THE EFFECTS OF
TROPICAL STORM AGNES
ON THE
CHESAPEAKE BAY ESTUARINE SYSTEM

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November 1976

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Chesapeake Biological Laboratory   May 3, 1977
Solomons, Maryland   20688

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SOME EFFECTS OF·TROPICAL STORM AGNES ON WATER QUALITY IN THE PATUXENT RIVER ESTUARY[1]

David A. Flemer[2]
Robert E. Ulanowicz[2]
Donald L. Taylor, Jr.[3]

ABSTRACT

A post-Agnes study emphasizing environmental factors was carried out on the Patuxent River estuary with weekly sampling at eight stations from 28 June to 30 August 1972. Spatial and temporal changes in the distribution of many factors, e.g., salinity, dissolved oxygen (DO), seston, particulate carbon and nitrogen, inorganic and organic fractions of dissolved nitrogen and phosphorus, and chlorophyll a were studied and compared to extensive earlier records. Patterns shown by the present data were compared especially with a local heavy storm that occurred in the Patuxent drainage basin during July 1963.

Estimates were made of the amounts of material contributed via upland drainage. A first approximation indicated that 14.8 x 10^3 metric tons of seston were contributed to the head of the estuary between 21 and 24 June. We estimated that 5.6 x 10^3 metric tons of seston were delivered to the upper estuary between 28 June and 30 August. Particulate carbon was 5% of the seston during the latter period. The particulate carbon:nitrogen ratio (wt/wt) of the material contributed for the 10-week interval, exclusive of the four-day peak flow, was about 4.7:1. From 28 June to 30 August about 135 metric tons of total dissolved nitrogen and 10.8 metric tons of total dissolved phosphorus were added to the estuary. These amounts of nitrogen and phosphorus greatly exceeded the requirement for plant primary production, especially during July.

Some interesting correlations were observed in the data. Particulate nitrogen and active chlorophyll a were usually correlated with a correlation coefficient of $\geq$ 0.50 (9d.f.) in the lower study area. In the tidal freshwater area (Nottingham), NH_3-N and NO_3-N and total dissolved phosphorus were negatively correlated with chlorophyll a. These correlations were not strong in the lower river. The atomic ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate-phosphorus was usually greater than 15 and often above 30, especially at the most seaward station (near Solomons) and in the tidal fresh waters. During August some of the above ratios were less than 2.0 in the middle portion of the estuary; this suggested that nitrogen would potentially become more limiting to phytoplankton growth than phosphorus. At this time the concentration of active chlorophyll a often approximated 30 to 60 mg m^{-3}.

The minimum surface salinity at Sandy Point, the most seaward station near Solomons was 1 ppt and occurred on 5 July. Strong vertical differences in salinity were noted in the middle portion of the river. In this region, bottom DO values were frequently <1.0 mg liter $^{-1}$.

INTRODUCTION

Tropical Storm Agnes entered the Chesapeake Bay area on 21 June 1972 and provided a unique opportunity to study the environmental impact of an event which usually is unavailable to estuarine scientists. Logistically, we were conveniently located on the Patuxent River estuary to engage in a field reconnaissance of several environmental factors, e.g., salinity, DO, nutrients, chlorophyll a, and seston. A field analysis of the above and other factors in the upper estuary had been completed between August 1968 and August 1970 (Flemer et al. 1970, much of this information will be published later), giving our present efforts considerable comparative value.

Though not as unique or as formidable as Agnes, an unusually heavy rainfall in the Patuxent drainage area occurred during late July 1969, and we compared the 1969 data with the present data. Our field studies in this investigation began on 28 June 1972, about one week after Agnes, and were continued at weekly intervals until 30 August 1972.

Extreme conditions imposed by Agnes were believed of general interest in the area of eutrophication. This study was planned to help characterize the relationship between phytoplankton and nitrogen and phosphorus. Questions regarding nutrient removal at wastewater treatment plants is still an unresolved problem in Maryland, and an active research program by the Chesapeake Research Consortium, Inc. in Chesapeake Bay is focusing on the effects of sewage on the estuarine ecosystem.

Detritus is considered an important source of energy for many deposit- and filter-feeding organisms. In the oligohaline area of the Patuxent, we have provided further evidence that the dominant spring copepod, *Eurytemora affinis*, feeds extensively on detritus (Heinle et al. 1974). We have attempted to characterize the input of detritus to the head of the estuary following the large runoff caused by Agnes. The elemental composition of the suspended material in the estuary complements work reported in a recent symposium (Melchiorri-Santolini & Hopton 1972), though relatively little information was presented for estuarine conditions.

DESCRIPTION OF THE STUDY AREA

The drainage basin of about 963 sq. miles (2,494 km^2) lies wholly within the State of Maryland on the western shore of the Bay and forms the next major tributary upstream from the Potomac River (Nash 1947). The basin lies in both the Piedmont Plateau and the Coastal Plain physiographic provinces. Urbanization is occurring, especially in the upper drainage basin near the Fall Line, which runs approximately between Washington, D. C. and Baltimore. Extensive tidal brackish water marshes are located within the upper two-thirds of the study area with the seaward extension of the marsh complex ending just upstream to Trueman Point (Fig. 1). The present study area included eight channel stations from tidal freshwater (Nottingham) to a location adjacent to Solomons (Sandy Point).

Tidal amplitude is small. Cory and Nauman (1967) report a difference of 0.55 m between mean high and mean low tides near Benedict Bridge and Mansueti (1961) gave a tidal range of 0.76 m near Nottingham. The estuary is typically a two-layered system (type B of Pritchard 1955) and occasionally changes to a three-layered system near the mouth.

METHODS AND PROCEDURES

Field Sampling Procedures

Field samples were obtained with a 13-foot Boston Whaler. Sampling began at Sandy Point and proceeded upstream following the node of the same slack current that preceded flood current. Water samples were pumped with a battery powered submersible pump (Teel Manufacturing Co., Model 1P811). DO and temperature were measured with a YSI Model 54 oxygen meter by placing the probe near the end of the sampling hose in a plastic bucket. Salinity was measured with an American Optical Company refractometer prior to 19 July, and a Beckman Model RS-5 salino-meter was used after this date. Samples were brought back to the laboratory and processed. Filtrates and unfiltered samples were frozen in polyethylene bottles. Filter pads were desiccated over silica gel and frozen. Chlorophyll a samples collected on filters were directly frozen without desiccation.

Analytical Methods

Samples for chlorophyll a were collected on Whatman GF/C filters and the chlorophyll a was estimated fluorometrically with a Turner fluorometer (Yentsch and Menzel 1963; Holm-Hansen et al. 1965) using our adaptation of these two methods (Flemer et al. 1970).

Seston, or total suspended material, was determined on tared GF/C filters after drying to constant weight over silica gel. Particulate carbon was deter-mined by the method of Menzel and Vaccaro (1964) using a Beckman Model 1R215 In-frared Analyzer and a Coleman CHO Analyzer. Particulate nitrogen was determined with a Coleman Model 29A Nitrogen Analyzer equipped with a Model 29 combustion tube and syringe.

Total phosphorus was determined with the oxidation method of Menzel and Corwin (1965). The same method was used to oxidize dissolved organic phosphorus materials after passing the sample through GF/C filter. Dissolved inorganic re-active phosphorus was determined with the composite reagent method (Strickland & Parsons 1968).

Ammonia nitrogen analysis followed the procedure of Solorzano (1969). Ni-trate and nitrite nitrogen were analyzed by the method of Strickland and Parsons (1965). Soluble organic nitrogen analysis employs a modification of the uv light oxidation (Strickland & Parsons 1968). A half-strength seawater solution is used for the solvent, for the blanks, ammonium sulfate, and pyridine standards. The seawater solution is made up according to Strickland's and Parsons' (1968) nitrate method, then diluted by one-half with double distilled, deionized water. This solution is used to dilute river water samples and to add salts to facilitate the uv oxidation (unpublished observations). We dilute, if necessary, 20 ml of river water sample to 100 ml with half-strength sea water. Two drops of 30% hydrogen peroxide are added to the sample in a quartz tube, and the sample is capped and irradiated 7 cm from a 1,200-watt Hanovia-Englehardt 189A lamp for 3 hours. Strickland's and Parsons' (1968) procedure is followed for the remainder of the analysis.

Freshwater Discharge to the Head of the Estuary

Discharge values were calculated for the contribution of fresh water from the drainage basin of the upper Patuxent River above the confluence with Western Branch and for the Western Branch drainage basin. Gaging stations were near the

headwaters of the tributaries; thus, the estimates of discharge were based on the ratio of area gaged to the area downstream of the gaging stations. The formulation employed was based on the work of Charles Hall, Maryland Department of Water Resources, where:

$$Q_T = Q_L + 5.9\ Q_W + 1.42\ Q_U + 4.2\ Q_G$$

and

Q_T = total fresh water to head of estuary (main stem of Patuxent, plus Western Branch)

Q_L = discharge at Laurel gaging station

Q_W = discharge at Western Branch gaging station near Largo.

Q_U = discharge near Unity gaging station

Q_G = discharge near Guilford gaging station.

The unpublished gaging station data were provided by the Geological Survey, Water Resources Division, U. S. Department of Interior, College Park, Md.

We determined the total discharge over Δt where the sampling date was near the mid-point. For example, the first sampling date of 28 June with three days before and three days after this date were used to estimate the weekly discharge. The same approach was employed for each succeeding sampling date. The concentration of a factor at Nottingham, e.g., seston, was multiplied by the total weekly discharge to estimate a flux for the interval. The 10 intervals were summed to provide an estimate of total flux.

RESULTS AND DISCUSSION

All data taken in this study are listed in Table 1 and in the appendix.

Temperature, Salinity and DO

Water temperatures measured in this study were characteristic for the summer (Table 1; Flemer et al. 1970). Maximum values occurred upstream in the general vicinity of the Chalk Point Power Plant. Exceptionally high values, some approximating $36^{\circ}C$, were noted in the upper study area on 26 July. Bottom values were sometimes slightly higher than surface values. These data supplement the extensive records of temperature in the upper River (Herman et al. 1968; Cory & Nauman 1967).

Salinities reflected the large rainfall in the drainage basin, and our data record the recovery of the low salinities back to the more normal regime (Table 1). Surface salinities were 0.0 ppt as far seaward as Benedict Bridge during most of July. Strong vertical differences in salinity were noted at Sheridan Point and seaward. The minimum surface salinity at Sandy Point was about 1.0 ppt and occurred on 5 July. Bottom salinities on two occasions at Sandy Point (28 June and 2 August) were about 1.5 ppt less than surface values. We point out these differences as possibly accurate observations since Nash (1947) made similar kinds of observations near Sandy Point.

Some perspective is gained by comparing surface salinities at Sandy Point

Table 1. Temperature (C), salinity (ppt), and dissolved oxygen (mg liter $^{-1}$), and top (T) and bottom (B), observed during the Patuxent River Post-Agnes Study, summer 1972.

