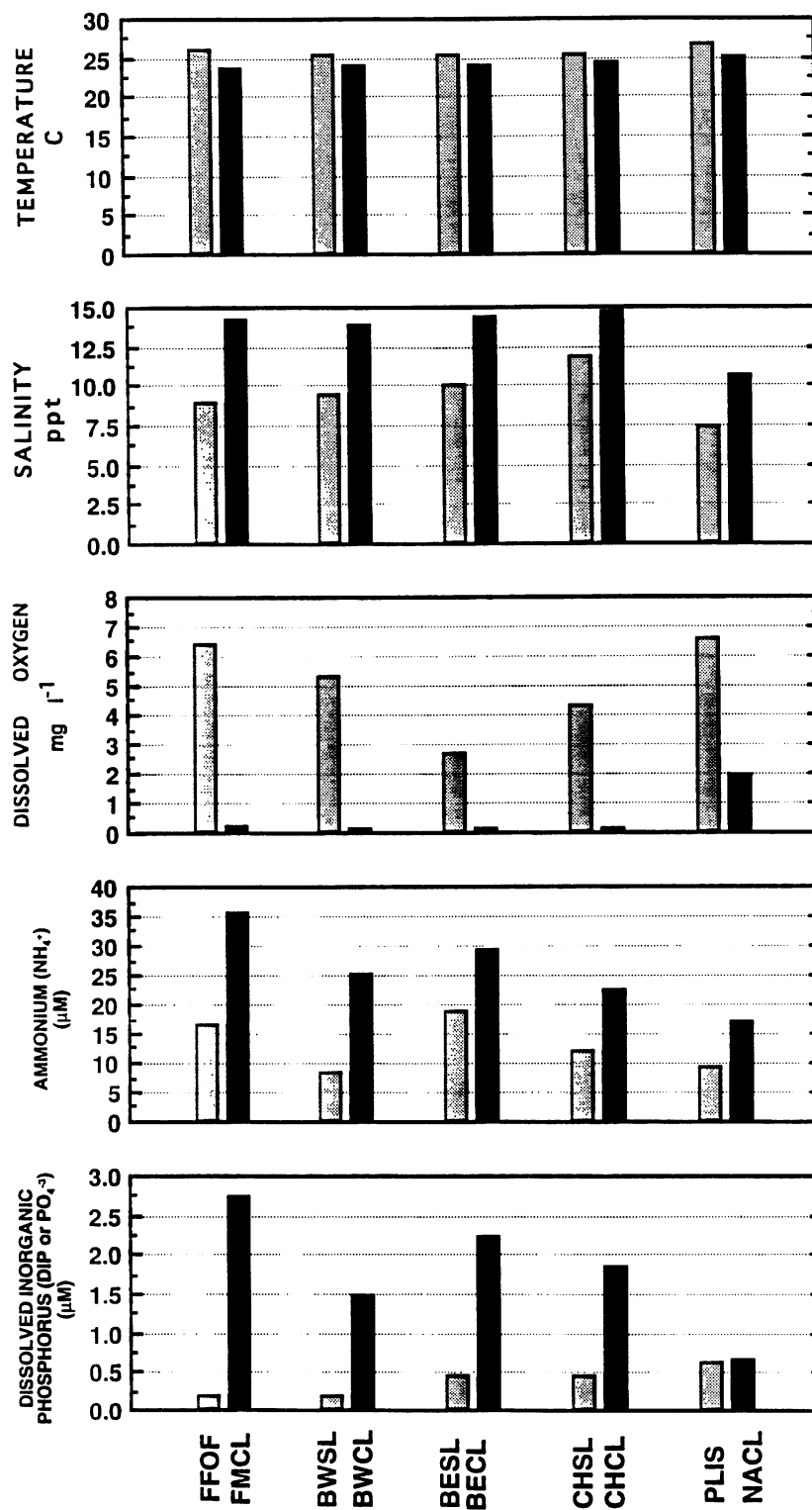


Figure 4. Bottom Water Temperature, Salinity, Dissolved Oxygen, Ammonium and Phosphorus concentrations at 5 pairs of shoal and channel stations in the Upper Bay.

Sediment Characteristics - Eh and Chemistry of the Surface 2mm

Sediment characteristics also exhibit some differences between years, but, at least at this point, differences were not as clear as those for water quality conditions. Measurements of sediment Eh indicated that at both surface (1 cm) and deeper zones (10 cm), sediments were oxidizing rather than reducing. The latter (reducing) condition is typical of most areas of the bay where deep water oxygen levels are low during summer months. The significance of elevated Eh values lies in the fact that under these oxidizing conditions phosphorus attached to inorganic particles tends to remain attached rather than become dissolved and diffuse back into the water. Furthermore, under these Eh conditions sediment nitrification (i.e. conversion of ammonium to nitrate) generally occurs and previous work (Kemp and Boynton, 1992) indicates that most of the nitrate created from this process is denitrified (i.e. converted from NO_3^- to N_2) and lost to the atmosphere.

In an earlier report (Boynton et al., 1992b), it was stated that sediment particulate carbon (PC) concentrations were high and that particulate nitrogen (PN) were relatively low in this area of the bay. The riverine source of terrestrial organic matter, which has little nitrogen in it, was suggested to be the cause. Earlier data collected in the upper bay indicated relatively high particulate carbon (PC) values compared to those typically observed in the lower Chesapeake Bay (1% or less). Concentrations of particulate nitrogen (PN) were low, as previously reported, relative to the amount of particulate carbon (PC) present. The resultant high PC:PN ratios indicate that much of the sediment organic matter was probably refractory and not as readily available to organisms for food or to decomposers as more labile organic material derived from phytoplankton production. Concentrations of particulate phosphorus (PP) in surface sediments were high relative to particulate carbon (PC) concentrations and high relative to particulate phosphorus (PP) concentrations generally found in the more saline portions of the bay. High particulate phosphorus (PP) concentrations in low salinity waters have been previously reported for other regions of the bay and this situation seems to result from binding of particulate phosphorus (PP) to sediment particles as they encounter saline waters (Boynton et al., 1992b). Unfortunately, it is not clear how much of this particulate phosphorus (PP) is available to biological communities. In most low salinity waters from which sediment-water phosphorus flux data are available, values tend to be low suggesting that only a small portion of the total particulate phosphorus (PP) is available for diffusion across the sediment-water interface (Boynton et al., 1992b).

Sediment particulate carbon (PC) content measured at shoal stations ranged between 3.32% to 4.24% and between 3.83% and 3.97% at channel stations (Appendix I). In 1997 sediment particulate carbon ranged from 3.75% to 4.34% at Pooles Island Reference station (PLIS). Sediment particulate nitrogen (PN) content measured at shoal stations ranged between 0.26% and 0.41% and between 0.27% and 0.47% at channel stations. In 1997 sediment particulate nitrogen ranged from 0.26% to 0.36% at Pooles Island Reference station (PLIS). Sediment particulate phosphorus (PP) content measured at shoal stations ranged between 0.19% and 0.81% and between 0.092% and 0.141% at channel stations. In 1997 sediment particulate phosphorus ranged from 0.080% to 0.097% at Pooles Island Reference station (PLIS). There were no strong differences observed between particulate materials collected from shoal and channel sediments during August 1997, despite obvious differences in the redox regimes.

Another useful measure of sediment properties is the mass of total chlorophyll-a present at the sediment surface. This variable is a useful index of labile (as opposed to total) organic matter available for rapid diagenesis. It is the products of early diagenesis that are thought to constitute most of the dissolved material measured in sediment-water flux estimates. In simple terms, this can serve as an index of the "fuel" available to support sediment-water oxygen and nutrient exchanges. Total chlorophyll-a at 1 cm at shoal stations ranged from 124.8 mg m⁻² to 213.4 mg m⁻² and at channel stations from 103.4 mg m⁻² to 182.8 mg m⁻² (Appendix I). In 1997 the total chlorophyll-a mass measured at 1 cm ranged from 118.8 to 167.4 mg m⁻² at Pooles Island Reference station (PLIS). Total chlorophyll-a values from channel areas were similar to those observed at PLIS and other shoal areas.

Sediment-Water Oxygen and Nutrient Fluxes

Average sediment oxygen consumption rates (SOC) ranged from -1.1 to -2.7 g O₂ m⁻² day⁻¹ at shoal stations and from -1.3 g O₂ m⁻² day⁻¹ to zero (0.0) at channel stations (Table 6; Figure 5). Average sediment oxygen consumption rates (SOC) in 1997 ranged from 1.96 to 2.42 g O₂ m⁻² day⁻¹ at Pooles Island Reference station (PLIS).

These rates measured at PLIS and other shoal stations were substantial relative to sediment oxygen consumption (SOC) rates observed in other areas of the mainstem Chesapeake Bay where low dissolved oxygen conditions in bottom waters severely depress sediment oxygen consumption rates. Shoal and PLIS values reported here are similar to those observed in tributary rivers where dissolved oxygen conditions in bottom waters are not depressed (>2 mg L⁻¹) and are higher than rates reported for a location about 15 kilometers north of the G-West Berm monitoring station. SOC rates measured in the channel areas were generally reduced and this most probably resulted because of depressed dissolved oxygen concentrations in these deeper areas of the upper bay.

Ammonium flux values recorded ranged from 238 to 394 μmol m⁻² h⁻¹ at shoal stations and from 113 to 617 μmol m⁻² h⁻¹ at channel stations (Table 6). Average fluxes of ammonium in 1997 ranged from 181.2 to 342.8 μmol m⁻² h⁻¹ at Pooles Island Reference station (PLIS). Ammonium fluxes were modest (200 - 400 μmol m⁻² h⁻¹) at all sites with the exception of a measurement taken in the northern approach channel (~600 μmol m⁻² h⁻¹). These modest fluxes probably resulted because of one or more of the following (1) primary production rates in this region of the bay are relatively low and hence the supply of labile phytoplankton detritus to sediments (which is the fuel for sediment-water fluxes) is limited; (2) these sediments are well oxidized and that promotes the coupled microbial processes of nitrification-denitrification which together serve to remove ammonium from the system (as N₂ gas); (3) the measurements were made in mid-August, towards the end of the period when sediment-water exchanges are at annual maxima, so it is possible that rates were decreasing from higher levels which may have occurred earlier in the summer.

Nitrite plus nitrate flux values ranged from -58 to 15 μmol m⁻² h⁻¹ at shoal stations and from -29 to 47 μmol m⁻² h⁻¹ at channel stations (Table 6). Average fluxes of nitrite plus nitrate in 1997

ranged from zero -11.87 to 16.59 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at the Pooles Island Reference station (PLIS).

Table 6. Summary Table of Sediment-Water Fluxes at Shoal and Channel Stations: sediment oxygen consumption (SOC), ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($\text{NO}_2^- + \text{NO}_3^-$), dissolved inorganic phosphorus (PO_4^{3-}) and silicate ($\text{Si}(\text{OH})_4$). Units are $\text{gO}_2 \text{m}^{-2} \text{d}^{-1}$ and for nutrients $\mu\text{mol m}^{-2} \text{h}^{-1}$. The Craighill Channel SOC fluxes were not interpretable.