Date		6/28			7/5			7/12			7/19			7/26		
		Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO
Station	Hours	14:15			08:15			13:35			07:05			13:45		
Nottingham	T	24.7	0.0	7.7	–	0.0	–	23.6	0.0	6.6	27.0	0.0	4.8	29.9	0.0	7.7
	B	24.0	0.1	7.2	–	0.0	–	23.3	0.0	5.7	26.5	0.0	4.7	34.5*	0.0	6.5
L. Marlboro	T	25.3	0.1	5.2	–	0.0	–	23.9	0.0	7.1	29.0	0.0	6.4	30.0	0.0	9.8
	B	25.0	0.1	5.3	–	0.0	–	23.5	0.0	6.6	30.0	0.0	6.0	36.0*	0.0	6.6
Trueman Point	T	27.2	1.4	5.3	–	0.0	–	25.0	0.0	7.0	29.9	0.0	7.0	30.0	0.5	6.5
	B	27.0	1.9	5.6	–	0.0	–	24.5	0.0	6.6	30.0	0.0	6.3	33.3	1.6	6.1
Benedict Bridge	T	26.0	2.5	5.3	24.0	0.0	5.4	25.4	0.0	7.2	28.0	0.0	7.2	29.7	2.3	6.7
	B	25.8	2.6	5.0	23.9	0.3	4.1	25.2	1.1	6.5	27.0	1.4	6.5	32.0	2.6	6.0
Sheridan Point	T	25.5	3.1	5.3	23.5	0.5	6.1	24.7	2.3	7.6	26.0	1.4	8.2	27.9	3.1	6.6
	B	24.1	4.1	2.8	21.0	2.3	2.9	24.0	2.5	3.3	24.0	4.5	2.0	27.6	4.0	4.0
Queen Tree	T	25.5	3.6	7.0	23.0	1.5	7.8	24.5	2.8	9.1	27.8	2.3	8.5	27.4	3.4	6.9
	B	25.0	4.4	2.6	21.2	4.0	2.5	23.9	3.4	3.5	23.5	5.0	1.5	26.7	4.4	1.9
Broome Island	T	26.0	4.2	7.4	22.5	1.3	7.0	24.2	2.3	9.2	26.0	2.3	8.6	27.0	3.4	6.3
	B	25.5	4.7	2.7	21.0	4.5	3.0	22.9	4.5	4.0	24.5	5.6	2.2	27.2	4.4	1.6
Sandy Point	T	26.0	4.7*	6.8	22.0	1.3	8.6	23.9	4.5	9.1	25.5	4.5	7.9	27.0	5.0	6.3
	B	24.5	3.1	2.3	21.0	4.5	4.2	22.9	5.6	5.4	24.5	5.6	4.6	27.2	5.0	4.3
	Hours	10:35			05:30			10:45			04:15			10:10		

*asterisk mark unusual results. Time in hours of initiation of sampling is given at bottom of each column and time of conclusion of sampling at the upstream station is given at the top of each column.

Table 1. Continued. Temperature (C), salinity (ppt), and dissolved oxygen (mg liter^{-1}), and top (T) and bottom (B), observed during the Patuxent River Post-Agnes Study, summer 1972.

Date		8/2 07:10			8/9 12:20			8/16 07:46			8/23 10:43			8/30 16:35		
Station	Hours	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO	Temp.	Sal.	DO
Nottingham	T	24.7	0.0	7.7	26.5	0.1	8.2	24.2	0.2	7.3	-	-	-	26.5	0.1	9.1
	B	24.0	0.1	7.2	25.0	0.2	8.4	23.8	0.2	7.1	-	-	-	26.5	0.1	8.9
L. Marlboro	T	25.3	0.0	5.2	27.0	0.0	6.8	25.0	0.8	6.4	-	-	-	27.5	0.3	7.5
	B	25.0	0.1	5.3	26.0	0.1	6.2	24.3	0.7	6.5	-	-	-	27.5	0.3	7.0
Trueman Point	T	27.2	1.4	5.3	27.5	0.9	7.8	25.1	2.2	6.7	27.2	2.8	6.8	28.5	2.5	6.4
	B	27.5	1.9	5.6	28.0	1.0	6.8	24.5	2.4	6.7	27.3	4.0	7.0	29.5	3.1	6.7
Benedict Bridge	T	26.0	2.5	5.3	27.0	2.7	7.8	24.1	5.4	5.5	27.0	5.3	6.5,	29.0	5.7	7.2
	B	25.8	2.6	5.0	27.0	2.9	6.5	24.1	6.2	3.7	26.5	5.6	5.3	28.0	6.3	4.3
Sheridan Point	T	25.5	3.1	5.3	26.5	3.4	9.8	24.5	5.2	5.7	27.9	6.2	7.9	25.5	6.9	7.3
	B	24.1	4.1	2.8	26.0	6.1	1.1	24.0	7.6	0.3	25.3	7.3	1.6	26.0	9.7	0.1
Queen Tree	T	25.5	3.6	7.0	26.0	3.8	9.4	24.8	5.4	6.9	26.9	6.4	7.8	25.5	7.6	7.1
	B	25.0	4.4	2.6	25.0	6.8	0.9	24.0	7.9	0.4	25.0	8.0	0.9	26.5	10.4	0.3
Broome Island	T	26.0	4.2	7.4	25.5	3.9	10.3	24.2	5.9	6.5	27.0	7.2	9.5	27.0	7.8	5.2
	B	24.5	4.7	2.7	20.3	9.3	0.4	24.0	9.3	0.4	24.5	7.3	0.2	26.5	10.4	0.4
Sandy Point	T	26.0	4.7*	6.8	25.1	6.0	8.6	24.0	7.7	6.5	24.5	8.6	7.5	26.0	9.3	2.3
	B	24.5	3.0	2.3	20.3	9.8	1.4	24.0	9.3	5.3	24.5	9.5	3.8	24.5	10.4	2.6
Hours		03:55			09:30			03:35			08:52			13:16		

*asterisk mark unusual results. Time in hours of initiation of sampling is given at bottom of each column and time of conclusion of sampling is given at top of each column.

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with those taken nearby at the Chesapeake Biological Laboratory pier. Daily salinities at the pier from 1 June to 20 June 1972 ranged between 7.9 and 10.8 ppt. These data are not continuous as observations are usually not made on weekends; however, on 28 June the salinity was 2.5 ppt and agreed closely with our data at Sandy Point. The monthly mean values at the pier during the period 1938 to 1957 for June, July, and August were 11.0, 12.5, and 13.5 ppt, respectively (Beaven 1960). Agnes resulted in very low salinities at a time when salinities normally proceed toward maximum values in the River.

Salinity data obtained during July 1969 reflect the aftermath of a heavy rainfall that occurred in the drainage basin. In the lower River, 11.85 inches of rain fell at Solomons on 23 July 1969, over a period of a few hours (NOAA, Ashland, N. C., central records for Solomons area). In the upper River, the surface salinity at Nottingham on 8 July 1969 was 2.7 ppt and on 30 July 1969, this salinity level was displaced seaward to a point near Trueman Point (Flemer et al. 1970).

Information is presented on DO that generally characterizes the oxygen resources of the River (Table 1). Only large changes can be evaluated for the summer since the same slack sampling required some cruises to be initiated at night. Very low concentrations of DO, e.g., 1.0 mg liter^{-1}, were measured in bottom waters between Sheridan Point and Broome Island.

Particulate Material

Seston. Highest concentrations of seston occurred upstream of Benedict Bridge (Fig. 2). A maximum value of 170 mg liter^{-1} was measured at Lower Marlboro in the bottom sample on 5 July. Seaward to Benedict Bridge the concentration of seston seldom was greater than 50 mg liter^{-1}. On 2 August, 168 mg liter^{-1} of seston were recorded at Nottingham, and 68 mg liter^{-1} of seston were measured as far seaward as Broome Island. The above pattern of seston in the River suggests that the maximum discharge of suspended solids associated with Agnes occurred before 28 June. The rapid washout of chlorophyll a, as discussed later, confirms this conclusion.

High sestonic levels were often encountered during earlier work in the River (Flemer et al. 1970). The upper tidal Patuxent received very high amounts of seston during late July 1969. Several values approached 200 mg liter^{-1}. We have no quantitative data on seston for this event at Solomons, but comparative data for the upper tidal River taken on 8 and 30 July 1969 documented the impact of this unusually large freshwater discharge to the estuary. These data indicated that the Patuxent River has received large concentrations of seston in the past but Agnes was a significant event in the history of the Patuxent system. Normally the so-called "sediment trap," which is well described for the main stem of Chesapeake Bay (Schubel 1968b; Schubel & Biggs 1969), extends seaward in the Patuxent estuary to about Chalk Point. Agnes briefly extended the seaward boundary of the sediment trap downstream to, at least, the mouth of the Patuxent River. The system returned quickly to steady-state conditions, and the seaward extension of the sediment trap moved upstream between Benedict Bridge and Sheridan Point.

Chlorophyll a. The concentration of active chlorophyll a, which is an index of the standing crop of phytoplankton (here possibly some mud-dwelling algae), showed a sharp decline between Nottingham and Sheridan Point (Figs. 3a and 3b) during the first two sampling periods. Surface values at this time were 5 to 8 mg m^{-3}. Seaward, between Broome Island and Sandy Point, the surface concentration of chlorophyll a ranged between 40 to 50 mg m^{-3}. This pattern probably resulted from the seaward displacement of normally high upstream concentrations.

Earlier work indicated that the high values observed during this study between Nottingham and Trueman Point from 19 July to 30 August are typical for the upper study area (Flemer et al. 1970). Maximum surface concentrations of chlorophyll a observed during the present study were 127 and 105 mg m^{-3}, which occurred at Nottingham and Broome Island on 9 August and 23 August, respectively. Most moderately deep temperate East Coast estuaries show a single sustained maximum concentration of chlorophyll a during the late summer, especially in the sediment trap area (Ryther 1963; Flemer 1970).

Seaward of Lower Marlboro there was a stronger temporal pattern in the distribution of surface chlorophyll a in the present study than that observed for the bottom waters. The low values measured at Queen Tree and Broome Island were associated with the low concentration of DO that was present in the bottom waters. In general, the concentration of chlorophyll a observed in the present study compares well with earlier studies on the River (Flemer & Olmon 1971; Flemer et al. 1970). A feature characteristic of Agnes was for more variations over time to occur in the surface waters at higher salinities.

For perspective, we are able to compare the present distribution of chlorophyll a in the River with that for the summer of 1969. The large amount of rain that occurred in late July 1969 was strongly associated with the low chlorophyll a values measured at that time. For example, values at Lower Marlboro rapidly decreased from 46 to 7 mg m^{-3}. This correlates well with the increased sestonic load received by the River during the July 1969 period and illustrates that the upper Patuxent has experienced an important washout of the phytoplankton at other times.

Particulate Carbon. The concentration of particulate carbon showed a surprising uniformity in the surface waters through most of the River until early August (Fig. 4a). Most values ranged between 100 and 200 µ moles liter^{-1} (1.2-2.4 mg liter^{-1}). Highest concentrations of particulate carbon in the surface and bottom waters (Fig. 4b) occurred during late August when chlorophyll a values were maximal.

We observed that the average values of the percent of carbon relative to seston in the surface waters ranged between 6 and 8% from Nottingham seaward to Queen Tree (Table 2). Exclusive of two unusually high concentrations of particulate carbon noted at Broome Island and Sandy Point, the values averaged 8.6 and 10.7% at these stations. The average values discussed above compare favorably to earlier work on the River (Flemer et al. 1970).

Seaward of Benedict Bridge the percent of carbon relative to seston in bottom samples was about one-half less than the surface average values. Several reasons may help explain these observations. Possibly a differential settling of inorganic material occurred, or the rate of decomposition was greater than that of carbon input from upland drainage, and marsh drainage, and plant production in the River. Also, dilution of the bottom suspended material from the sediments could influence the above pattern (Schubel & Biggs 1969). If we assume that the carbon values represent about 50% of the organic matter on a dry weight basis, then our values agree more closely with the winter and spring data on organic matter in the upper Chesapeake Bay (Schubel 1968a).

Particulate Nitrogen. In contrast to the distribution of particulate carbon, particulate nitrogen in the surface waters varied more with time than it did with position in the river. Most maximum values approximated 40 to 50 µ moles liter^{-1} or 600 to 750 µg liter^{-1} (Fig. 5a). The fairly high correlation between nitrogen

Table 2. The percent particulate carbon of seston in the surface (S) and bottom (B) waters, Post-Agnes Study, Patuxent River Estuary, summer 1972.

Table 2. The percent particulate carbon of seston in the surface (S) and bottom (B) waters, Post-Agnes Study, Patuxent River Estuary, summer 1972.

| | STATIONS |
Date	Nottingham S	Nottingham B	Lower Marlboro S	Lower Marlboro B	Trueman Pt. S	Trueman Pt. B	Benedict Br. S	Benedict Br. B	Sheridan Pt. S	Sheridan Pt. B	Queen Tree S	Queen Tree B	Broome Is. S	Broome Is. B	Sandy Pt. S	Sandy Pt. B
6/28	4.8	4.0	-	3.3	2.6	2.8	2.6	2.2	2.7	2.3	4.5	1.4	7.4	2.2	8.2	2.2
7/5	3.7	3.5	4.0	3.9	2.1	3.8	3.8	4.3	1.4	5.0	8.1	4.0	6.9	2.9	8.3	3.5
7/13	5.0	4.0	4.4	4.0	3.5	4.2	2.7	2.9	4.3	2.1	2.9	5.0	7.5	2.9	11.5	2.5
7/19	0.9	3.1	5.0	5.0	4.2	5.0	4.7	7.6	3.9	2.8	7.9	2.8	7.9	3.6	12.0	11.2
7/26	4.8	5.6	4.4	3.0	3.0	5.1	4.0	6.0	3.6	5.6	2.8	5.0	4.5	3.6	9.0	7.1
8/2	4.7	3.8	3.6	3.1	3.4	3.0	2.1	2.8	5.6	3.2	5.0	2.7	8.0	3.7	10.8	6.7
8/9	8.7	10.0	7.5	6.7	6.2	2.0	8.1	5.5	17.9	4.6	13.0	5.8	20.0	2.5	13.1	4.2
8/16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/23	-	-	-	-	7.5	6.9	8.9	6.6	10.4	5.7	7.5	5.4	60.4	3.0	12.5	6.8
8/30	17.1	16.7	10.8	6.5	6.9	4.6	21.1	13.5	22.5	2.9	11.4	2.5	6.4	2.9	-	4.4
$\bar{x}$	6.2	6.3	5.7	4.4	4.4	4.2	6.4	5.7	8.0	3.8	7.0	3.8	8.6[1]	3.0	10.7	5.4

[1]average exclusive of high value observed on 8/23.

and chlorophyll a is obvious from the contour diagrams. Conversely, the pattern
of particulate nitrogen in the bottom waters was characterized more by position
than times in the river; in fact, a relatively sharp decrease occurred throughout
the study in the concentration of particulate nitrogen at Sheridan Point (Fig. 5b).
A similar trend was noted for chlorophyll a. The concentration of particulate ni-
trogen measured during this study approximated that measured previously (Flemer et
al. 1970).

Nutrients

Phosphorus. Data on several fractions of phosphorus, e.g., total phosphorus,
total dissolved phosphorus, and dissolved inorganic reactive phosphate-phosphorus,
are illustrated in Fig. 6 for four stations along the River. Total phosphorus
approximated 6.0 µg at liter^{-1} at Nottingham and showed a gradual decrease sea-
ward to Sandy Point where the concentration ranged between 2 and 4 µg at liter^{-1}.
Inadvertent filtration of samples from 5 July through 19 July prevented analysis
for total phosphorus. Total dissolved phosphorus usually ranged between 20 and
50% of the total phosphorus. Thus, by difference, particulate phosphorus consti-
tuted a substantial portion of the phosphorus in the river. Dissolved inorganic
phosphate usually accounted for most of the total dissolved phosphorus. There-
fore, relatively little dissolved organic phosphorus was present. On a few occa-
sions the dissolved inorganic values were analytically greater than values for
total dissolved phosphorus. We believe that the total dissolved values should be
considered only approximate. Work is under way in an attempt to resolve this
problem.

Compared to data obtained during the summer of 1969, we conclude that the
general pattern of phosphorus distribution and concentrations in the River did not
differ in any important way (see Fig. 6).

We should mention that the inorganic phosphate concentration is largely con-
trolled in turbid estuaries through sorption reactions with suspended sediments
(Pomeroy, Smith, & Grant 1965). We expect that such reactions strongly influenced
the level of phosphate observed in the present study as the Patuxent qualifies as
a turbid estuary. The exchange is apparently near-equilibrium when the water has
a phosphorus content about 0.7 to 1.5 µg at liter^{-1} (Butler & Tibbitts 1972).
In the Tamar estuary, near the Plymouth Laboratory, England, in contrast to our
findings, the total dissolved phosphorus was relatively constant before and after
a heavy rain throughout the estuary. The concentration of total dissolved phos-
phorus in the Patuxent showed a substantial decrease from Nottingham seaward but
relatively less change over time during the present study.

Nitrogen. Nitrogen determinations presented in Fig. 7 show the total nitro-
gen as represented by several fractions. The dissolved organic and inorganic
fractions (NH_4^+, NO_2^-, and NO_3^-) are added to the particulate nitrogen. Some com-
parative data taken during the summer of 1969 are included on the figure (Flemer
et al. 1970).

Maximum total nitrogen occurred at Nottingham and during the first six weeks
many values ranged between 80 and 100 µg at liter^{-1}. Most values of total ni-
trogen during the first six weeks at Benedict Bridge and Queen Tree ranged be-
tween 60 and 80 µg at liter^{-1}. At Sandy Point during this period there was a
slight increase in the total nitrogen. A maximum value for the entire study of
146 µg at liter^{-1} occurred at Sandy Point on 28 June which presumably was re-
lated to the displaced upstream material. Total nitrogen decreased about 50%
at all stations during the latter half of the study with few exceptions. One

notable exception occurred at Nottingham on 30 August where a concentration of
140 µg at liter^{-1} was measured.

The limited data available from the summer of 1969 suggest that total nitro-
gen was more highly concentrated during the recovery period of Agnes than noted
during the summer of 1969. By comparison, the concentration of total phosphorus
failed to show a consistent increase over that of the summer of 1969.

We examined the relative proportion of NH_3-N, NO_2-N, and NO_3-N to the total
inorganic nitrogen (Appendix). The concentration of NH_3-N decreased more rapid-
ly than the concentration of NO_3-N at Nottingham and Benedict Bridge from 28 June
to 19 July. The pattern was not as clearly discernible at Queen Tree as noted
at the upstream stations. At Sandy Point, the concentrations of NH_3-N and NO_3-N
decreased together proportionally for most of the study with the pronounced ex-
ception on 30 August. It is tempting to ascribe the more rapid decrease in NH_3-
N relative to NO_3-N to differential uptake by phytoplankton (Harvy 1960). The
analysis is complicated by a rapid increase in primary production, unknown
changes in the relative rate of supply of the two nutrients and nitrification.
Nitrite-nitrogen was quantitatively unimportant compared to the other inorganic
nitrogen sources throughout the study.

The concentration of dissolved organic nitrogen often approximated or ex-
ceeded the concentration of dissolved inorganic nitrogen (Fig. 7). Most of the
dissolved nitrogen was in the form of dissolved organic nitrogen at Benedict
Bridge and Queen Tree on 9, 16, and 23 August (Appendix). At this time the
significance of dissolved organic nitrogen to the biological system is not appar-
ent but presumably contributes to the available nitrogen pool in the long-term.

Ratios and Correlations

Data on C:N ratios (atomic) for surface and bottom waters are given in Figs.
8a and 8b. Surface ratios showed more variation with time than position along
the axis of the estuary. Both surface and bottom ratios usually were within the
range of 3-10. Living phytoplankton typically have a C:N (atomic) ratio of about
7 (Strickland 1960). The relative constancy of the ratios is dissimilar to the
data reported for the upper Chesapeake Bay (Flemer & Biggs 1971). However, max-
imum values in the upper Chesapeake Bay usually followed the maximum discharge
related to snow melt in the Susquehanna River basin. Possible the small range in
values over the summer in the Patuxent resulted from averaging the high C:N ratios
associated with higher plant material with the lower ratios associated with phyto-
plankton (Gucluer & Gross 1964).

Particulate carbon (PC) was highly correlated, $\sqrt{} < 0.80$, with PN at Trueman
Point (bottom), Broome Island (surface and bottom), and Sandy Point (surface and
bottom) (Table 3). At Sheridan Point and seaward, except Queen Tree, we observed
that PC with chlorophyll a and PN with chlorophyll a were significantly correlated
(Table 3). These correlations are more likely in the more seaward of the estuary
where phytoplanktonic material is relatively more abundant than upstream where
considerable material is derived from upland drainage. In earlier work we observed
that PN x chlorophyll a were highly correlated at the more seaward stations, (e.
g., Trueman Point and seaward to Queen Tree). Brooks (1970) reported for the
Brazos River, Texas, that the particulate organic carbon was directly related to
river discharge. In the Patuxent autochthonous sources of particulate organic
carbon probably mask the relationship between river flow and the concentration
of particulate carbon, especially at the more seaward stations.

The measured ratio of PC:chlorophyll a is another way to view the relation-
ship between living algal material and the total suspended particulate carbon

Table 3. Correlation coefficients equal to or greater than +0.80 or −0.70.
Post-Agnes study, Patuxent River Estuary, 28 June–30 August 1972.

Station	Factors	Correlation Coefficient	d.f.	P
Nottingham				
Surface		Positive		
	NO_2 x TDN	0.87	7	0.998
	NO_3 x TDN	0.97	7	1.000
	NO_3 x TDP	0.87	7	0.998
	TDN x DIP	0.95	7	1.990
	TDN x TDP	0.87	7	0.998
	DIP x TDP	0.90	7	0.999
	TCL x ACL	0.996	8	1.000
		Negative		
	NO_3 x PC	−0.86	8	0.999
	NO_3 x TCL	−0.86	8	0.999
	NO_3 x ACL	−0.82	8	0.997
	NH_3 x TCL	−0.85	6	0.992
	NH_3 x ACL	−0.82	6	0.988
	TDN x PN	−0.75	7	0.983
	TDN x PC	−0.83	7	0.994
	TDN x TCL	−0.81	7	0.992
	TDN x ACL	−0.76	7	0.985
	TDN x SAL	−0.77	7	0.987
	TDP x PC	−0.91	7	0.999
	TDP x ACL	−0.74	7	0.982
	TP x SAL	−0.78	5	0.968
Bottom		Positive		
	PN x TCL	0.92	7	1.000
	PN x ACL	0.92	7	0.994
	TCL x ACL	0.99	8	1.000
		Negative (none)		
Lower Marlboro				
Surface		Positive		
	TCL x ACL	0.99	8	1.000
		Negative (none)		
Bottom		Positive		
	PC x SES	0.95	7	1.000
	TCL x ACL	0.99	8	1.000
		Negative (none)		
Trueman Point				
Surface		Positive		
	TCL x ACL	0.99	9	1.000
		Negative (none)		
Bottom		Positive		
	PN x PC	0.84	9	0.999
	PN x SES	0.83	8	0.999
	TCL x ACL	1.00	9	1.000
		Negative (none)		
Benedict Bridge				
Surface		Positive		
	NO_2 x NO_3	0.99	9	1.000
	NO_2 x TDN	0.88	8	0.999
	NO_3 x TDN	0.88	8	0.999

Table 3. (Cont'd)