STATION	SOC FLUX MEAN	NH_4^+ FLUX MEAN	NO_2^- FLUX MEAN	$\text{NO}_2^- + \text{NO}_3^-$ FLUX MEAN	DIP FLUX MEAN	SILICATE FLUX MEAN
Fairfield Outfall	-2.1	394	-1.8	-58	13	296
Fort McHenry Channel	0.0	377	0.0	0	17	134
Brewerton Shoal West	-1.1	238	0.0	-21	5	115
Brewerton Channel West	-0.2	373	0.0	0	18	0
Brewerton Shoal East	-2.7	271	0.0	22	20	454
Brewerton Channel East	-0.3	290	NI	0	-7	185
Craighill Shoal	-2.3	330	3.7	0	25	359
Craighill Channel	NI	113	0.0	0	-25	154
Pooles Island Reference Station	-2.0	288	0.0	-25	17	322
Northern Approach Channel	-1.3	617	0.0	47	29	0

It is interesting to note that the majority of nitrite plus nitrate fluxes at Pooles Island Reference station (PLIS) have been either zero or from sediments to water, even in June when water column concentrations of nitrate are still elevated. The opposite flux direction would have been expected. In earlier work, nitrate fluxes into sediments have been reported in areas where nitrate concentrations in overlying waters are appreciable, as in the upper bay (Boynton et al., 1991b). Direct measurements are not available but it is probable that the nitrate diffusing out of sediments was due to substantial nitrification rates in sediments. The well oxygenated sediments of the upper bay would appear to be good sites for nitrification. The ultimate fate of the nitrate diffusing from water to sediments is probably denitrification wherein nitrogen is lost to the atmosphere as N_2 gas (Kemp and Boynton, 1992). Nitrite plus nitrate fluxes at the shoal and channel sites tended to be either zero (no net flux in either direction) or into sediments but small enough to have little effect on water quality conditions. The few positive fluxes clearly indicate that nitrification is taking place in these sediments and this is a sign of good sediment quality.

Dissolved inorganic phosphate fluxes ranged from 13 to 25 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at shoal stations and from -25 to 29 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at channel stations (Table 6). Dissolved inorganic phosphate fluxes in 1997 ranged from 13.77 to 19.12 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at Pooles Island Reference station (PLIS).

Most of the phosphorus fluxes observed in this survey were modest ($< 20 \mu\text{mol m}^{-2} \text{h}^{-1}$) compared to other regions of the Bay. In general, highest phosphorus fluxes in the bay region have been observed in areas with hypoxic or anoxic overlying waters. It is surprising that higher phosphorus fluxes were not observed in the channel areas as dissolved oxygen concentrations in bottom waters were quite low in August, 1997. However, it may be that these sediments have been exposed to low dissolved oxygen conditions for most of the summer preceding our measurements and most of the phosphorus that could readily diffuse from these sediments had already done so. Jasinski (1996) has shown that there is only a 45 day supply of phosphorus in mid-Chesapeake Bay sediments available to support high phosphorus fluxes from sediments to overlying waters. On two occasions phosphorus fluxes were directed from overlying waters into sediments which is not a well understood process (probably sorption to fine particulates) but is also a relatively rare occurrence.

Silicate fluxes ranged from 115 to 454 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at shoal stations and from zero (0.0) to 185 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at channel stations (Table 6). In 1997 silicate values ranged from 94 to 477 $\mu\text{mol m}^{-2} \text{h}^{-1}$ at Pooles Island Reference station (PLIS). These values are within the range of those observed in other portions of Chesapeake Bay.

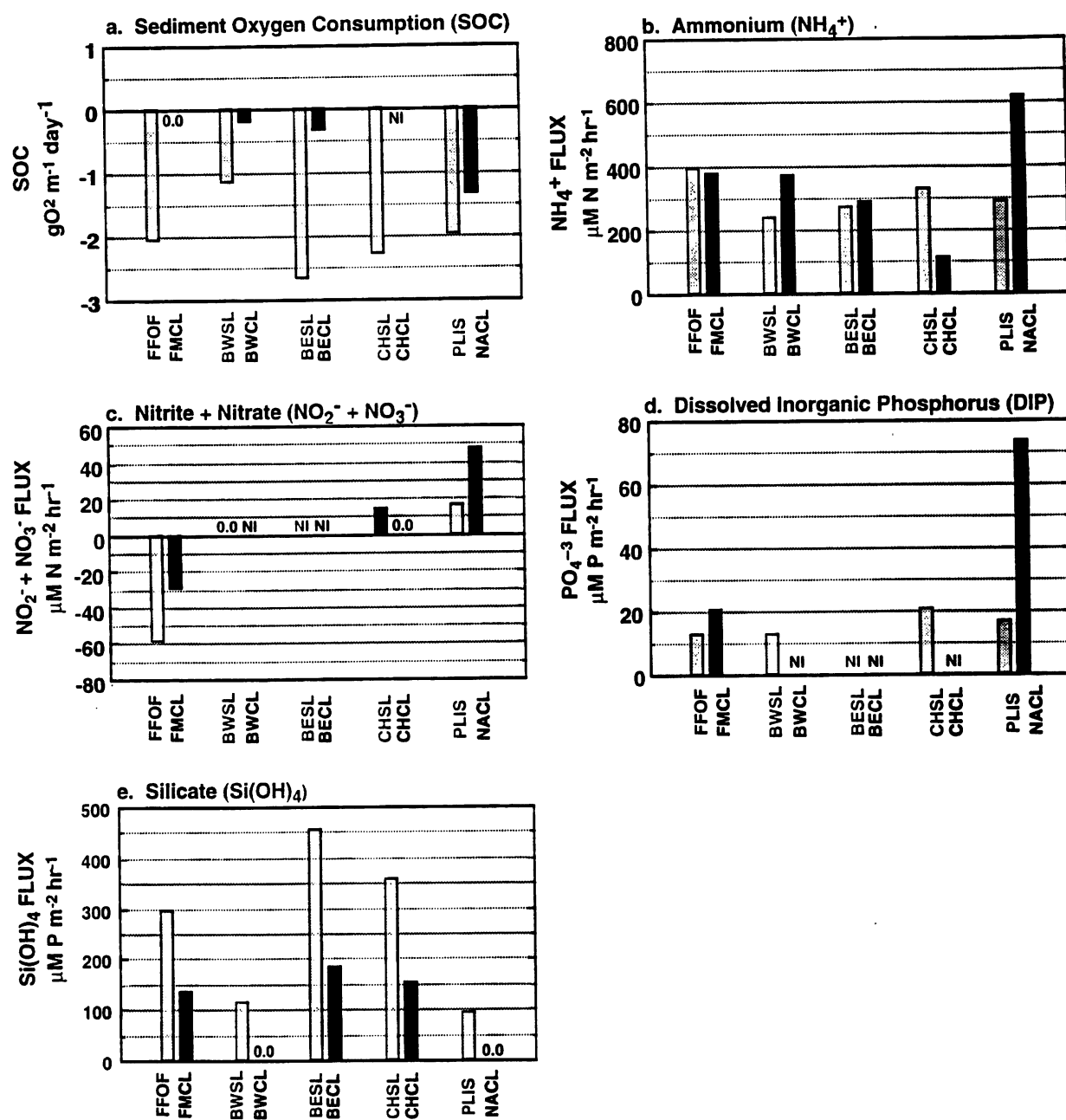


Figure 5. Sediment-water oxygen and nutrient exchanges at shoal and channel stations.

Pore Water Chemistry

Pore water sulfate concentrations decrease downcore (Figure 6), with sulfate depletion of $\sim 5\text{--}8$ mmol L⁻¹. These downcore decreases are typical of estuarine sediments (Cornwell and Sampou 1995) and indicate the presence of sulfate reduction. The total sulfate depletion deep in the Brewerton West channel and Fairfield Channel cores may indicate that methane production would occur at these greater depths (i.e. Reeburgh 1969). With the exception of the Craighill channel site, a greater degree of sulfate depletion (with increasing sediment depth) is found in the channel sites; no explanation for the difference at the Craighill site is obvious.

Sharp increases in the concentration of ammonium (Figure 7) are found in many parts of the Chesapeake Bay (Cornwell and Owens 1997) and indicate that ammonium is being regenerated within the sediments. Typical increases at 10 cm were 1-2 mmol L⁻¹ for the channel sediments and 0.1-0.5 mmol L⁻¹ for shoal sediments. The sharper gradients and greater downcore ammonium increases in the channel sediments may indicate higher rates of ammonium production or rapid burial of ammonium below depths in which it may not rapidly diffuse back to the water column. The higher ammonium concentrations at the sediment-water interface should provide higher fluxes of ammonium to the water column. These channel sediment data are generally consistent with long-core profiles from Cornwell and Owens (1999) and Bray (1973).

Pore water soluble reactive phosphorus concentrations generally increased downcore (Figure 8), with higher concentrations in the channel sediments (except for the Northern Approach Channel). In most cores, relatively strong gradients of phosphate were observed in the top few centimeters of sediment, indicating a strong upward flux. The two profiles with the most vertical structure, Fairfield Channel and Brewerton Channel, had high phosphate concentrations where dissolved iron was low and lower phosphate concentrations where iron was high (Figure 9); this suggests iron control of the pore water phosphate. Bray (1973) has suggested that the formation of Fe(II) phosphate minerals may account for these profile shapes.

Pore water iron concentrations (Figure 9) were relatively high, with considerable vertical structure. The absence of measurable hydrogen sulfide indicates that the rate of sulfate reduction is insufficient to produce enough hydrogen sulfide to reduce all of the iron oxide to iron sulfides. Deep decreases are found in a number of cores, suggesting that iron sulfide production at depth may consume some, but not all, of the pore water iron. In comparison to mesohaline sediments such as at Site 104 (Cornwell and Owens 1999), it appears that these sediments are not very reducing or sulfidic. This observation has important implications for the cycling of phosphorus; increased sulfate reduction and iron oxide conversion to iron sulfides may be an important process for release of phosphorus in mesohaline sediments.

Solid Phase Chemistry

Differences between organic carbon profiles in channel and shoal sediments are not consistent (Figure 10). For Northern Approach Channel and Brewerton Channel Eastern Extension, the channels have slightly higher concentrations of carbon. In the top 5 cm of sediment, the channel sediments at Craighill and Fairfield are lower than that for the shoals; at Brewerton Channel, the

profiles are quite similar. The carbon concentrations observed in this study are consistent with the more detailed mapping study of Hennessee et al. (1986). Only the Craighill sites showed much vertical change in the concentration of organic carbon; such downcore increases in organic carbon can arise both from normal decomposition and increased carbon loading to the surface of the sediment (Cornwell et al. 1996).

The total nitrogen profiles (Figure 11) were generally similar to the organic carbon profiles, with most data between 0.2 and 5 mg g⁻¹. At three sites, channel sediment total nitrogen was higher than that in the shoals; at two sites, the reverse pattern was observed.

At all sites, inorganic P accounted for a majority of total P, with much of the vertical structure of total P in the cores clearly a result of the change in inorganic P (Figure 12). Total P was generally below 1.5 mg g⁻¹ (0.15%), with pronounced P enrichments evident in near-surface sediments at the Craighill channel and shoal sites. While the concentrations of inorganic and total P are generally similar to those of Site 104 (Cornwell and Owens 1998), virtually all of the Site 104 core profiles had larger downcore decreases in inorganic phosphorus.

The HCl-extractable iron concentrations (Figure 13) were similar to those found in the upper Chesapeake Bay (Cornwell and Sampou 1995) and somewhat higher than generally found at Site 104 (12-18 mg g⁻¹; Cornwell and Owens 1998). The iron concentration in channel sediments was clearly higher than for shoal sediments in the Fairfield and Brewerton East shoal/channel pairs; the other cases had no consistent pattern.

The concentrations of acid volatile sulfide and total reduced sulfur showed downcore increases (Figure 14), with AVS generally a small to modest proportion of total reduced sulfur. The shoal site at Fairfield had the highest total reduced sulfur, exceeding 500 μmol g⁻¹. The highest AVS concentrations were found at Fairfield shoal, the channel sites for Brewerton Channel Eastern Extension, and both channel and shoal sites at Brewerton Channel. Overall, these profiles are similar to those in the upper bay (Cornwell and Sampou 1995). The iron associated with AVS is extracted with the 1 N HCl iron analysis. If HCl-extractable iron is 10-20 mg g⁻¹ (~180-360 μmol g⁻¹ Fe), most HCl-extractable iron is not in the form of AVS. These data suggest that there is some iron oxide being buried at these sites; in the mesohaline Chesapeake, there is relatively little iron oxide preservation. The difference between the total reduced sulfur and the AVS concentration is pyrite sulfur. Pyrite is the dominant form of iron sulfide in our shoal and channel cores; this is typical of sediments throughout the Chesapeake Bay (Cornwell and Sampou 1995).

Figure 6. Pore water sulfate concentrations.

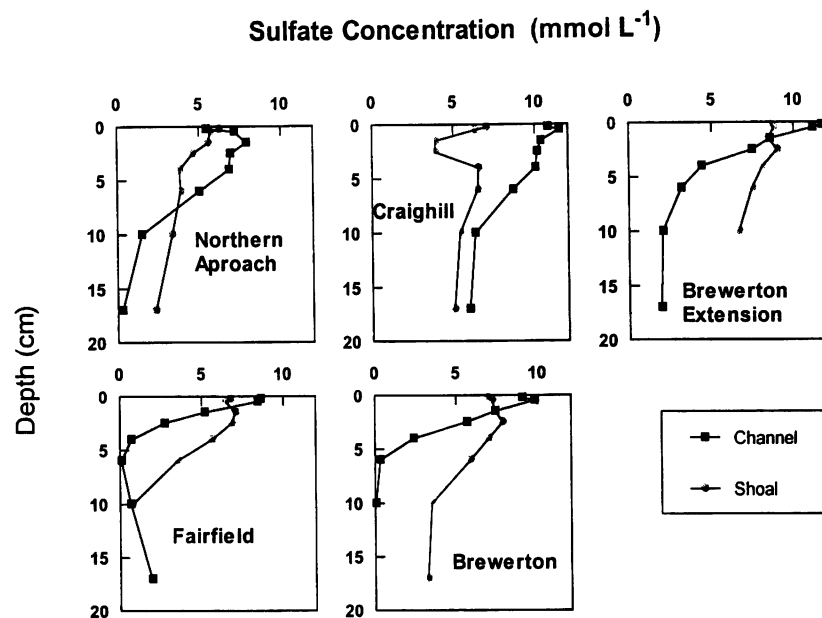


Figure 7. Pore water ammonium concentrations.

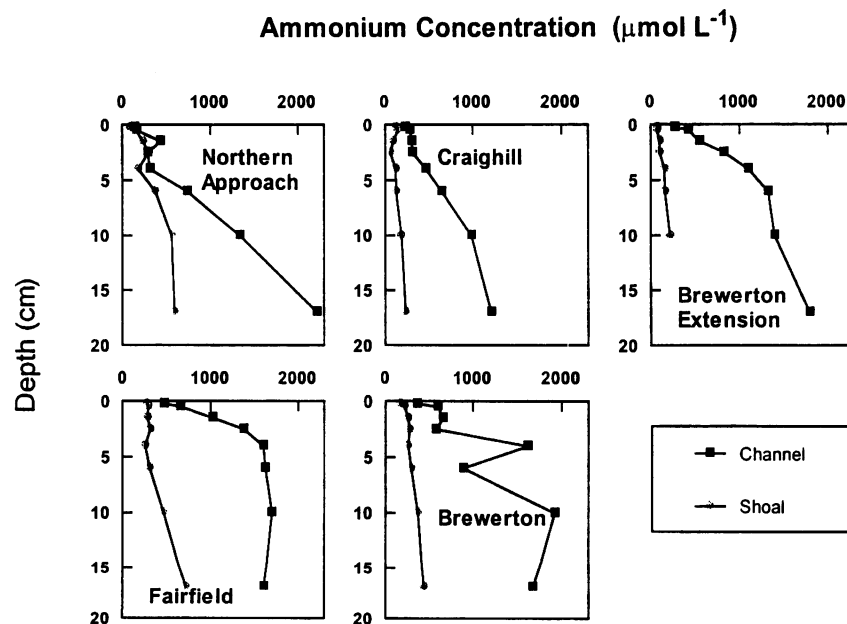


Figure 8. Pore water soluble reactive phosphorus (phosphate) concentration.

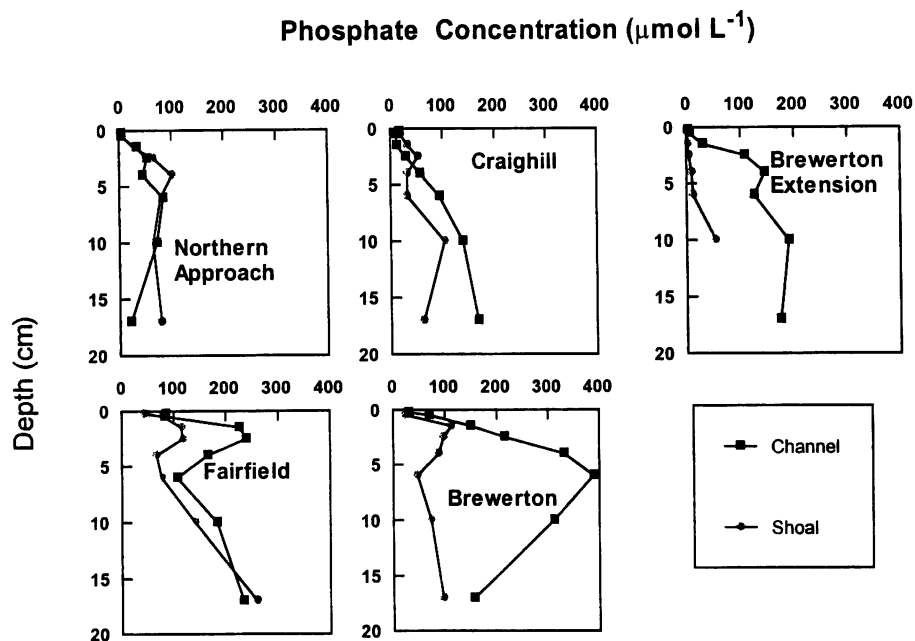


Figure 9. Pore water iron concentration.

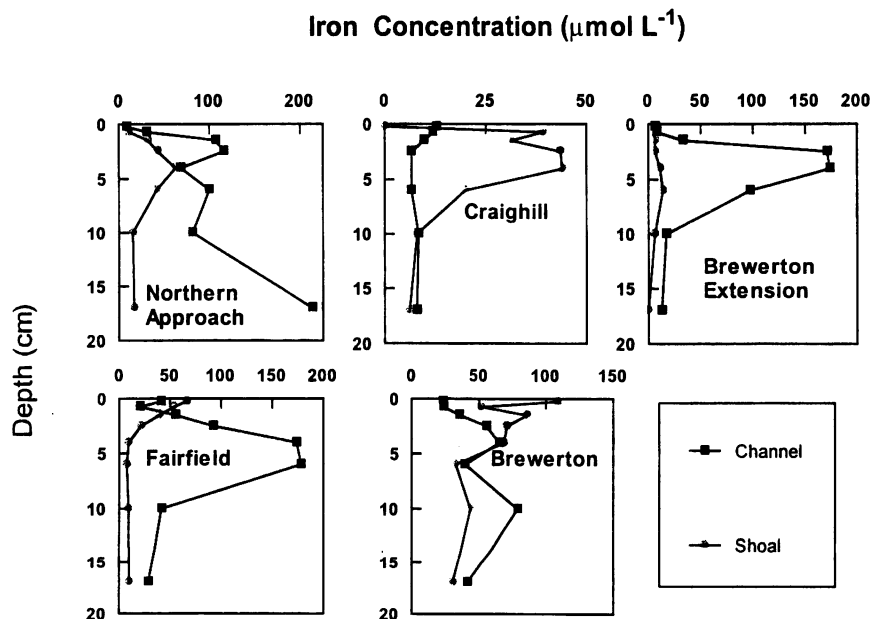


Figure 10. Solid phase total carbon.

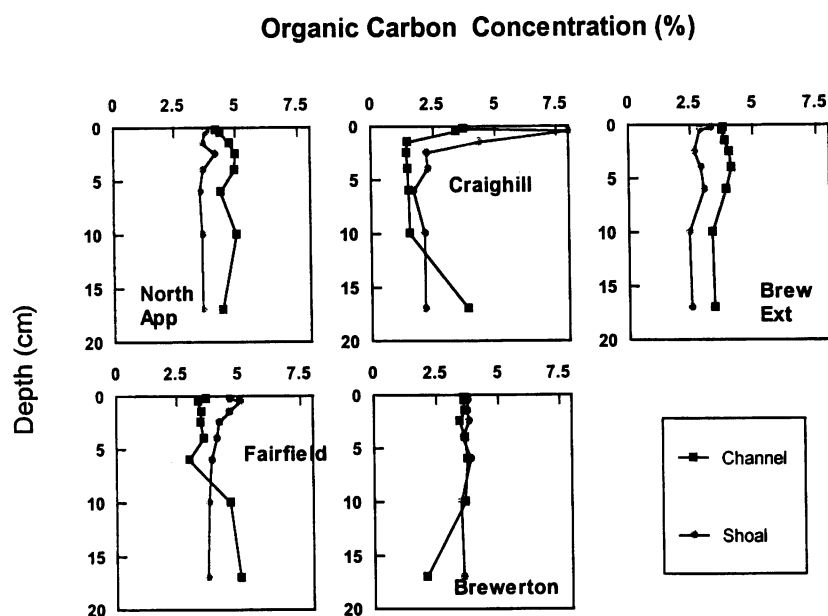


Figure 11. Solid phase total nitrogen.

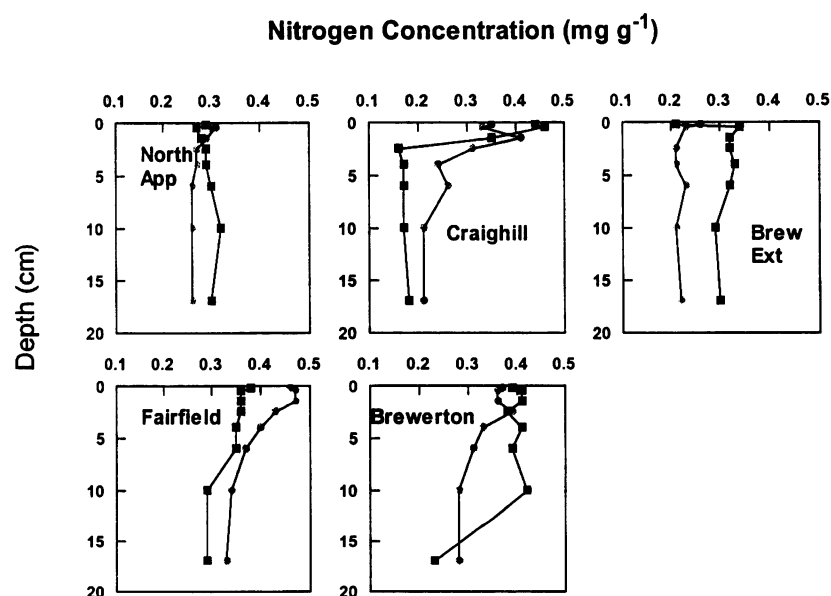


Figure12. Solid phase inorganic and total phosphorus.