Station	Factors	Correlation Coefficient	d.f.	P
Benedict Bridge				
Surface		Positive		
	NO_3 x DIP	0.82	9	0.998
	TCL x ACL	0.99	9	1.000
		Negative		
	NO_2 x SAL	-0.78	9	0.996
	NO_3 x TCL	-0.74	9	0.993
	NO_3 x ACL	-0.76	9	0.995
	NO_3 x SAL	-0.76	9	0.995
	TDN x PC	-0.71	8	0.984
	TDN x SAL	-0.78	8	0.993
	DIP x SAL	-0.70	9	0.987
Bottom		Positive		
	TCL x ACL	1.00	9	1.000
		Negative		
	PC x SES	-0.71	8	0.984
Sheridan Point				
Surface		Positive		
	PN x TCL	0.96	9	1.000
	PN x ACL	0.96	9	1.000
	TCL x ACL	0.98	9	1.000
		Negative (none)		
Bottom		Positive		
	TCL x ACL	0.96	9	1.000
		Negative (none)		
Queen Tree				
Surface		Positive		
	NO_2 x TDN	0.85	9	0.999
	TDP x SAL	0.84	9	0.999
	TCL x ACL	0.99	9	1.000
		Negative (none)		
Bottom		Positive		
	TCL x ACL	0.97	9	1.000
		Negative (none)		
Broome Island				
Surface		Positive		
	PN x PC	0.97	9	1.000
	PN x TCL	0.94	9	1.000
	PN x ACL	0.93	9	1.000
	PN x SES	0.90	8	1.000
	PC x TCL	0.90	9	1.000
	PC x ACL	0.89	9	1.000
	PC x SES	0.89	8	0.994
	TCL x ACL	1.00	9	1.000
		Negative (none)		
Bottom		Positive		
	PN x PC	0.80	9	0.998
	PN x SES	0.82	8	0.999
	PC x SES	0.95	8	1.000
	TCL x ACL	0.87	9	0.999
		Negative (none)		

Table 3.   (Cont'd)

Station	Factors	Correlation Coefficient	d.f.	P
Sandy Point				
Surface		Positive		
	NO_3 x NH_3	0.82	9	0.998
	NO_3 x TDN	0.94	9	1.000
	NH_3 x TDN	0.85	9	0.999
	PN x TP	0.91	6	0.998
	PN x PC	0.84	9	0.999
	PN x TCL	0.87	9	0.999
	PN x ACL	0.86	9	0.999
	TP x TCL	0.93	6	0.999
	TP x ACL	0.94	6	0.999
	TCL x ACL	1.00	9	1.000
		Negative		
	NO_3 x TDP	-0.73	8	0.988
	NO_3 x SAL	-0.70	9	0.980
	TDN x SAL	-0.74	9	0.992
	DON x TP	-0.78	6	0.980
Bottom		Positive		
	PN x PC	0.94	9	1.000
	PN x TCL	0.86	9	0.999
	PN x ACL	0.87	9	0.999
	PC x TCL	0.94	9	1.000
	PC x ACL	0.95	9	1.000
	TCL x ACL	1.00	9	1.000
		Negative (none)		

(Figs. 9a and 9b). High ratios indicate a relatively low contribution of living plant material. Throughout most of the study the ratio was less than 100:1, and frequently values between 35 and 50:1 were observed. These ratios are consistently less than those observed during earlier summer work on the River (Flemer et al. 1970) and these low ratios are believed to be atypical of temperate coastal waters. As discussed in the preceding paragraph, these ratios suggest a high percentage of living algal carbon relative to the total measured particulate carbon. Many laboratory algal cultures under good growth conditions will have C:chl a ratios between 30:1 and 50:1 (Parsons et al. 1961). Ratios greater than 150:1 were associated with the early washout of the phytoplankton, and high ratios followed the sudden decline from relatively high concentrations of chlorophyll a, especially at Benedict Bridge and seaward during the latter part of this study. We attempted to use the ratio of 50:1 of PC:chlorophyll a to partition the measured surface PC into that related to living phytoplankton and a residual (Fig. 10). The residual would presumably contain material from such sources as detritus and small heterotrophs. Some inconsistent results were noted, especially at the most upstream station, Nottingham; however, the use of a reasonable but still lower ratio of 30:1 eliminated most inconsistencies, except at Nottingham. Average values by station, exclusive of Nottingham, of the percent living carbon ranged between 52 and 79%. No clear axial trend along the estuary was noted in this analysis.

An effort was made to assess the impact of Agnes in terms of the ratio of dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphate-phosphorus (DIP) (Table 4). Typically, during the summer in many temperate coastal waters, the ratios of DIN:DIP are less than 15-10:1 (Ryther & Dunstan 1971) which is interpreted that nitrogen would probably become limiting to phytoplanktonic growth before phosphorus. Frequently, the ratio of DIN:DIP was less than 5:1 during the summer studies of 1969 and 1970 (Flemer et al. 1970). The ratios in the River following Agnes were usually very high, often between 15 and 50:1, except at Benedict Bridge and Queen Tree from 9 August to 23 August where several values approximated 1 to 2. These low ratios were generally consistent with high concentrations of chlorophyll a. The rapid decline of this bloom following the very low DIN:DIP ratio is some evidence that nitrogen may have controlled maximum plant biomass. At Sandy Point the ratio of DIN:DIP remained fairly high, a fact which we would not have predicted based on the present and previous work in the River. It is possible that the nutrient regime in the main stem of the Bay influenced the pattern noted at Sandy Point.

Table 4. The ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate-phosphorus, Patuxent River Post-Agnes Study, summer 1972.

	Stations			
Date	Nottingham	Benedict Bridge	Queen Tree	Sandy Point
28 June	31	-	33	179
5 July	28	24	13	95
12 July	25	17	46	74
19 July	22	8	15	86
26 July	17	15	276	66
2 Aug.	28	22	54	60
9 Aug.	-	0.7	1.6	48
16 Aug.	17	1.6	2.0	15
23 Aug.	-	1.1	2.2	37
30 Aug.	73	13	50	34

Many other correlations are given in Table 5. At Nottingham many of the nutrient fractions were correlated, e.g., NO_3-N x total dissolved nitrogen (TDN), and TDN x DIP, and nutrients were negatively correlated with several particulate fractions, e.g., NO_3-N x ACL (active chlorophyll a). Nutrients would be expected to decrease as particulate material is formed via photosynthesis. The lack of many of these high correlations seaward to Nottingham is evidence that recycling probably dominated the nutrient uptake kinetics, especially from 9 to 23 August.

The C:N:P ratio gives some insight into the relative abundance of elements in the particulate material. Though somewhat variable, living phytoplankton usually are characterized by a C:N:P ratio of 106:10-15:1 (Redfield et al. 1963; Ryther & Dunstan 1971). In this study N:P ratios were 10:1 to 15:1 about half of the time (Table 5) with the remaining comparisons above or below the ratio of 10:1 to 15:1. C to P was more variable than N to P. In 13 out of 25 comparisons, the C:P ratio was less than 84:1, six times the ratio was between 85-126:1 and six times the ratio was greater than 127:1. These ratios indicate that often the particulate material is richer in P relative to C. Below the euphotic zone in the ocean the particulate material usually is phosphorus poor relative to carbon and nitrogen (Menzel & Ryther 1964). The question is still open regarding the relative proportion of dissolved phosphorus that is associated with inorganic material between the open sea and coastal waters.

Table 5.   The atomic ratio of C:N:P in particulate material, Patuxent River Post-Agnes Study, summer 1972.

| | Stations | | | |
Date	Nottingham C:N:P	Benedict Bridge C:N:P	Queen Tree C:N:P	Sandy Point C:N:P
28 June	39:6:1	–	99:23:1	80:12:1
7 July	–	–	–	–
12 July	–	–	–	–
19 July	–	–	–	–
26 July	42:8:1	48:7:1	49:10:1	78:11:1
2 Aug.	55:7:1	21:6:1	63:11:1	96:17:1
9 Aug.	–	73:10:1	135:16:1	89:10:1
16 Aug.	68:8:1	118:9:1	49:11:1	129:21:1
23 Aug.	–	107:10:1	160:20:1	108:13:1
30 Aug.	69:37:1	218:11:1	132:12:1	434:21:1

Flux of Material to the Head of the Estuary

We estimated that about 5.6×10^3 metric tons of seston, 262 metric tons of PC, 46 metric tons of PN, 135 metric tons of TDN, and 11 metric tons of TDP passed Nottingham between 25 June and 2 September 1972 (Table 6). During the peak flow from Agnes between 21 and 24 June, we estimated that 14.8×10^3 metric tons of seston were transported to the head of the estuary. This estimate was based on an assumed concentration of 100 mg liter^{-1} since no data on concentrations were available at this time. The estimate is probably conservative when compared to other observations during high flows (Flemer et al. 1970). Further estimates are possible if we assume that the ratio of the various fractions, e.g., PC and TDN, relative to seston contributed between 25 June and 2 September would apply during peak flows of Agnes. This crude approach yielded the following estimates of flux between 21 and 24 June: PC = 696, PN = 121, TDN = 352, and TDP = 28 metric tons, respectively.

Table 6. Flux of materials to the head of the Patuxent River Estuary, Post-Agnes Study, summer 1972.

Date	$Q_T/\Delta t$ m^3 x 10^6	SESTON $\bar{x}$ conc. mgl^{-1}	Flux g x 10^9	PC $\bar{x}$ conc. mgl^{-1}	Flux g x 10^6	PN $\bar{x}$ conc. mgl^{-1}	Flux g x 10^6	TDN conc. µg atl^{-1}	Flux g x 10^6	TDP conc. µg atl^{-1}	Flux g x 10^6
28 June	42.6	33	1.4	1.4	59.6	0.257	10.9	73.8	44.0	2.87	3.8
5 July	21.1	54	1.1	2.0	42.2	0.257	5.4	84.6	25.0	2.38	1.6
12 July	16.8	32	0.5	1.4	23.5	0.355	6.0	81.2	19.1	2.62	1.4
19 July	18.1	32	0.5	0.6	10.9	0.138	2.5	91.4	23.2	2.99	1.7
26 July	7.9	48	0.4	2.5	19.8	0.548	4.3	56.3	6.2	2.18	0.54
2 Aug	8.1	120	1.0	4.9	39.7	0.600	4.9	64.0	7.3	1.45	0.36
9 Aug	6.9	40	0.3	3.8	26.2	0.400	2.8	40.0[1]	3.9	4.00[2]	0.86
16 Aug	6.0	35[1]	0.2	1.8	10.8	0.433	2.6	38.5	3.2	1.09	0.20
23 Aug	3.8	20[1]	0.08	3.0[1]	11.4	0.6[1]	2.3	20.0[1]	1.1	1.17[1]	0.14
30 Aug	4.4	24	0.1	4.0	17.6	1.030	4.5	53.1	2.0	1.21	0.17
Total			5.6		261.7		46.2		135		10.8

[1] estimates based on flow and values preceding and following missing data.
[2] based on DIP
Note -Q_T is an estimate of total freshwater discharge to the head of the estuary.

It is only possible to give a semiquantitative comparison of the flux of material between Agnes and July 1969 since only three samples were taken between the end of June and the end of August 1969. However, for simplicity, the relative flows are instructive. We estimated that for 28 July 1969 and 22 June 1972, times of peak flows, that 3,104 and 42,554 cfs of water, respectively, were delivered to the head of the estuary. As a minimum, the impact of Agnes was 14 times that of the rainfall of July 1969 in terms of water transported to the upper estuarine area.

In the Patuxent, upland drainage is a significant source of nutrients. In the Ythan estuary, just north of Aberdeen, Scotland, marine water contributed about 70% of the phosphate, and fresh water supplied about 70% of the nitrate (Leach 1971). This author presents interesting comparative data on the contribution of nutrients via fresh water. Based on a semidiurnal tidal cycle (like that of the Chesapeake Bay), the Ythan estuary received about 16.8 kg of inorganic phosphate during the summer. By comparison, we estimated that about 360 kg of total dissolved phosphorus per tidal cycle on the average entered the Patuxent estuary from upstream between 25 June and 2 September. We should emphasize that most of the dissolved phosphorus in the Patuxent is apparently inorganic phosphate, thus the comparison has validity.