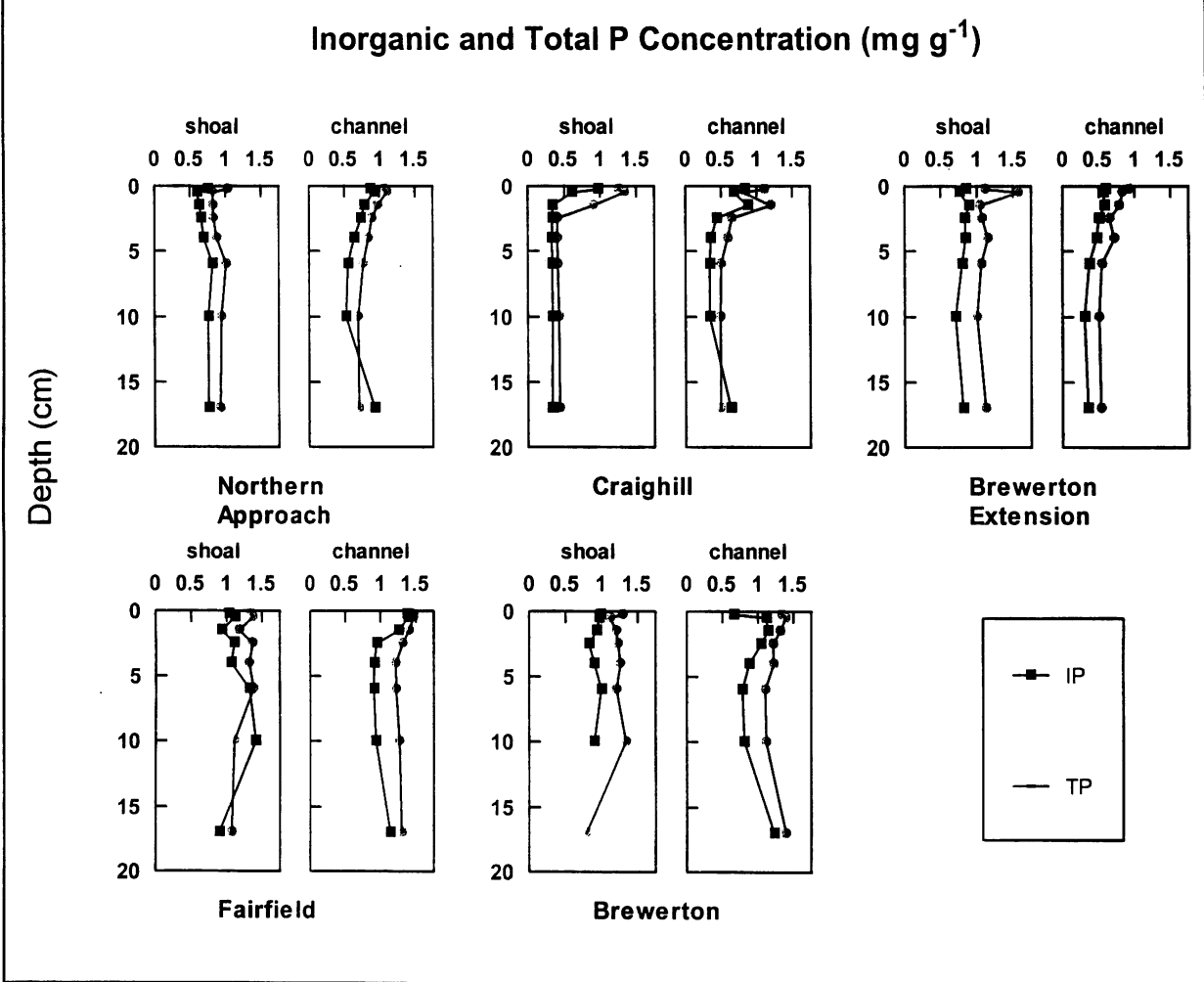


Figure 13. Solid phase HCl-extractable iron.

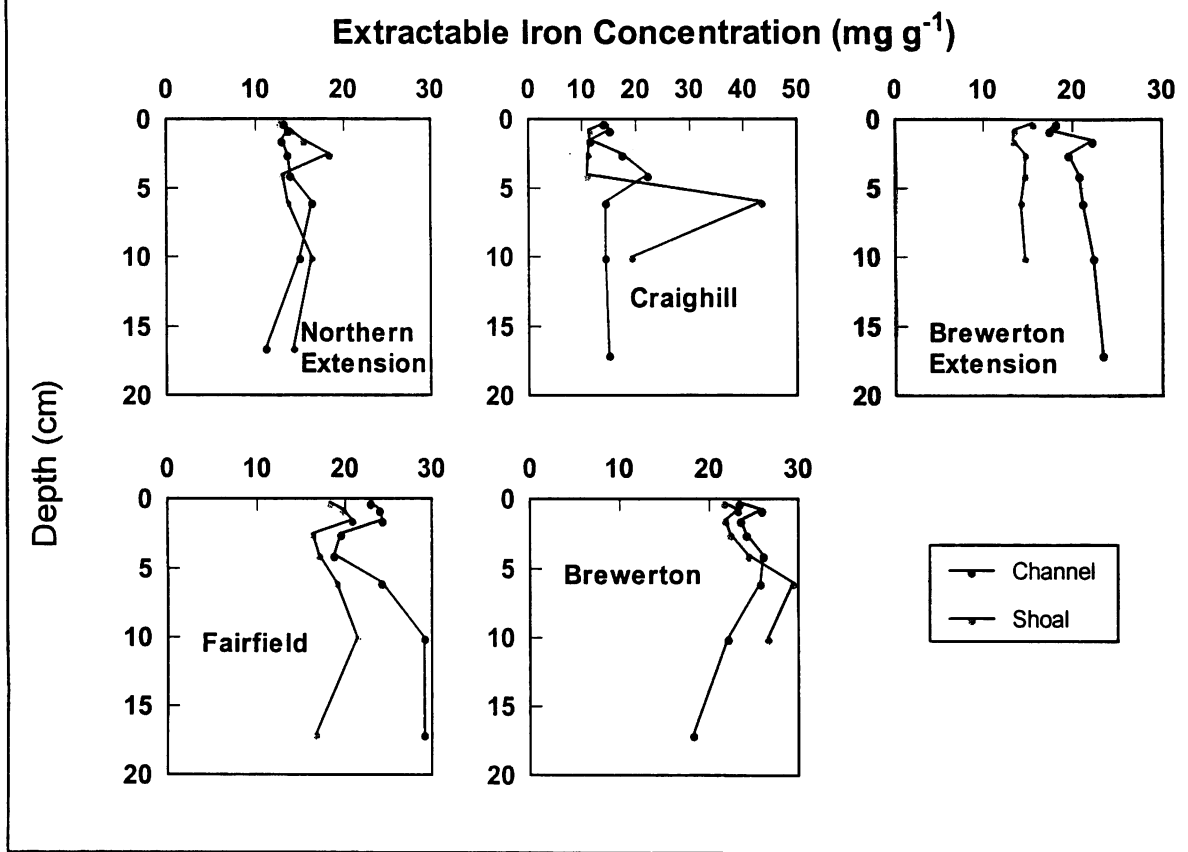
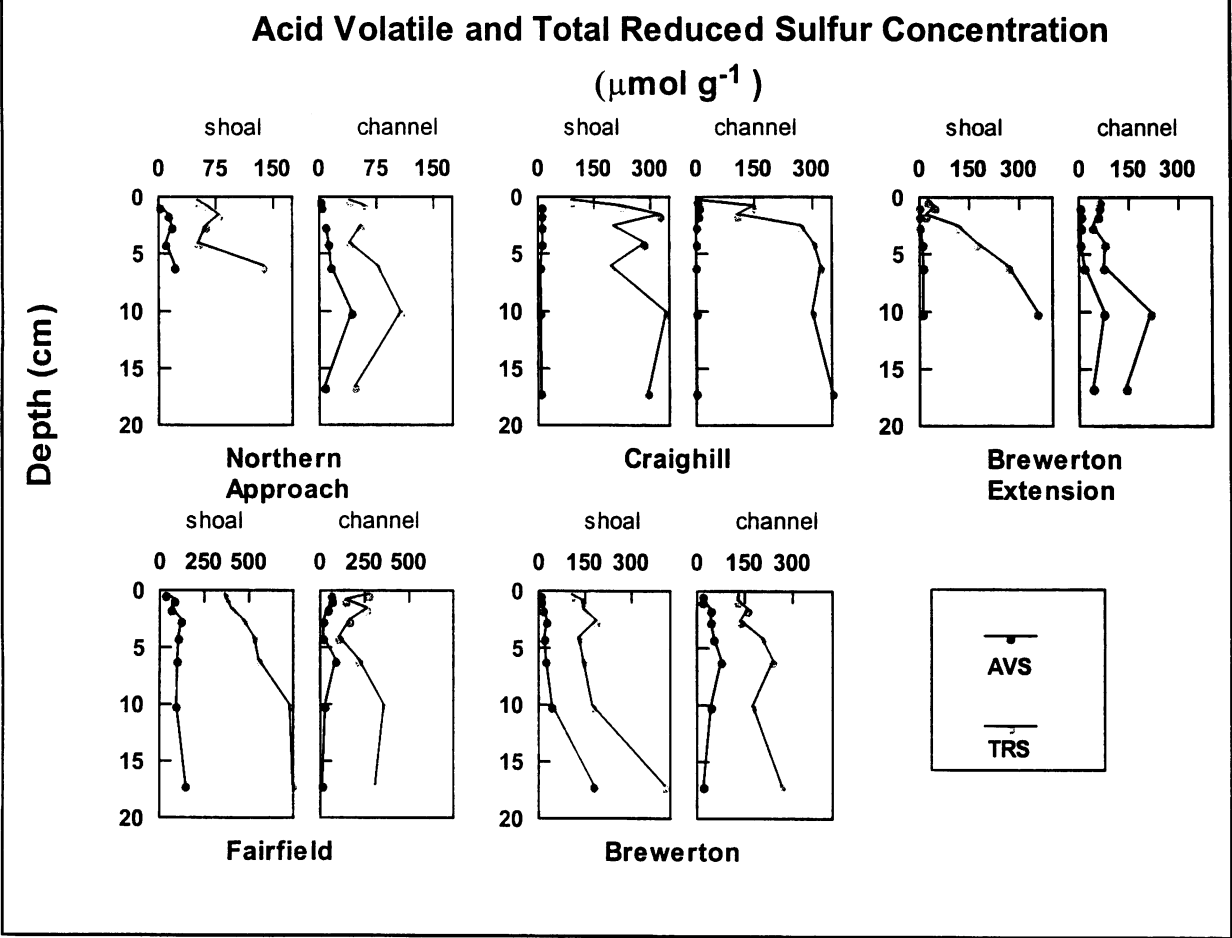


Figure 14. Solid phase acid volatile and total reduced sulfur.



Pore Water and Solid Phase Chemistry - Implications

The pore water and solid phase chemistry of these sites are generally more similar than we expected. Although the channel sites have higher sedimentation rates and experience restricted bottom water oxygen concentrations in the summer, the solid phase chemistry is remarkably similar. Moreover, there is no consistent pattern of difference in the pore water chemistry. Only the ammonium profiles differ consistently with the channel sites having higher concentrations. This difference is interesting since sediment-water exchange rates of ammonium are not consistently higher in the channel sediments. The only explanations for the higher ammonium concentrations in pore water with similar flux rates are 1) the rapid burial of pore water ammonium to depths at which it cannot diffuse to the sediment-water interface or 2) more efficient nitrification/denitrification at the sediment-water interface. We do not have sediment accretion rates for these sites, but it is a reasonable assumption that the rates of accretion are higher in the channels that require dredging of > 0.5 m of sediment every 3-4 years. "Normal" sedimentation rates in the Chesapeake are ~ 0.005 m y^{-1} (Officer et al. 1984), considerably lower than channel sedimentation; sedimentation rates at shoal sites should be similarly low. While denitrification rates are not available for these sites, other work (Cornwell and Owens 1999) has shown very high winter denitrification rates.

5 CONCLUSIONS

This small study shows that the channel sediments that were investigated generally do not have higher rates of metabolism than the shoal sites. In the Chesapeake Bay below the Bay Bridge to the south of these sites, shallow water sites (relative to deep water sites) often have lower rates of sediment metabolism, nutrient regeneration, and sediment accretion. Sediment "focusing", the general tendency to move sediment from shallow water sediments to deep sediments (often by wind-induced resuspension), results in enhanced sedimentation rates at greater depths. Both inorganic particulates and labile, algal-derived organic matter are swept into these deeper sedimentary environments as a consequence of this focusing process. This leads to an increase in the organic matter remineralization relative to shoal sites.

In the upper bay, it appears that the mesohaline pattern of increased sediment metabolism in channels is not an appropriate model. High inputs of inorganic sediments in winter/early spring conditions, combined with low inputs of algae at that time, lead to relatively low nitrogen and phosphorus release rates in the channels. The apparent low organic inputs to the channels does not lead to sufficient sulfate reduction to result in loss of all iron oxide minerals and subsequent release of iron-bound phosphorus.

Overall, the channel sediments are surprisingly unreactive given their high rates of sediment accretion.

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Appendix I. Sediment-Water Exchange Data From Chesapeake Biological Laboratory

All tables are labelled as “B” series tables.

TABLE B-1.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

WATER COLUMN PROFILES: Vertical profiles of temperature, salinity, dissolved oxygen
and other characteristics at shoal and channel stations

FILENAME : SHHPAG97

REVISED : 9SEP97

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 (%)
BECL	19970811	1115	12.0	1.2	WP05	0.5	26.0	15.8	9.0	9.09	117.9
						2.0	25.4	16.5	9.5	6.36	81.8
						4.0	25.3	16.7	9.6	6.41	82.4
						6.0	25.2	17.5	10.1	5.09	65.5
						8.0	25.0	18.1	10.5	4.11	52.8
						10.0	24.3	21.2	12.5	0.07	0.9
						11.0	24.0	23.0	13.7	0.07	0.9
BESL	19970811	1232	5.7	1.2	WP05	0.5	26.4	16.5	9.5	11.03	144.5
						1.0	25.7	16.4	9.4	8.69	112.3
						2.0	25.5	16.7	9.6	6.99	90.1
						3.0	25.4	16.6	9.5	6.50	83.6
						4.0	25.3	17.2	9.9	5.49	70.7
						5.0	25.3	17.4	10.0	5.30	68.3
BWCL	19970812	1545	16.4	0.7	WP05	0.5	27.2	14.7	8.3	11.11	146.7
						2.0	26.4	14.8	8.4	9.03	117.6
						4.0	25.8	15.6	8.9	5.63	72.7
						6.0	25.3	16.8	9.7	2.54	32.7
						8.0	24.9	18.1	10.5	1.36	17.4
						10.0	24.5	19.4	11.3	0.58	7.4
						12.0	24.1	20.5	12.1	0.10	1.3
						14.0	23.8	23.3	13.9	0.10	1.3
BWSL	19970812	1648	6.0	0.5	WP05	0.5	27.7	14.6	8.2	13.10	174.5
						1.0	26.7	14.9	8.4	9.61	125.8
						2.0	26.6	14.9	8.4	9.02	117.8
						3.0	26.5	14.9	8.4	8.75	114.1
						4.0	26.0	15.8	9.0	5.62	72.9
						5.0	25.4	16.8	9.7	2.64	34.0

TABLE B-1.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

WATER COLUMN PROFILES: Vertical profiles of temperature, salinity, dissolved oxygen
and other characteristics at shoal and channel stations

FILENAME : SHHPAG97

REVISED : 9SEP97

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 (%)
CHCL	19970811	840	16.0	1.4	WP05	0.5	24.8	18.1	10.5	5.82	74.5
						1.0	24.8	17.8	10.3	6.02	76.9
						3.0	24.8	19.0	11.1	4.74	60.9
						5.0	24.9	19.2	11.2	4.96	63.9
						7.0	25.0	19.6	11.5	4.84	62.6
						9.0	25.0	19.9	11.7	4.31	55.8
						11.0	24.9	20.1	11.8	3.23	41.7
						13.0	24.1	23.5	14.1	0.08	1.0
						15.0	24.1	23.8	14.3	0.08	1.0
CHSL	19970811	955	10.0	1.3	WP05	0.5	25.4	19.0	11.1	6.62	86.0
						2.0	25.3	19.1	11.1	6.07	78.7
						4.0	25.2	19.3	11.3	5.57	72.2
						6.0	25.2	19.5	11.4	4.84	62.7
						8.0	25.2	20.0	11.7	4.17	54.2
						9.5	25.2	20.0	11.7	4.30	55.8
FMCL	19970812	1415	16.4	1.3	WP05	0.5	27.1	15.2	8.6	10.04	132.5
						3.0	26.1	15.4	8.8	7.42	96.3
						5.0	25.8	16.0	9.1	5.03	65.0
						7.0	25.3	17.2	9.9	2.66	34.3
						9.0	24.5	19.2	11.2	0.75	9.6
						11.0	23.7	21.6	12.8	0.10	1.3
						13.0	23.6	23.2	13.9	0.12	1.5
						15.0	23.5	23.6	14.1	0.16	2.0
FFOF	19970812	1045	5.7	1.3	WP05	0.5	26.7	15.0	8.5	8.83	115.6
						1.0	26.5	15.2	8.6	8.45	110.4
						2.0	26.3	15.4	8.8	7.61	99.1
						3.0	26.1	15.5	8.8	7.18	93.2
						4.0	26.0	15.5	8.8	6.97	90.4
						5.0	26.0	15.6	8.9	6.35	82.3

TABLE B-1.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

WATER COLUMN PROFILES: Vertical profiles of temperature, salinity, dissolved oxygen
and other characteristics at shoal and channel stations

FILENAME : SHHPAG97

REVISED : 9SEP97

STATION	DATE	TIME	TOTAL	SECCHI	GEAR	SAMPLE	TEMP	COND	SALIN	DO	DO SAT
			DEPTH	DEPTH	CODE	DEPTH					
			(m)	(m)		(m)	(C)	(mmho/cm)	(ppt)	(mg/l)	(%)
NACL	19970811	1420	13.0	1.3	WP05	0.5	26.0	13.7	7.7	6.83	88.0
						2.0	25.9	13.7	7.7	6.60	84.9
						4.0	25.8	13.7	7.7	6.39	82.0
						6.0	25.6	13.7	7.7	5.73	73.2
						8.0	25.4	15.4	8.8	4.60	59.0
						10.0	25.0	18.0	10.4	2.40	30.8
						12.5	25.0	18.3	10.6	1.94	25.0
PLIS	19970814	737	3.9	1.9	WP05	0.5	26.4	12.5	6.9	7.10	91.8
						1.0	26.5	12.6	7.0	7.04	91.1
						2.0	26.5	12.8	7.1	6.82	88.3
						3.0	26.5	13.1	7.3	6.53	84.7

TABLE B-2.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL CHANNEL STUDY
 WATER COLUMN NUTRIENTS: Dissolved and particulate nutrient concentrations in surface
 and bottom waters at shoal and channel stations

FILENAME : SHNTAG97
 REVISED : 13JUL98

STATION	DATE	TOTAL DEPTH (m)	SAMPLE DEPTH (m)	DISSOLVED NUTRIENTS				
				NH ₄ ⁺ (μM)	NO ₂ (μM)	NO ₂ +NO ₃ (μM)	CORR DIP (μM)	Si(OH) ₄ (μM)
BECL	19970811	12.0	11.0	25.0	0.19	0.22	1.46	44.7
BESL	19970811	5.7	5.0	8.3	0.30	3.00	0.16	38.9
BWCL	19970812	16.4	16.0	29.3	0.05	0.09	2.23	47.4
BWSL	19970812	6.0	5.0	18.7	0.78	0.48	5.92	42.0
CHCL	19970811	16.0	15.0	22.2	0.24	0.49	1.83	45.1
CHSL	19970811	10.0	9.5	11.8	0.19	0.91	0.46	39.4
FMCL	19970812	16.4	15.0	35.5	0.08	0.11	2.72	46.8
FFOF	19970812	5.7	5.0	16.5	1.20	10.60	0.17	38.4
NACL	19970811	13.0	12.5	16.9	0.42	3.34	0.64	45.8
PLIS	19970814	3.9	3.0	8.9	0.58	11.00	0.60	40.8

TABLE B-3.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL AND CHANNEL STUDY

SEDIMENT PROFILES: Vertical sediment profiles of Eh and surficial
sediment characteristics at shoal and channel stations

FILENAME : SHPFAG97

REVISED : 13JUL98

STATION	DATE	TIME	CORE DEPTH (cm)	Eh MEAS (mV)	Eh CORR (mV)	SURFICIAL SEDIMENT PARTICULATES (2-3 mm)			SEDIMENT CHLOROPHYLL-a (1 cm)	
						SED PC %(wt)	SED PN %(wt)	SED PP %(wt)	SED CHLa TOTAL (mg/m ²)	SED CHLa ACTIVE (mg/m ²)
BECL	19970811	1101	1.0	118	362					
			0.0	117	361					
			-1.0	-211	33	3.83	0.340	0.101	155.4	85.8
			-2.0	-206	38					
			-3.0	HH	HH					
			-4.0	-276	-32					
			-5.0	HH	HH					
			-6.0	-249	-5					
			-7.0	HH	HH					
			-8.0	-230	14					
			-9.0	HH	HH					
			-10.0	-191	53					
BESL	19970811	1226	1.0	130	374					
			0.0	147	391					
			-1.0	-344	-100	3.32	0.270	0.081	135.8	63.9
			-2.0	-190	54					
			-3.0	HH	HH					
			-4.0	-123	121					
			-5.0	HH	HH					
			-6.0	-93	151					
			-7.0	HH	HH					
			-8.0	-100	144					
			-9.0	HH	HH					
			-10.0	-69	175					

TABLE B-3.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL AND CHANNEL STUDY
 SEDIMENT PROFILES: Vertical sediment profiles of Eh and surficial
 sediment characteristics at shoal and channel stations

FILENAME : SHPFAG97

REVISED : 13JUL98

STATION	DATE	TIME	CORE DEPTH (cm)	Eh MEAS (mV)	Eh CORR (mV)	SURFICIAL SEDIMENT PARTICULATES (2-3 mm)			SEDIMENT CHLOROPHYLL-a (1 cm)	
						SED PC %(wt)	SED PN %(wt)	SED PP %(wt)	SED CHLa TOTAL (mg/m ²)	SED CHLa ACTIVE (mg/m ²)
BWCL	19970812	1536	1.0	102	346					
			0.0	-26	218					
			-1.0	-161	83	3.73	0.420	0.128	164.0	101.9
			-2.0	-163	81					
			-3.0	HH	HH					
			-4.0	-34	210					
			-5.0	HH	HH					
			-6.0	-61	183					
			-7.0	HH	HH					
			-8.0	-56	188					
			-9.0	HH	HH					
			-10.0	-32	212					
BWSL	19970812	1644	1.0	94	338					
			0.0	111	355					
			-1.0	-172	72	3.71	0.350	0.134	160.63	94.44
			-2.0	-237	7					
			-3.0	HH	HH					
			-4.0	-210	34					
			-5.0	HH	HH					
			-6.0	-169	75					
			-7.0	HH	HH					
			-8.0	-136	108					
			-9.0	HH	HH					
			-10.0	-99	145					

TABLE B-3.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL AND CHANNEL STUDY

SEDIMENT PROFILES: Vertical sediment profiles of Eh and surficial
sediment characteristics at shoal and channel stations