GENERAL DISCUSSION

Earlier work in the Patuxent River estuary showed that the upper tidal system probably borders on hypertrophication (Stross & Stottlemyer 1965; Herman et al. 1968; Flemer et al. 1970). Important increases in recent years have occurred in primary productivity, the concentration of chlorophyll a, nitrogen, and phosphorus. The increase in available nitrogen seems especially striking. In view of this information, we were especially interested in the impact of Agnes as a possible stimulant to further overenrichment. It is surprising that the Patuxent is still free of the massive bluegreen algal growths so characteristic of the upper Potomac estuary (Jaworski et al. 1972). The dilutions of the wastewaters received by the Patuxent and Potomac Rivers are quite similar (Brush 1972). Other factors surely play important roles. For example, the extensive tidal marshes characteristic of the Patuxent, but not abundant in the upper Potomac, may play the role of a tertiary treatment system. Salt marsh plots near Woods Hole, Mass., have been shown to retain a large fraction of the nitrogen and phosphorus that were experimentally added as sewage sludge (Valiela et al. 1973). We are currently studying the flux of nutrients between a marsh and its dominant tidal creek in the upper Patuxent; however, results are unavailable for this paper (Heinle et al. 1974). Partial information is available for the Patuxent River on the rate of grazing as an important controlling mechanism to excessive biomass (Heinle 1974). If an additional trophic level occurs between phytoplankton and copepods, then it is suspected that grazing will be an important regulator to the standing crop of phytoplankton. Unfortunately, we were unable to obtain data on zooplankton during this study to aid in interpretation of their rate of grazing during the extreme hydrographic conditions imposed by Agnes. It must be emphasized that conditions that lead to massive bluegreen algal growths are a problem in ecological succession and not simply one of uptake kinetics or development of algal biomass.

The fact that moderately high concentrations of phytoplanktonic biomass occurred during this study compared to previous studies in the Patuxent probably is strongly linked to washout. The apparent displacement of high chlorophyll levels typical of the sediment trap area to the mouth of the River substantiates this conclusion for the initial phase following Agnes. The sustained high levels of chlorophyll a at the two upper stations after 26 July suggest that washout was of much less significance at this time. The periods of low and high chlorophyll a

concentrations seaward to Lower Marlboro after about 26 July reflect the dominance of other factors that are known to control phytoplankton biomass. Though other nutrients were not measured, we would suspect from the N:P ratios that nitrogen played an important role. Welch et al. (1972) have shown that phytoplankton blooms in the Duwamish estuary (Seattle, Washington) are strongly influenced by hydrographic conditions.

Comparative information obtained in our post-Agnes study shows that factors measured in the Patuxent are high relative to most temperate estuaries; Thayer (1971) has summarized much of the pertinent data for these systems. Little information is published on the effects of large floods on water quality in temperate estuarine systems. A phenomenon of comparative interest is the monsoon rain that occurs in some tropical areas. These disturbances are a partial natural analog to Agnes in the Patuxent. In the Cochin Backwater, S. W. India, the depth profile of nutrients, e.g., nitrogen and phosphorus, showed a marked seasonal change induced by land runoff (Sankaranarayanan & Qasim 1969). The system changes annually from a marine estuary during the premonsoon period to a freshwater system during the monsoon period. At times of maximum discharge and turbidity, the quantity of settled detritus was comparatively low. This resulted from the strong stratification or halocline that developed in the estuary (Qasim and Sankaranarayanan 1972). In S. E. India the nutrients were increased with monsoon season in the Vellar estuary (Krishnamurthy 1967). For example, total phosphorus ranged between 1.01 and 5.05 µg at liter^{-1} near the mouth of the Vellar estuary. We would not like to overdraw the above comparison, but the partial environmental parallel seemed worthy of mention.

Ratios of C:N:P and C:chl $\underline{a}$ and N:chl $\underline{a}$ used to characterize the particulate material suggest that some important effects resulted from Agnes. Generally, the emergent picture shows that much of the suspended material found in coastal waters, exclusive of temporary algal blooms, is in the form of organic detritus. Compared to previous data for summer conditions in the Patuxent, the relative amount of living algal carbon to total particulate carbon seemed quite high. Some speculations might prove useful, and they may be tested as hypotheses under experimental conditions. It is surmised that the large-scale flushing of the estuary following Agnes reduced the numbers of many grazers and, consequently, the abundant fecal pellets usually observed in water samples from the Patuxent (Heinle, pers. com.). Also, the detrital carbon derived from upland drainage apparently was diluted. It should be noted that we did not observe exceptionally high levels of particulate carbon. Consequences of a high percent of living carbon in a system usually dominated by detrital carbon would be interesting to examine in terms of food web dynamics.

In the wake of an event such as Agnes we were interested to learn if the flux of particulate carbon that entered the tidal fresh waters above Nottingham was a significant fraction compared to primary production in the estuary. Cronin (1971) gives the mean low water area of the Patuxent from the mouth to approximately Nottingham as $137 \times 10^6 m^2$. As a first approximation, we can assume that net primary production averaged about 1 gCm^{-2} day^{-1} (Stross & Sotttlemyer 1965). Turbidity caused the rate to become somewhat higher downriver and less in the upper portion of the estuary. Thus 10.1×10^9 gC were estimated to be fixed photosythetically in the estuary from 21 June to 2 September 1972. Thus, 10.1×10^3 metric tons of fixed carbon from phytoplankton activity far exceed the estimated 958 metric tons of PC derived from upland drainage above Nottingham. It is reasonable to assume that Agnes contributed much organic material to the head of the estuary where photosynthesis was minimal on an areal basis, but over the 10-week period following the storm, the allochthonous sources of PC were quantitatively minor for the whole estuary.

Compare this result with that obtained from the upper Chesapeake Bay, where
on an annual basis the PC derived from upland drainage constituted about 90% of
the PC pool (Biggs & Flemer 1972). In the Strait of Georgia, British Columbia,
the allochthonous organic material contributed per year by upland drainage approx-
imated the natural primary production of the area (Seki, Stephens, & Parsons 1969).
Thus, for coastal bodies of water, there is a broad range in the relative amount
of PC derived from land sources compared to natural primary production.

ACKNOWLEDGEMENTS

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APPENDIX
PATUXENT RIVER POST-AGNES DATA SUMMARY, SUMMER OF 1972

Seston (mg liter^{-1})

Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	33	12	20	20	20	12	16	--	24	12
	B	45	20	28	32	28	24	24	--	25	16
Broome Is.	T	27	16	16	24	20	20	16	--	48	28
	B	45	24	28	28	25	68	24	--	70	24
Queen Tree	T	40	16	28	24	25	20	20	--	20	28
	B	35	20	36	32	20	56	24	--	24	24
Sheridan Pt.	T	40	64	35	28	25	16	24	--	24	32
	B	35	36	48	36	25	25	28	--	28	28
Benedict Br.	T	50	24	56	36	45	24	36	--	35	36
	B	55	44	48	25	35	64	40	--	35	20
Trueman Pt.	T	87	67	48	50	64	35	32	--	48	32
	B	80	120	48	40	35	64	64	--	48	48
L. Marlboro	T	40	47	32	32	48	56	24	--	--	24
	B	60	170	40	40	40	136	24	--	--	40
Nottingham	T	27	54	24	32	48	72	32	--	--	24
	B	40	54	40	32	48	168	48	--	--	24

T=Top; B=Bottom

Active chlorophyll a (mg m^{-3})

Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	46.0	13.2	33.5	35.9	31.2	19.2	38.3	9.3	44.9	54.5
	B	2.0	5.7	3.6	38.3	18.0	26.3	10.2	55.1	9.9	6.3
Broome Is.	T	44.0	18.0	18.0	22.4	9.8	31.2	74.2	16.2	127.2	18.0
	B	1.5	2.2	5.6	7.3	6.9	7.2	5.7	4.6	4.3	4.5
Queen Tree	T	24.0	21.6	25.2	34.7	10.7	14.4	55.1	19.2	15.0	36.5
	B	1.5	6.9	3.2	6.8	14.4	6.5	18.0	3.6	7.3	1.1
Sheridan Pt.	T	9.5	11.0	14.7	29.9	10.8	19.2	53.8	26.3	31.5	43.1
	B	3.5	4.2	5.2	7.2	20.3	7.3	12.0	5.2	11.6	1.6
Benedict Br.	T	3.0	8.7	15.6	29.9	35.3	13.2	49.4	19.2	29.2	38.3
	B	2.0	6.8	9.6	39.0	49.1	10.8	40.4	27.5	15.5	18.0
Trueman Pt.	T	6.0	8.6	16.3	29.9	28.7	10.8	46.4	31.1	23.9	18.9
	B	4.0	8.7	14.9	28.7	38.3	8.2	34.4	28.7	27.5	19.2
L. Marlboro	T	6.0	5.0	17.8	43.1	69.4	20.3	33.4	35.9	--	33.5
	B	5.0	6.6	19.7	38.3	20.3	26.4	23.9	31.1	--	35.5
Nottingham	T	4.0	5.5	15.5	7.0	81.4	71.8	105.3	45.4	--	74.2
	B	4.0	6.0	10.2	6.6	103.0	105.3	35.9	52.6	--	75.3

APPENDIX (Cont'd)

Station		Total chlorophyll a (mg m⁻³) Date									
		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	52.7	17.6	38.5	40.3	36.6	23.4	44.6	11.9	54.4	66.6
	B	3.5	8.7	5.7	43.9	22.0	31.5	13.0	64.4	13.2	8.0
Broome Is.	T	51.3	21.2	21.2	28.2	14.2	38.8	83.4	19.0	149.7	22.0
	B	2.5	4.9	8.9	11.9	11.0	7.8	11.4	6.0	5.6	6.6
Queen Tree	T	29.5	25.6	30.8	43.2	14.7	19.8	64.4	23.4	18.7	39.9
	B	2.5	11.7	7.0	11.4	19.0	13.2	23.4	5.2	9.1	1.1
Sheridan Pt.	T	11.0	14.4	20.5	36.6	16.8	24.2	71.7	34.4	36.1	46.4
	B	4.5	7.9	10.2	14.3	26.4	11.7	16.1	8.0	12.6	2.6
Benedict Br.	T	4.0	11.6	20.5	38.5	44.6	17.6	58.6	23.4	35.2	41.2
	B	3.5	10.4	14.6	48.5	60.0	17.6	51.2	32.9	19.5	19.3
Trueman Pt.	T	9.0	11.2	22.5	38.5	37.3	14.6	57.6	42.5	30.7	24.4
	B	6.0	12.8	20.7	36.6	46.8	13.5	45.8	36.6	35.1	24.9
L. Marl-boro	T	7.0	7.5	21.6	51.3	82.0	27.8	42.5	51.2	--	46.8
	B	6.0	9.5	24.9	46.9	27.1	39.5	32.0	41.0	--	46.8
Notting-ham	T	5.0	8.3	19.5	9.9	92.2	84.9	120.1	61.5	--	95.2
	B	5.0	8.2	13.7	9.5	115.6	118.6	45.4	70.3	--	96.6