FILENAME : SHPFAG97

REVISED : 13JUL98

STATION	DATE	TIME	CORE DEPTH (cm)	Eh MEAS (mV)	Eh CORR (mV)	SURFICIAL SEDIMENT PARTICULATES (2-3 mm)			SEDIMENT CHLOROPHYL
						SED PC %(wt)	SED PN %(wt)	SED PP %(wt)	SED CHLa TOTAL (mg/m ²)
CHCL	19970811	819	1.0	95	339				
			0.0	-68	176				
			-1.0	13	257	3.64	0.470	0.127	103.43
			-2.0	-273	-29				
			-3.0	HH	HH				
			-4.0	-471	-227				
			-5.0	HH	HH				
			-6.0	-284	-40				
			-7.0	HH	HH				
			-8.0	-185	59				
			-9.0	HH	HH				
			-10.0	-196	48				
CHSL	19970811	926	1.0	137	381				
			0.0	132	376				
			-1.0	-165	79	3.85	0.380	0.109	213.39
			-2.0	-171	73				
			-3.0	HH	HH				
			-4.0	-142	102				
			-5.0	HH	HH				
			-6.0	-62	182				
			-7.0	HH	HH				
			-8.0	25	269				
			-9.0	HH	HH				
			-10.0	-40	204				

TABLE B-3.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL AND CHANNEL STUDY
 SEDIMENT PROFILES: Vertical sediment profiles of Eh and surficial
 sediment characteristics at shoal and channel stations

FILENAME : SHPFAG97
 REVISED : 13JUL98

STATION	DATE	TIME	CORE DEPTH (cm)	Eh MEAS (mV)	Eh CORR (mV)	SURFICIAL SEDIMENT PARTICULATES (2-3 mm)			SEDIMENT CHLOROPHYLL-a (1 cm)	
						SED PC %(wt)	SED PN %(wt)	SED PP %(wt)	SED CHLa TOTAL (mg/m ²)	SED CHLa ACTIVE (mg/m ²)
FMCL	19970812	1404	1.0	123	367					
			0.0	111	355					
			-1.0	-87	157	3.75	0.440	0.141	182.83	129.57
			-2.0	-54	190					
			-3.0	HH	HH					
			-4.0	-102	142					
			-5.0	HH	HH					
			-6.0	-216	28					
			-7.0	HH	HH					
			-8.0	-201	43					
			-9.0	HH	HH					
			-10.0	-176	68					
FFOF	19970812	1024	1.0	113	357					
			0.0	-66	178					
			-1.0	-213	31	4.24	0.410	0.163	171.91	89.71
			-2.0	-193	51					
			-3.0	-159	85					
			-4.0	-166	78					
			-5.0	-76	168					
			-6.0	-77	167					
			-7.0	-132	112					
			-8.0	-256	-12					
			-9.0	-313	-69					
			-10.0	-292	-48					

TABLE B-3.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL AND CHANNEL STUDY

SEDIMENT PROFILES: Vertical sediment profiles of Eh and surficial
sediment characteristics at shoal and channel stations

FILENAME : SHPFAG97

REVISED : 13JUL98

STATION	DATE	TIME	CORE DEPTH (cm)	Eh MEAS (mV)	Eh CORR (mV)	SURFICIAL SEDIMENT PARTICULATES (2-3 mm)			SEDIMENT CHLOROPHYLL-a (1 cm)	
						SED PC %(wt)	SED PN %(wt)	SED PP %(wt)	SED CHLa TOTAL (mg/m ²)	SED CHLa ACTIVE (mg/m ²)
NACL	19970811	1406	1.0	135	379					
			0.0	125	369					
			-1.0	124	368	3.97	0.270	0.092	176.56	101.35
			-2.0	-172	72					
			-3.0	HH	HH					
			-4.0	-178	66					
			-5.0	HH	HH					
			-6.0	-186	58					
			-7.0	HH	HH					
			-8.0	-182	62					
			-9.0	HH	HH					
			-10.0	-166	78					
PLIS	19970814	720	1.0	95	339					
			0.0	92	336					
			-1.0	84	328	3.75	0.260	0.097	124.82	28.49
			-2.0	-131	113					
			-3.0	-84	160					
			-4.0	-37	207					
			-5.0	-73	171					
			-6.0	-112	132					
			-7.0	-97	147					
			-8.0	-106	138					
			-9.0	-37	207					
			-10.0	-75	169					

TABLE B-4.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL AND CHANNEL STUDY

CORE DATA: Dissolved nutrient and oxygen concentrations in shoal
and channel sediment-water flux chambers

FILENAME : SHCDAG97

REVISED : 8SEP97

STATION	DATE	CORE NO	TIME OF SAMPLE (hr min)		TIME DELTA (min)	TIME SUM (min)	DO (mg/l)	AA VIAL NO	NH ₄ ⁺ (μM)	NO ₂ (μM)	NO ₂ +NO ₃ (μM)	DIP (μM)	Si(OH) ₄ (μM)
BECL	19970811	1	12	40	0	0	0.67	10	26.5	0.07	0.73	1.47	45.1
			13	40	60	60	0.53	13	29.0	0.07	0.68	1.40	44.3
			14	42	62	122	0.44	17	31.1	0.21	0.78	1.32	46.0
			15	40	58	180	0.35	20	33.7	0.15	0.64	1.31	47.3
BESL	19970811	1	13	55	0	0	5.00	14	9.1	0.31	2.53	0.22	43.1
			14	55	60	60	4.10	18	10.8	0.37	2.66	0.35	47.4
			15	55	60	120	3.35	21	12.8	0.34	2.83	0.49	49.6
			16	55	60	180	2.70	23	14.9	0.71	3.00	0.65	48.0
BWCL	19970812	1	16	55	0	0	0.35	73	30.9	0.28	0.10	2.24	46.3
			17	56	61	61	0.29	76	34.0	0.31	0.34	2.34	45.7
			18	55	59	120	0.24	79	35.2	0.32	0.10	2.44	47.2
			19	55	60	180	0.19	81	38.7	0.13	0.13	2.60	47.1
BWSL	19970812	1	17	40	0	0	2.70	75	18.2	0.58	5.46	0.50	44.2
			18	40	60	60	2.27	78	20.4	0.59	5.34	0.54	44.6
			19	40	60	120	1.93	80	22.3	0.57	5.09	0.59	45.2
			20	40	60	180	1.67	82	23.6	0.55	5.02	0.61	46.9
CHCL	19970811	1	9	50	0	0	0.30	3	22.8	0.24	0.38	1.88	45.4
			10	50	60	60	0.45	4	23.7	0.19	0.90	1.58	46.8
			11	50	60	120	0.99	7	24.2	0.18	0.32	1.49	48.1
			12	50	60	180	1.72	11	25.3	0.18	0.33	1.33	48.6
CHSL	19970811	1	11	25	0	0	4.38	6	11.2	0.22	0.91	0.50	43.2
			12	30	65	65	3.48	8	13.9	0.28	0.98	0.72	45.0
			13	25	55	120	2.86	12	14.5	0.29	0.94	0.89	48.0
			14	25	60	180	2.33	15	19.4	0.31	0.98	1.07	51.4
FMCL	19970812	1	15	30	0	0	0.29	69	36.9	0.21	0.11	2.66	47.3
			16	30	60	60	0.20	71	40.5	0.06	0.11	2.75	50.9
			17	32	62	122	0.15	74	44.8	0.11	0.31	2.89	49.1
			18	30	58	180	0.22	77	46.0	0.07	0.33	3.09	50.8

TABLE B-4.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL AND CHANNEL STUDY
 CORE DATA: Dissolved nutrient and oxygen concentrations in shoal
 and channel sediment-water flux chambers

FILENAME : SHCDAG97
 REVISED : 8SEP97

STATION	DATE	CORE NO	TIME OF SAMPLE (hr min)		TIME DELTA (min)	TIME SUM (min)	DO (mg/l)	AA VIAL NO	NH ₄ ⁺ (μM)	NO ₂ (μM)	NO ₂ +NO ₃ (μM)	DIP (μM)	Si(OH) ₄ (μM)
FFOF	19970812	B	12	10	0	0	5.60	36	15.3	1.06	10.40	0.24	37.6
			13	10	60	60	5.52	44	15.3	1.20	9.37	0.24	37.0
			14	10	60	120	5.50	52	15.6	1.37	10.00	0.23	38.6
			15	10	60	180	5.48	60	14.3	1.02	10.10	0.23	38.1
			16	10	60	240	5.42	65	14.6	1.04	10.20	0.27	38.6
		1	12	10	0	0	6.12	37	18.1	1.18	10.20	0.35	38.6
			13	10	60	60	5.33	45	20.2	1.00	9.47	0.50	40.6
			14	10	60	120	4.64	53	24.0	1.43	8.83	0.60	43.5
			15	10	60	180	4.12	61	26.1	1.02	8.66	0.76	45.8
			16	10	60	240	3.55	66	29.3	0.98	8.28	0.95	49.2
		2	12	10	0	0	6.93	38	18.4	1.23	10.10	0.34	38.3
			13	10	60	60	5.89	46	20.0	1.02	9.57	0.36	40.3
			14	10	60	120	5.12	54	24.8	1.16	9.64	0.44	41.3
			15	10	60	180	4.59	62	23.6	1.08	9.69	0.46	42.9
			16	10	60	240	4.05	67	28.9	1.08	8.88	0.49	44.9
		3	12	10	0	0	6.09	39	19.4	1.06	10.10	0.46	40.0
			13	10	60	60	5.44	47	22.2	1.21	9.80	0.60	40.6
			14	10	60	120	4.87	55	24.4	1.00	9.11	0.57	43.9
			15	10	60	180	4.44	63	26.8	1.07	8.81	0.70	45.5
			16	10	60	240	3.98	68	29.0	1.00	8.56	0.78	46.2

TABLE B-4.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL AND CHANNEL STUDY
 CORE DATA: Dissolved nutrient and oxygen concentrations in shoal
 and channel sediment-water flux chambers

FILENAME : SHCDAG97
 REVISED : 8SEP97

STATION	DATE	CORE NO	TIME OF SAMPLE (hr min)		TIME DELTA (min)	TIME SUM (min)	DO (mg/l)	AA VIAL NO	NH ₄ ⁺ (μM)	NO ₂ (μM)	NO ₂ +NO ₃ (μM)	DIP (μM)	Si(OH) ₄ (μM)
NACL	19970811	1	15	30	0	0	1.96	19	17.4	0.31	3.46	0.76	44.7
			16	30	60	60	1.59	22	19.9	0.33	3.33	0.92	40.6
			17	30	60	120	1.21	24	25.1	0.45	3.16	1.02	46.7
			18	30	60	180	0.91	25	29.4	0.34	2.95	1.37	43.9
PLIS	19970814	B	8	55	0	0	6.70	147	9.0	0.52	10.70	0.59	42.8
			9	55	60	60	6.56	152	8.7	0.48	11.50	0.61	42.2
			10	55	60	120	6.51	156	8.6	0.50	11.85	0.61	44.9
			11	55	60	180	6.50	168	8.7	0.56	11.40	0.60	46.8
			12	55	60	240	6.49	172	8.3	0.50	11.30	0.62	49.0
		1	8	55	0	0	6.29	148	10.8	0.81	11.50	0.83	44.8
			9	55	60	60	5.22	153	14.1	0.50	11.70	1.08	46.8
			10	55	60	120	4.73	157	15.0	0.48	12.00	1.24	52.0
			11	55	60	180	4.33	169	17.0	0.64	11.90	1.24	55.3
			12	55	60	240	3.78	173	18.0	0.49	12.00	1.27	56.3
		2	8	55	0	0	6.09	149	11.6	0.50	11.50	0.85	42.7
			9	55	60	60	5.08	154	16.5	0.53	11.80	1.32	44.7
			10	55	60	120	4.64	158	14.9	0.48	11.60	1.21	45.8
			11	55	60	180	4.11	170	14.4	0.44	12.00	1.37	48.5
			12	55	60	240	3.45	174	19.0	0.50	12.10	1.38	50.6
		3	8	55	0	0	6.14	150	11.0	0.47	11.30	0.82	42.5
			9	55	60	60	4.83	155	16.5	0.55	11.40	1.04	44.9
			10	55	60	120	4.29	159	17.5	0.46	11.70	1.20	46.4
			11	55	60	180	3.81	171	19.6	0.59	11.70	1.28	49.4
			12	55	60	240	3.25	175	21.2	0.46	11.70	1.33	50.9

TABLE B-5.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

SEDIMENT-WATER FLUX: Net sediment-water exchange rates of dissolved oxygen ($\text{gO}_2/(\text{m}^2.\text{day})$)
and nutrients (μMN , P, Si and S/ $(\text{m}^2.\text{hr})$)

FILENAME : SHFLAG97

REVISED : 13JUL98

STATION	DATE	NO	CORE H2O	DEPTH (m)	SLOPE (mg/(l.min))	DO		NH ₄ ⁺		
			VOL (ml)			FLUX ($\text{gO}_2/(\text{m}^2.\text{day})$)	MEAN	SLOPE ($\mu\text{MN}/\text{min}$)	FLUX ($\mu\text{MN}/(\text{m}^2.\text{hr})$)	FLUX MEAN
BECL	19970811	1	1710	0.123	-0.001813	-0.32	-0.32	0.039345	290.4	290.4
BESL	19970811	1	1940	0.140	-0.013290	-2.67	-2.67	0.032333	270.8	270.8
BWCL	19970812	1	2100	0.151	-0.000936	-0.20	-0.20	0.041096	372.5	372.5
BWSL	19970812	1	1830	0.132	-0.005985	-1.13	-1.13	0.030167	238.3	238.3
CHCL	19970811	1	1960	0.141	NI	NI	NI	0.013333	112.8	112.8
CHSL	19970811	1	1800	0.129	-0.012201	-2.28	-2.28	0.042427	329.6	329.6
FMCL	19970812	1	1660	0.119	0.000000	0.00	0.00	0.052613	377.0	377.0
FFOF	19970812	1	2020	0.145	-0.010583	-2.08	-2.06	0.047167	411.3	394.1
		2	1876	0.135	-0.011767	-2.16		0.045762	370.5	
		3	2340	0.168	-0.008700	-1.95		0.039667	400.7	
NACL	19970811	1	2080	0.150	-0.006146	-1.32	-1.32	0.068667	616.5	616.5
PLIS	19970814	1	1810	0.130	-0.009850	-1.78	-1.96	0.028833	246.9	288.1
		2	1960	0.141	-0.010417	-2.04		NI	NI	
		3	1820	0.131	-0.011333	-2.07		0.039167	329.4	

TABLE B-5.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

SEDIMENT-WATER FLUX: Net sediment-water exchange rates of dissolved oxygen ($\text{gO}_2/(\text{m}^2\cdot\text{day})$)
and nutrients (μMN , P, Si and S/ $(\text{m}^2\cdot\text{hr})$)

Part 2 of 4

FILENAME : SHFLAG97

REVISED : 13JUL98

STATION	DATE	NO	CORE H2O VOL (ml)	DEPTH (m)	SLOPE ($\mu\text{MN}/(\text{l}\cdot\text{min})$)	NO ₂		NO ₂ + NO ₃		
						FLUX ($\mu\text{MN}/(\text{m}^2\cdot\text{hr})$)	MEAN	SLOPE ($\mu\text{MN}/(\text{l}\cdot\text{min})$)	FLUX ($\mu\text{MN}/(\text{m}^2\cdot\text{hr})$)	FLUX MEAN
BECL	19970811	1	1710	0.123	NI	NI	NI	NI	NI	NI
BESL	19970811	1	1940	0.140	0.000000	0.00	0.0	NI	NI	NI
BWCL	19970812	1	2100	0.151	0.000000	0.00	0.0	NI	NI	NI
BWSL	19970812	1	1830	0.132	0.000000	0.00	0.0	0.000000	0.00	0.0
CHCL	19970811	1	1960	0.141	0.000000	0.00	0.0	0.000000	0.00	0.0
CHSL	19970811	1	1800	0.129	0.000475	3.69	3.7	0.001919	14.91	14.9
FMCL	19970812	1	1660	0.119	0.000000	0.00	0.0	-0.004000	-28.66	-28.7
FFOF	19970812	1	2020	0.145	0.000000	0.00	-1.8	-0.007750	-67.58	-58.0
		2	1876	0.135	-0.000681	-5.51		-0.004691	-37.98	
		3	2340	0.168	0.000000	0.00		-0.006783	-68.51	
NACL	19970811	1	2080	0.150	0.000000	0.00	0.0	0.005270	47.32	47.3
PLIS	19970814	1	1810	0.130	NI	NI	0.0	0.002000	15.63	16.6
		2	1960	0.141	0.000000	0.00		0.002333	19.74	
		3	1820	0.131	NI	NI		0.001833	14.40	

TABLE B-5.1. MARYLAND ENVIRONMENTAL SERVICE

SHOAL CHANNEL STUDY

SEDIMENT-WATER FLUX: Net sediment-water exchange rates of dissolved oxygen ($\text{gO}_2/(\text{m}^2.\text{day})$)
and nutrients (μMN , P, Si and S/ $(\text{m}^2.\text{hr})$)

Part 3 of 4

FILENAME : SHFLAG97

REVISED : 13JUL98

STATION	DATE	CORE NO	CORE H2O VOL (ml)	DEPTH (m)	SLOPE ($\mu\text{MP}/(\text{l}.\text{min})$)	DIP FLUX ($\mu\text{MP}/(\text{m}^2.\text{hr})$)	FLUX MEAN	SLOPE ($\mu\text{MSi}/(\text{l}.\text{min})$)	SILICATE FLUX ($\mu\text{MSi}/(\text{m}^2.\text{hr})$)	FLUX MEAN
BECL	19970811	1	1710	0.123	NI	NI	NI	0.025028	184.74	184.7
BESL	19970811	1	1940	0.140	NI	NI	NI	0.054167	453.60	453.6
BWCL	19970812	1	2100	0.151	NI	NI	NI	0.000000	0.00	0.0
BWSL	19970812	1	1830	0.132	0.001607	12.69	12.7	0.014500	114.54	114.5
CHCL	19970811	1	1960	0.141	NI	NI	NI	0.018167	153.70	153.7
CHSL	19970811	1	1800	0.129	0.002647	20.57	20.6	0.046194	358.92	358.9
FMCL	19970812	1	1660	0.119	0.002871	20.57	20.6	0.018721	134.14	134.1
FFOF	19970812	1	2020	0.145	0.002433	21.21	13.0	0.044000	383.65	296.0
		2	1876	0.135	0.000667	5.40		0.026333	213.19	
		3	2340	0.168	0.001233	12.45		0.028833	291.23	
NACL	19970811	1	2080	0.150	0.008202	73.64	73.6	NI	0.00	0.0
PLIS	19970814	1	1810	0.130	0.001733	13.54	16.6	0.052500	188.82	93.9
		2	1960	0.141	0.002338	19.78		0.032667	36.67	
		3	1820	0.131	0.002100	16.50		0.035500	56.30	

TABLE B-5.1. MARYLAND ENVIRONMENTAL SERVICE
 SHOAL CHANNEL STUDY
 SEDIMENT-WATER FLUX: Net sediment-water exchange rates of dissolved oxygen (gO₂/(m².day))
 and nutrients (μMN, P, Si and S/(m².hr))

Part 4 of 4

FILENAME : SHFLAG97
 REVISED : 13JUL98

STATION	DATE	NO	CORE H2O VOL (ml)	DEPTH (m)	BLANK DO (mg/(l.min))	BLANK NH ₄ ⁺ (μMN/(l.min))	BLANK NO ₂ (μMN/(l.min))	BLANK NO ₂ +NO ₃ (μMP/(l.min))	BLANK DIP (μMP/(l.min))	BLANK Si(OH) ₄ (uMSi/(l.min))
BECL	19970811	1	1710	0.123	YB	YB	YB	YB	YB	YB
BESL	19970811	1	1940	0.140	YB	YB	YB	YB	YB	YB
BWCL	19970812	1	2100	0.151	YB	YB	YB	YB	YB	YB
BWSL	19970812	1	1830	0.132	YB	YB	YB	YB	YB	YB
CHCL	19970811	1	1960	0.141	YB	YB	YB	YB	YB	YB
CHSL	19970811	1	1800	0.129	YB	YB	YB	YB	YB	YB
FMCL	19970812	1	1660	0.119	YB	YB	YB	YB	YB	YB
FFOF	19970812	1	2020	0.145	-0.000667	0.000000	0.000000	0.000000	0.000000	0.000000
		2	1876	0.135	-0.000667	0.000000	0.000000	0.000000	0.000000	0.000000
		3	2340	0.168	-0.000667	0.000000	0.000000	0.000000	0.000000	0.000000
NACL	19970811	1	2080	0.150	YB	YB	YB	YB	YB	YB
PLIS	19970814	1	1810	0.130	-0.000367	-0.002762	0.000000	0.000000	0.000000	0.028333
		2	1960	0.141	-0.000367	-0.002762	0.000000	0.000000	0.000000	0.028333
		3	1820	0.131	-0.000367	-0.002762	0.000000	0.000000	0.000000	0.028333

Appendix II. Pore water and solid phase data.

Analyte ID's:

SO4	pore water sulfate
Cl	pore water chloride
NH4	pore water ammonium
Fe	pore water iron
Si	pore water silicate
H2S	pore water hydrogen sulfide
AVS	acid volatile sulfide
CRS	chromium reducible sulfur
Total S	total reduced sulfur (AVS + CRS)
HCl-Fe	HCl-extractable solid phase iron
IP	inorganic solid phase phosphorus
TP	total phosphorus
C	total carbon
N	total nitrogen

Station/ Sample	depth (cm)	SO ₄ umol L ⁻¹		Cl umol L ⁻¹		NH ₄ umol L ⁻¹		PO ₄ umol L ⁻¹		Fe umol L ⁻¹	
North Approach		channel	shoal	channel	shoal	channel	shoal	channel	shoal	channel	shoal
1	0.25	5.45	6.26	115	121	144	88	3.7	3.7	8.80	8.36
2	0.5	7.19	5.71	150	115	164	156	3.7	6.2	30.80	11.44
3	1.5	7.91	5.58	159	114	436	237	33.4	28.5	106.93	32.12
4	2.5	6.94	4.62	159	100	291	296	53.2	65.6	115.73	43.13
5	4	6.83	3.81	169	88	316	181	44.5	101.4	68.65	62.49
6	6	5.00	3.88	170	91	739	375	84.	79.2	99.89	41.81
7	10	1.49	3.35	143	83	1334	560	71.7	64.3	81.41	15.40
8	17	0.29	2.33	114	75	2218	594	21.0	80.4	213.43	16.72
Craig 1	0.25	10.79	7.07	204	148	234	130	17.3	12.4	12.76	0.00
2	0.5	11.49	6.37	212	137	285	145	11.1	19.8	11.88	39.17
3	1.5	10.37	3.91	202	84	305	94	12.4	33.4	9.68	31.24
4	2.5	10.15	3.89	194	84	313	60	29.7	53.2	6.60	43.57
5	4	10.03	6.56	221	139	464	122	56.9	32.2	no data	44.01
6	6	8.67	6.50	213	142	647	125	94.0	32.2	6.60	19.80
7	10	6.36	5.41	179	128	983	184	138.5	103.9	8.36	7.92
8	17	5.99	5.05	199	132	1211	230	168.2	63.1	7.92	6.16
Fairfield 1	0.25	8.63	6.76	217	135	474	279	85.4	44.5	41.37	66.89
2	0.5	8.44	6.50	242	129	658	293	82.9	80.4	20.68	53.69
3	1.5	5.18	7.06	219	143	1026	288	226.4	115.0	55.45	39.61
4	2.5	2.76	6.85	220	140	1376	316	240.0	117.5	92.41	21.56
5	4	0.70	5.64	192	130	1604	257	165.8	66.8	173.82	9.24
6	6	0.10	3.52	188	131	1623	307	106.4	76.7	178.22	7.48
7	10	0.66	0.76	176	112	1699	464	183.1	141.0	41.0	9.24
8	17	1.95	no data	165	no data	1606	720	233.8	259.8	28.60	9.68
Brew Ext 1	0.25	11.74	8.62	239	169	276	74	3.7	2.5	6.60	9.24
2	0.5	11.17	8.77	255	170	428	74	6.2	2.5	8.36	6.16
3	1.5	8.54	8.46	216	162	551	103	30.9	2.5	33.44	6.60
4	2.5	7.44	8.99	245	179	826	103	108.9	4.9	171.18	6.60
5	4	4.40	8.08	197	155	1099	156	146.0	9.9	173.82	11.44
6	6	3.17	7.44	198	138	1323	159	126.2	12.4	97.25	14.08
7	10	2.03	6.63	184	135	1393	218	190.5	54.4	17.16	6.16
8	17	1.94	no data	181	no data	1797	no data	174.4	no data	12.76	no data
Brewerton 1	0.25	9.07	6.98	188	136	363	172	30.9	26.0	23.32	108.69
2	0.5	9.81	7.25	249	139	599	218	70.5	24.7	23.76	51.93
3	1.5	7.41	7.41	216	148	661	260	149.7	112.6	35.64	85.11
4	2.5	5.68	7.90	214	165	579	276	215.2	97.7	55.45	70.85
5	4	2.38	7.02	227	151	1620	260	331.5	87.7	65.19	68.65
6	6	0.33	5.91	218	135	891	293	388.4	47.0	39.61	32.56
7	10	0.06	3.49	218	122	1923	369	311.7	73.0	78.77	43.57
8	17	no data	3.23	197	113	1676	436	155.9	96.5	41.37	30.36