Station		Particulate Carbon (mg liter⁻¹) Date									
		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	2.7	1.0	2.3	2.4	1.8	1.3	2.1	1.1	3.0	14.6
	B	1.0	0.7	0.7	3.6	2.0	1.6	1.0	4.0	1.7	0.7
Broome Is.	T	2.0	1.1	1.2	1.9	0.9	1.6	3.2	1.3	29.0	1.8
	B	1.0	0.7	0.8	1.0	0.9	2.5	0.6	0.8	2.1	0.7
Queen Tree	T	1.8	1.3	0.8	1.9	0.7	1.0	2.6	1.1	1.5	3.2
	B	0.5	0.8	1.8	0.9	1.0	1.5	1.4	1.1	1.3	0.6
Sheridan Pt.	T	1.1	0.9	1.5	1.1	0.9	0.9	4.3	3.1	2.5	7.2
	B	0.8	1.8	1.0	1.0	1.4	0.8	1.3	1.5	1.6	0.8
Benedict Br.	T	1.3	0.9	1.5	1.7	1.8	0.5	2.9	2.3	3.1	7.6
	B	1.2	1.9	1.4	1.9	2.1	1.8	2.2	2.5	2.3	2.7
Trueman Pt.	T	2.3	1.4	1.7	2.1	1.9	1.2	2.0	3.0	3.6	2.2
	B	2.2	4.6	2.0	2.0	1.8	1.9	1.3	3.8	3.3	2.2
L. Marl-boro	T	--	1.9	1.4	1.6	2.1	2.0	1.8	1.1	--	2.6
	B	2.0	6.6	1.6	2.0	1.2	4.2	1.6	2.0	--	2.6
Notting-ham	T	1.3	2.0	1.2	0.3	2.3	3.4	2.8	2.7	--	4.1
	B	1.6	1.9	1.6	1.0	2.7	6.4	4.8	0.9	--	4.0

APPENDIX (Cont'd)

		Particulate Nitrogen (mg liter^{-1})
		Date
Station		6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.	T	0.567	0.157	0.436	0.497	0.281	0.265	0.285	0.209	0.441	0.823
	B	0.131	0.193	0.181	0.628	0.369	0.287	0.156	0.484	0.250	0.162
Broome Is.	T	0.521	0.251	0.275	0.487	0.135	0.328	0.486	0.200	1.584	0.316
	B	0.306	0.215	0.140	0.323	0.157	0.387	0.148	0.121	0.346	0.166
Queen	T	0.484	0.215	0.328	0.437	0.157	0.202	0.368	0.284	0.231	0.356
Tree	B	0.083	0.189	0.216	0.225	0.207	0.271	0.230	0.135	0.144	0.100
Sheridan	T	0.111	0.179	0.282	0.407	0.163	0.189	0.595	0.284	0.352	0.465
Pt.	B	0.354	0.428	0.299	0.183	0.224	0.047	0.203	0.138	0.202	0.164
Benedict	T	0.196	0.193	0.501	0.470	0.327	0.174	0.474	0.210	0.342	0.458
Br.	B	0.128	0.280	0.483	0.467	0.409	0.448	0.342	0.378	0.258	0.295
Trueman	T	0.345	0.362	0.520	0.329	0.326	0.285	0.373	0.382	0.170	0.511
Pt.	B	0.367	0.778	0.375	0.363	0.327	0.278	0.408	0.535	0.385	0.317
L. Marl-	T	0.422	0.448	0.620	0.608	0.638	0.189	0.319	0.296	--	0.370
boro	B	0.455	0.642	0.378	0.454	0.090	0.546	0.195	0.445	--	0.396
Notting-	T	0.259	0.257	0.387	0.098	0.503	0.502	0.266	0.394	--	1.504
ham	B	0.254	--	0.323	0.179	0.593	0.698	0.534	0.472	--	0.555

Dissolved inorganic phosphate-phosphorus (DIP), total dissolved phosphorus (TDP) and total phosphorus (TP) at the surface (µg at liter^{-1})
Date
	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
Sandy Pt.
DIP	0.56	0.66	0.56	0.41	--	0.56	0.41	0.76	0.20	0.71
TDP	--	0.26	0.58	0.34	--	0.57	0.55	0.82	0.58	1.25
TP	3.79	--	--	--	--	1.64	2.51	1.54	2.91	4.04
Queen Tree
DIP	0.81	1.83	0.36	0.41	--	0.25	0.56	0.61	0.40	0.60
TDP	0.63	0.35	0.46	0.63	--	0.58	0.40	0.59	0.87	1.22
TP	2.15	--	--	--	--	1.88	2.03	2.39	1.69	3.20
Benedict Br.
DIP	1.42	1.83	1.98	1.68	--	1.02	0.76	0.81	1.21	1.01
TDP	--	1.70	1.68	1.11	--	1.44	0.88	0.93	1.84	1.53
TP	4.31	--	--	--	--	3.44	4.22	2.49	4.21	4.41
Nottingham
DIP	1.88	2.19	2.34	2.85	--	1.17	3.97	0.92	--	0.71
TDP	2.87	2.38	2.62	2.99	--	1.45	--	1.09	--	1.21
TP	5.68	--	--	--	--	6.55	4.76	4.36	--	6.09

APPENDIX (Cont'd)

					Date					
	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30

Ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), dissolved organic nitrogen (DON) and total dissolved nitrogen (TDN) at the surface (μg at liter^{-1})

Sandy Pt.

	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
NH_3	48.1	29.6	16.7	16.0	--	9.8	7.7	3.1	2.7	21.5
NO_2	1.1	0.9	1.4	1.3	--	1.8	1.0	0.7	0.2	0.4
NO_3	51.1	32.1	23.4	18.1	--	22.2	11.0	7.6	4.6	2.6
DON	5.0	13.4	20.3	12.6	--	25.8	25.6	22.4	12.1	6.3
TDN	105.3	76.0	61.8	48.0	--	59.6	45.2	33.8	19.6	30.8

Queen Tree

	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
NH_3	7.7	3.0	6.6	4.2	--	5.5	0.4	0.7	0.6	--
NO_2	0.7	1.0	0.7	0.1	--	0.8	0.0	0.0	0.1	0.0
NO_3	18.2	20.7	9.2	1.8	--	7.3	0.5	0.5	0.2	0.1
DON	15.6	11.9	23.7	29.2	--	25.4	11.0	19.6	22.2	--
TDN	42.2	36.6	40.2	35.4	--	39.0	11.9	20.8	23.1	22.8

Benedict Br.

	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
NH_3	--	12.5	2.9	1.5	--	10.8	0.4	1.1	0.0	--
NO_2	0.8	1.5	1.0	0.4	--	0.6	0.0	0.0	0.0	0.1
NO_3	23.1	30.3	29.4	12.8	--	10.9	0.1	0.2	0.0	0.0
DON	--	11.6	27.4	11.5	--	28.1	26.4	14.9	20.6	--
TDN	--	55.9	60.7	26.2	--	50.4	26.9	16.2	20.6	11.1