Station/ Sample	depth (cm)	Si umol L ⁻¹		H ₂ S umol L ⁻¹		AVS umol S		CRS umol S		total S umol L ⁻¹	
North Approach		channel	shoal	channel	shoal	channel	shoal	channel	shoal	channel	shoal
1	0.25	135	242	2	3	2.36	0.00	37.03	51.21	39.39	51.21
2	0.5	151	238	0	5	3.66	1.69	55.80	62.17	59.46	63.86
3	1.5	216	336	0	5	no data	12.99	no data	66.01	no data	79.00
4	2.5	296	266	3	7	8.82	17.48	45.32	44.50	54.14	61.98
5	4	354	312	0	10	12.36	9.37	27.11	42.64	39.47	52.0
6	6	372	410	3	8	15.11	21.41	60.84	115.24	75.95	136.65
7	10	430	468	2	8	42.33	no data	64.07	no data	106.40	no data
8	17	565	459	0	8	7.33	no data	39.25	no data	46.58	no data
Craig 1	0.25	no data	no data	2	7	3.94	0.00	no data	89.41	ISF data	89.41
2	0.5	191	286	2	0	9.19	11.58	137.66	211.61	146.85	223.19
3	1.5	188	276	3	2	6.99	11.53	99.45	313.45	106.44	324.98
4	2.5	324	326	no data	3	1.04	10.78	269.05	189.94	270.09	200.72
5	4	191	314	no data	5	0.68	11.35	302.09	272.55	302.77	283.90
6	6	602	382	no data	0	0.29	6.67	320.57	187.32	320.86	193.99
7	10	740	688	no data	5	1.48	7.18	298.32	333.04	299.80	340.22
8	17	716	597	no data	11	1.10	8.05	350.32	285.79	351.42	293.84
Fairfield 1	0.25	376	224	0	0	64.32	38.76	210.54	330.70	274.86	369.46
2	0.5	452	304	2	0	68.19	82.48	75.51	291.53	143.70	374.01
3	1.5	588	240	3	0	43.75	65.22	218.88	335.94	262.63	401.16
4	2.5	552	250	5	2	19.93	121.25	145.80	347.33	165.73	468.58
5	4	568	380	2	18	17.70	104.63	172.30	421.50	190.00	526.13
6	6	662	272	3	65	86.86	99.28	128.55	454.17	215.41	553.45
7	10	546	352	7	418	26.90	93.58	327.92	632.57	354.82	726.15
8	17	664	429	3	1017	12.00	146.44	294.98	596.87	306.98	743.31
Brew Ext 1	0.25	163	165	10	3	0.00	0.00	64.04	26.09	64.04	26.09
2	0.5	216	161	5	2	4.83	0.11	57.41	46.13	62.24	46.24
3	1.5	320	185	3	8	7.53	0.12	50.51	19.42	58.04	19.54
4	2.5	442	210	5	2	6.44	1.16	35.61	115.17	42.05	116.33
5	4	408	266	5	2	4.81	9.20	73.63	163.84	78.44	173.04
6	6	380	298	5	3	16.72	11.87	57.77	255.05	74.01	266.92
7	10	522	378	5	2	75.82	10.37	140.60	210.09	216.42	220.46
8	17	491	no data	7	2	42.82	no data	99.13	no data	141.95	no data
Brewerton 1	0.25	186	174	0	2	18.79	7.34	111.57	99.30	130.36	106.64
2	0.5	256	246	3	0	18.44	8.76	109.80	132.25	128.24	141.01
3	1.5	336	278	0	3	43.11	14.82	116.65	129.42	159.76	144.24
4	2.5	384	372	0	0	43.48	25.97	92.84	159.84	136.32	185.81
5	4	410	392	2	0	52.32	18.55	150.96	111.30	203.28	129.85
6	6	478	382	0	0	75.60	22.77	162.59	121.09	238.19	143.86
7	550	424	0	8	43.33	42.41	130.84	130.73	174.17	173.14	
8	17	652	446	1	no data	20.27	177.43	243.73	228.01	264.00	405.44

Station/ Sample	depth (cm)	HCl-Fe mg g ⁻¹		IP mg g ⁻¹		TP mg g ⁻¹		C mg g ⁻¹		N mg g ⁻¹	
		channel	shoal	channel	shoal	channel	shoal	channel	shoal	channel	shoal
North Approach											
1	0.25	13.19	12.71	0.75	0.87	1.04	1.07	4.22	3.92	0.29	0.29
2	0.5	13.63	13.93	0.60	0.93	0.82	1.10	4.40	3.77	0.27	0.31
3	1.5	12.92	15.43	0.63	0.79	0.83	0.98	4.77	3.68	0.28	0.29
4	2.5	13.59	18.35	0.66	0.74	0.83	0.89	5.00	4.18	0.29	0.27
5	4	13.92	13.01	0.69	0.64	0.88	0.84	4.97	3.68	0.29	.027
6	6	16.37	13.62	0.82	0.55	1.01	0.77	4.40	3.56	0.30	.026
7	10	14.98	16.33	0.76	0.53	0.94	0.70	5.04	3.64	0.32	0.26
8	17	11.13	14.25	0.76	0.93	0.93	0.71	4.46	3.66	0.30	0.26
Craig 1	0.25	13.98	14.51	0.97	0.83	1.26	1.11	3.70	3.86	0.44	0.35
2	0.5	15.16	11.36	0.61	0.68	1.34	0.82	3.42	7.97	0.46	0.33
3	1.5	11.59	11.46	0.34	0.88	0.91	1.20	1.47	4.35	0.35	0.41
4	2.5	17.52	11.14	0.34	0.44	0.41	0.65	1.43	2.24	0.16	0.31
5	4	22.20	10.97	0.33	0.35	0.41	0.59	1.47	2.27	0.17	0.24
6	6	14.39	43.46	0.33	0.34	0.41	0.50	1.51	1.71	0.17	0.26
7	10	14.36	19.19	0.34	0.34	0.43	0.49	1.54	2.15	0.17	0.21
8	17	15.00	no data	0.33	0.64	0.44	0.49	3.87	2.15	0.18	0.21
Fairfield 1	0.25	18.25	22.92	1.03	1.38	1.34	1.47	3.71	4.68	0.38	0.46
2	0.5	19.78	23.97	1.11	1.39	1.37	1.47	3.38	5.09	0.6	0.47
3	1.5	20.82	24.30	0.93	1.26	1.18	1.40	3.51	4.66	0.36	0.47
4	2.5	16.30	19.53	1.11	0.95	1.37	1.32	3.48	4.24	0.36	0.43
5	4	17.05	18.75	1.07	0.91	1.32	1.22	3.60	4.14	0.35	0.40
6	6	19.02	24.24	1.33	0.91	1.38	1.22	3.01	3.92	0.35	0.37
7	10	21.40	29.17	1.41	0.94	1.11	1.27	4.68	3.81	0.29	0.34
8	17	16.67	29.13	0.90	1.14	1.08	1.30	5.09	3.76	0.29	0.33
Brew Ext 1	0.25	18.17	15.54	0.85	0.60	1.11	0.93	3.83	3.33	0.21	0.26
2	0.5	17.42	13.46	0.76	0.57	1.57	0.83	3.78	2.89	0.34	0.23
3	1.5	22.18	13.39	0.89	0.58	1.04	0.79	3.90	no data	0.32	no data
4	2.5	19.52	14.70	0.84	0.51	1.07	0.65	4.06	2.67	0.32	0.21
5	4	20.69	14.67	0.85	0.48	1.15	0.72	4.15	2.92	0.33	0.21
6	6	21.09	14.21	0.80	0.38	1.06	0.55	3.94	3.05	0.32	0.23
7	10	22.28	14.67	0.71	0.31	1.01	0.51	3.37	2.45	0.29	0.21
8	17	23.34	18.17	0.81	0.35	1.12	0.53	3.45	2.53	0.30	0.22
Brewerton 1	0.25	23.38	21.67	0.98	0.66	1.29	1.34	3.61	3.77	0.39	0.37
2	0.5	25.90	23.21	0.97	1.12	1.12	1.39	3.61	3.78	0.41	0.36
3	1.5	23.52	21.79	0.93	0.14	1.20	1.31	3.64	3.76	0.41	0.36
4	2.5	24.17	22.36	0.82	1.04	1.23	1.22	3.44	3.82	0.38	0.39
5	4	26.08	24.39	0.90	0.88	1.26	1.23	3.65	3.57	0.41	0.33
6	6	25.72	29.41	0.90	0.78	1.21	1.11	3.75	3.89	0.39	0.31
7	10	22.10	26.57	1.00	0.80	1.34	1.12	3.65	3.49	0.42	0.28
8	17	18.20	no data	0.90	1.23	0.79	1.40	2.08	3.58	0.23	0.28

Station/ Sample	depth (cm)	% H ₂ O	
North Approach		channel	shoal
1	0.25	73.7	73.3
2	0.5	61.5	69.4
3	1.5	60.2	67.1
4	2.5	58.8	65.1
5	4	57.6	61.3
6	6	56.1	60.1
7	10	58.2	60.7
8	17	55.0	62.7
Craig 1	0.25	89.3	82.8
2	0.5	87.4	75.2
3	1.5	79.6	68.0
4	2.5	57.9	65.4
5	4	58.9	62.4
6	6	57.8	62.9
7	10	58.0	64.8
8	17	58.5	64.9
Fairfield 1	0.25	87.2	86.5
2	0.5	81.6	84.3
3	1.5	77.7	81.9
4	2.5	76.2	78.2
5	4	74.2	75.6
6	6	72.5	72.9
7	10	67.9	72.3
8	17	67.8	74.6
Brew Ext 1	0.25	81.8	72.6
2	0.5	78.4	64.9
3	1.5	69.9	57.3
4	2.5	68.7	54.3
5	4	76.3	53.2
6	6	66.4	58.7
7	10	63.5	59.9
8	17	64.5	no data
Brewerton 1	0.25	87.4	80.7
2	0.5	83.2	79.7
3	1.5	81.7	75.5
4	2.5	79.5	70.9
5	4	78.9	68.5
6	6	76.8	65.9
7	10	77.1	62.0
8	17	63.7	68.3