Nottingham

	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30
NH_3	16.0	13.9	6.9	9.3	--	3.1	--	0.6	--	--
NO_2	1.4	2.0	2.3	2.3	--	2.1	1.9	1.0	--	0.9
NO_3	41.7	45.0	49.7	50.8	--	27.6	19.2	14.4	--	7.2
DON	13.9	23.8	22.3	29.0	--	31.3	--	22.6	--	--
TDN	73.0	84.9	81.2	91.4	--	64.1	--	38.6	--	33.1
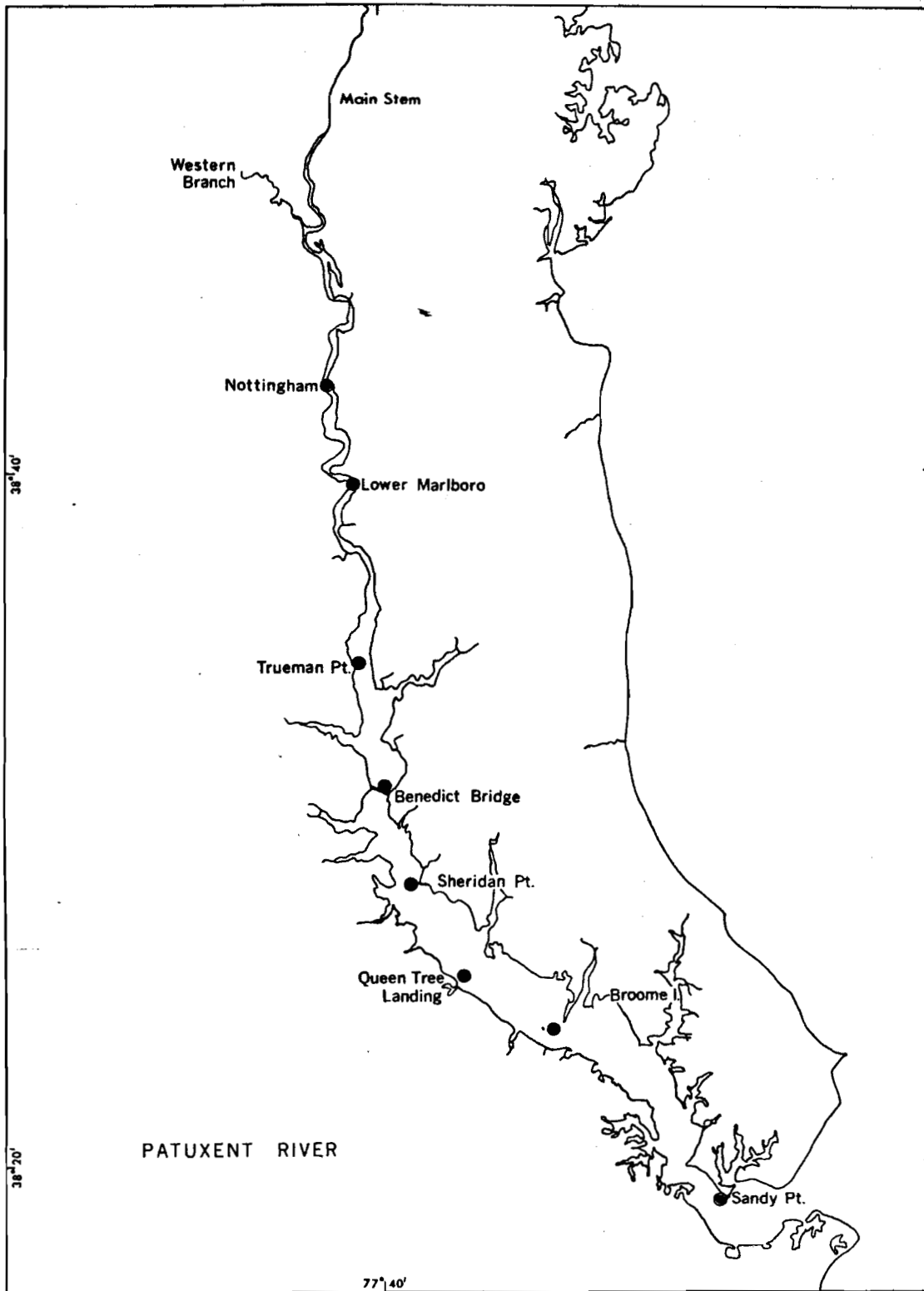
Figure 1.   Map of the Patuxent River estuary showing station locations.
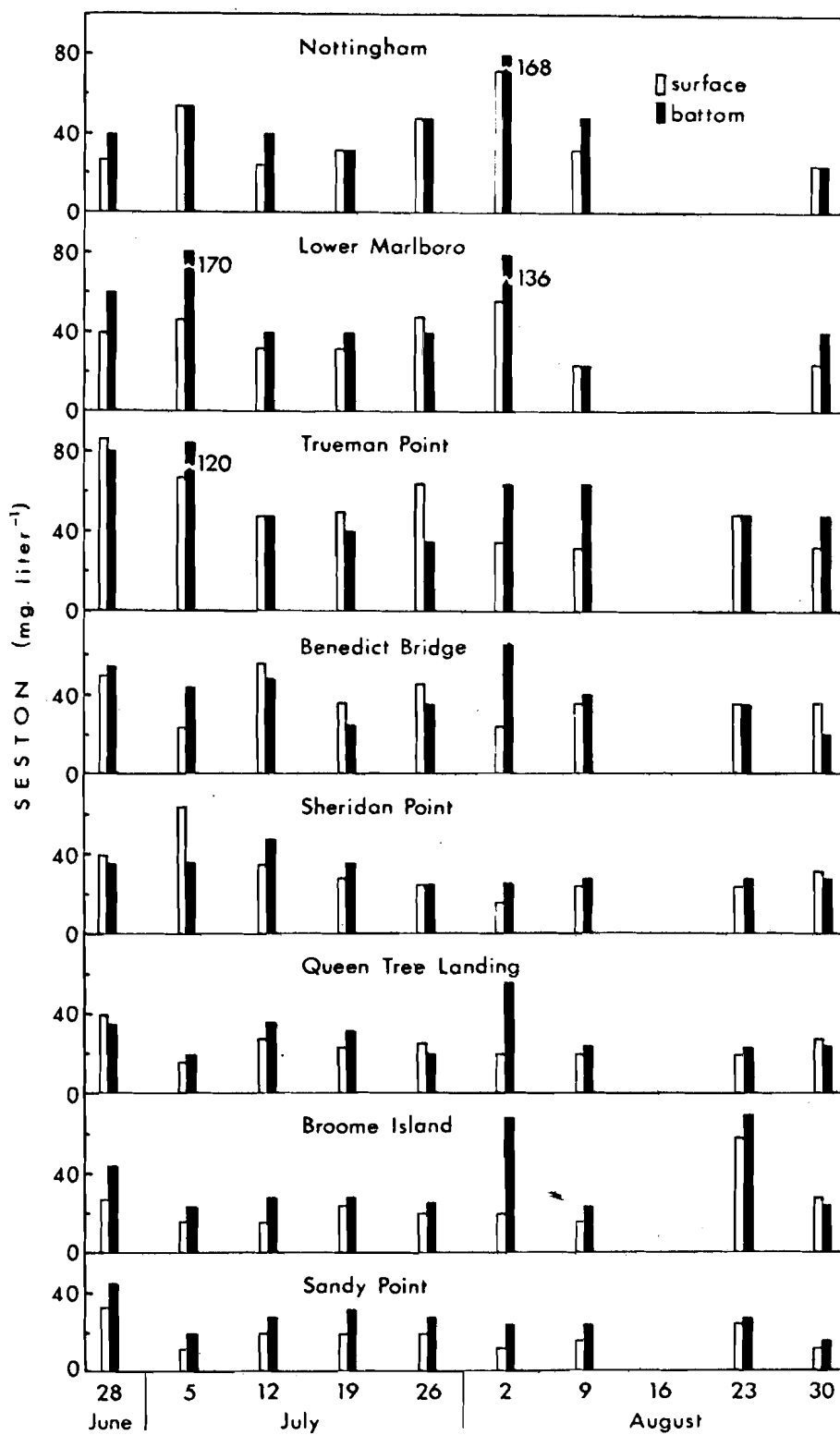
Figure 2. Surface and bottom seston concentrations (mg liter^{-1}) observed in the Patuxent River estuary during the Post-Agnes study, Summer 1972.
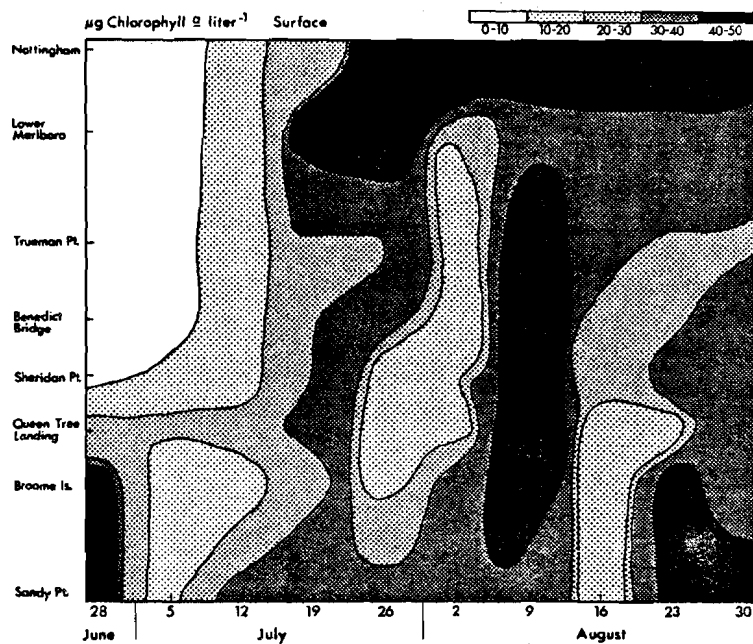
Figure 3a.   Surface concentration of active chlorophyll $\underline{a}$ (mg m^{-3}) observed in the Patuxent River estuary during the Post-Agnes study, Summer 1972.
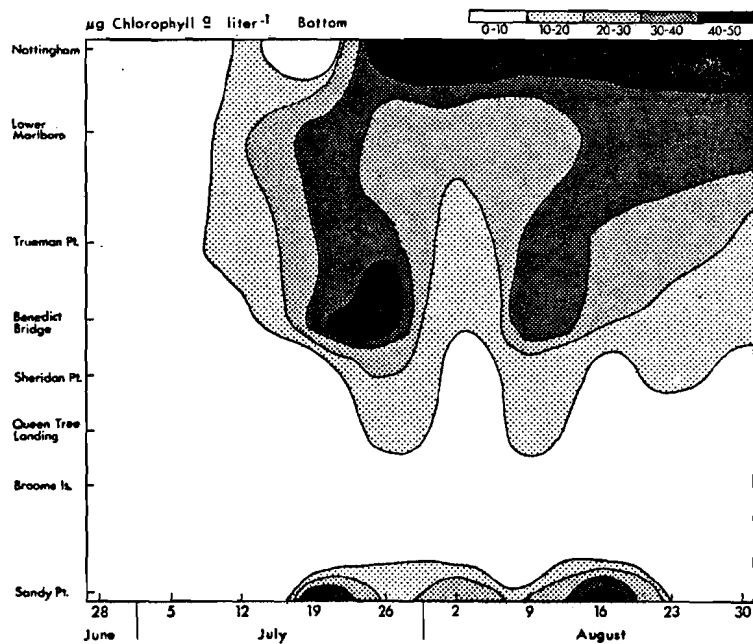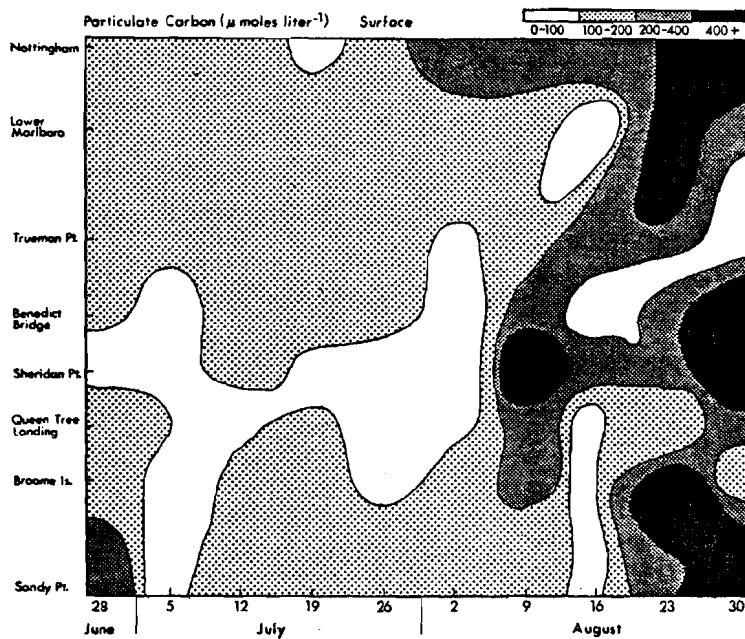

Figure 3b.   Bottom concentration of active chlorophyll $\underline{a}$ (mg m^{-3}) observed in the Patuxent River estuary during the Post-Agnes study, Summer 1972.

Figure 4a. Surface concentration of particulate carbon
(μ moles liter^{-1}) observed in the Patuxent River
estuary during the Post-Agnes study, Summer 1972.
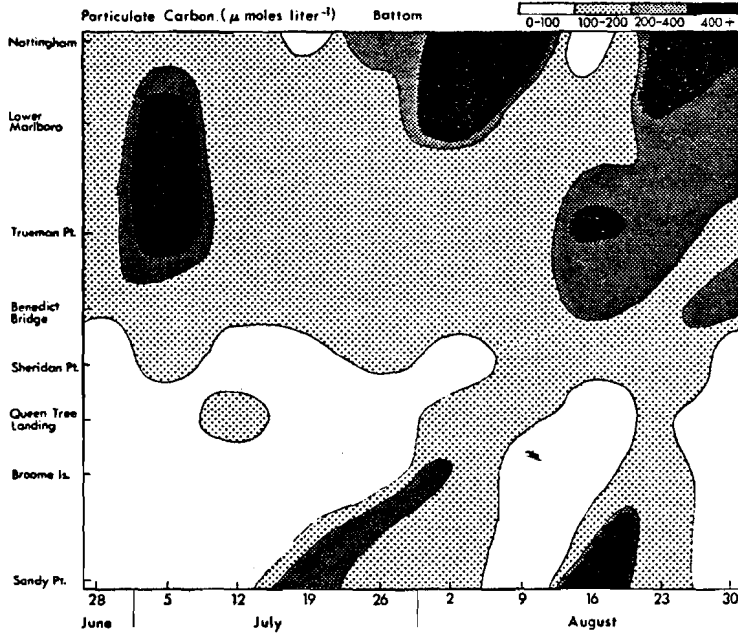
Figure 4b. Bottom concentration of particulate carbon
(μ moles liter^{-1}) observed in the Patuxent River
estuary during the Post-Agnes study, Summer 1972.
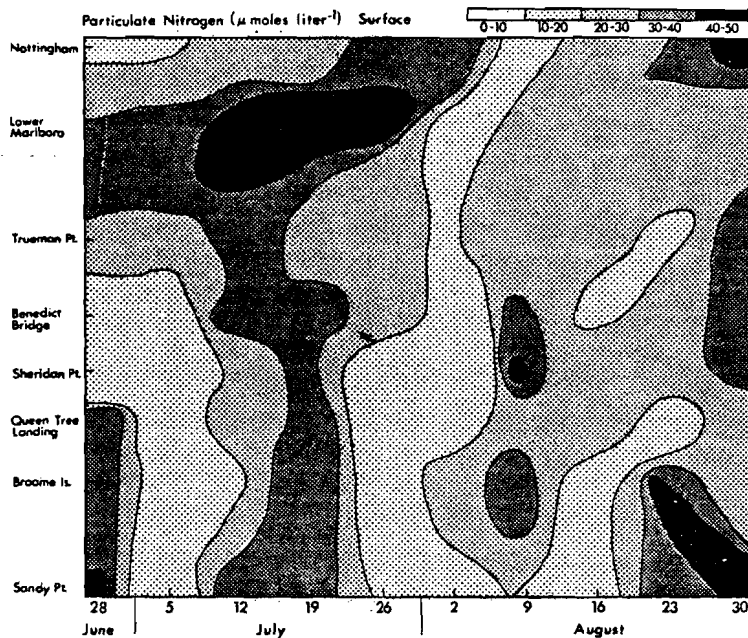
Figure 5a.   Surface concentration of particulate nitrogen
(μ moles liter^{-1}) observed in the Patuxent River
estuary during the Post-Agnes study, Summer 1972.
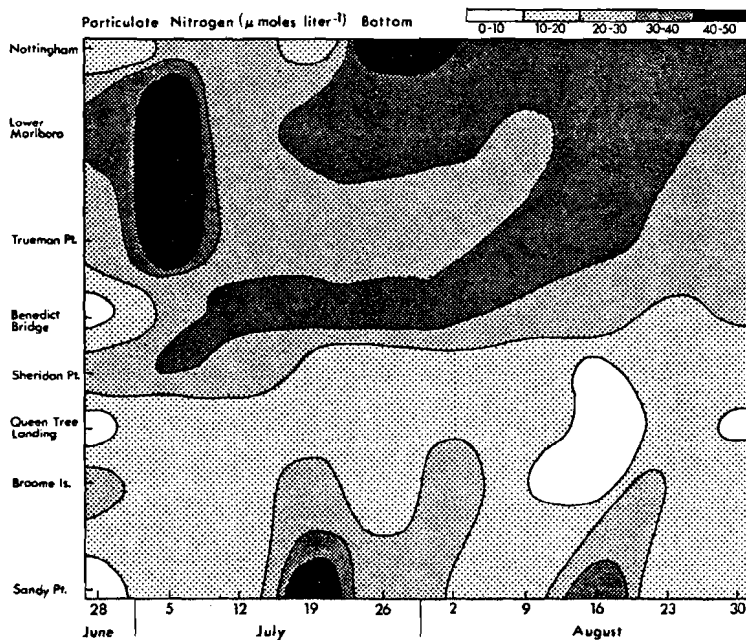
Figure 5b.   Bottom concentration of particulate nitrogen
(μ moles liter^{-1}) observed in the Patuxent River
estuary during the Post-Agnes study, Summer 1972.
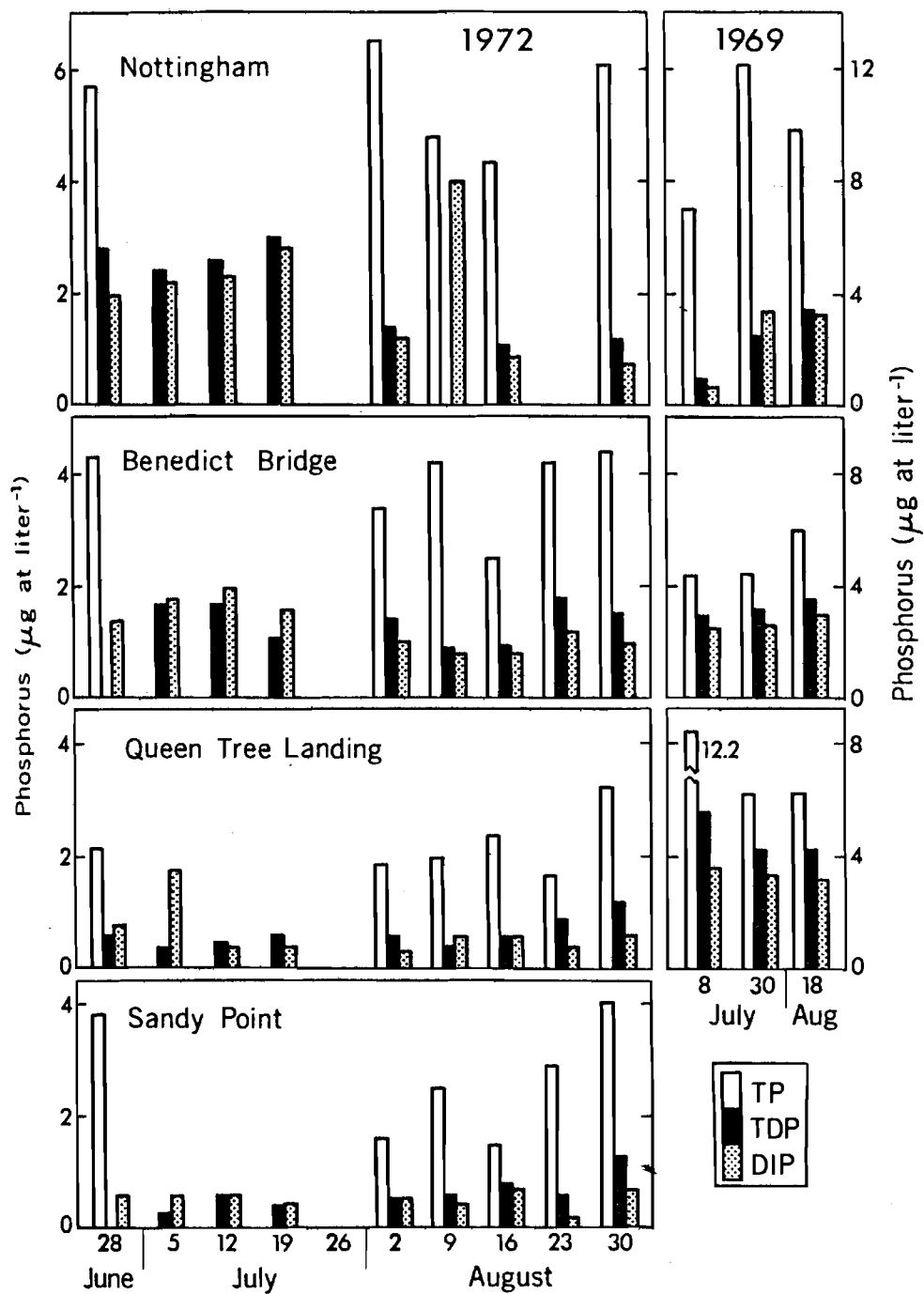
Figure 6.   The concentration (µg at liter^{-1}) of total phosphorus (TP),
total dissolved phosphorus (TDP), and dissolved inorganic phos-
phorus (DIP) at selected stations, Patuxent River Post-Agnes
study, Summer 1972.   Shown on the figures are comparative data
for July and August 1969 (from Flemer et al. 1970).
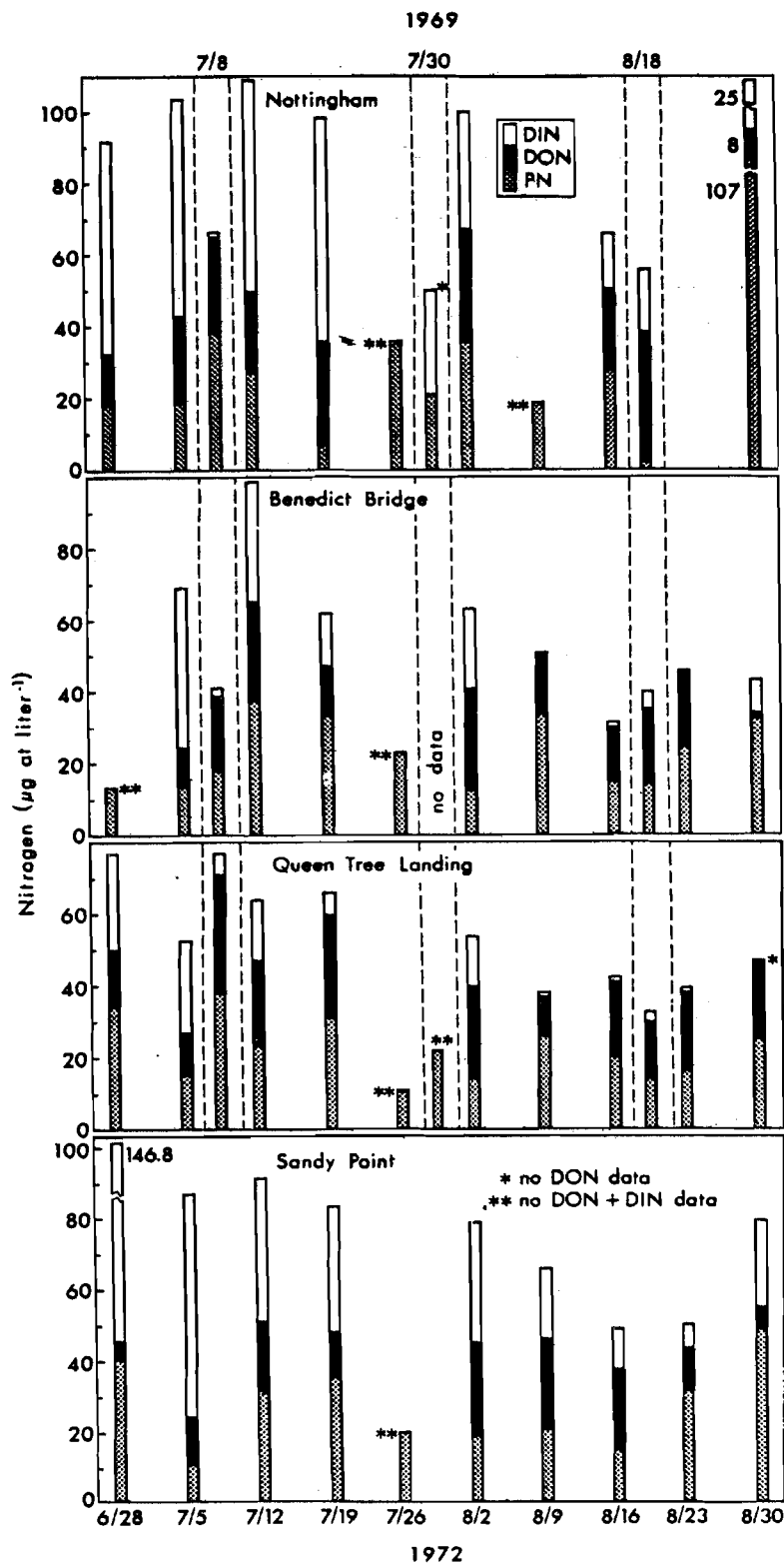
Figure 7. The concentration (µg at liter^{-1}) of particulate nitrogen (PN), dissolved inorganic nitrogen (DIN), and dissolved organic nitrogen (DON) at selected stations, Patuxent River Post-Agnes study, Summer 1972. Shown in the figures are comparative data for July and August 1969 (from Flemer et al. 1970).
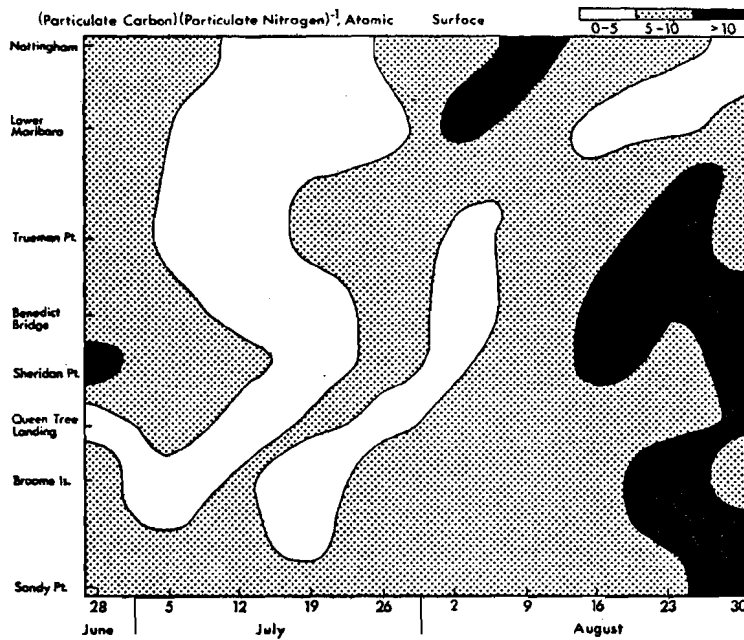
Figure 8a. The particulate carbon:particulate nitrogen ratio
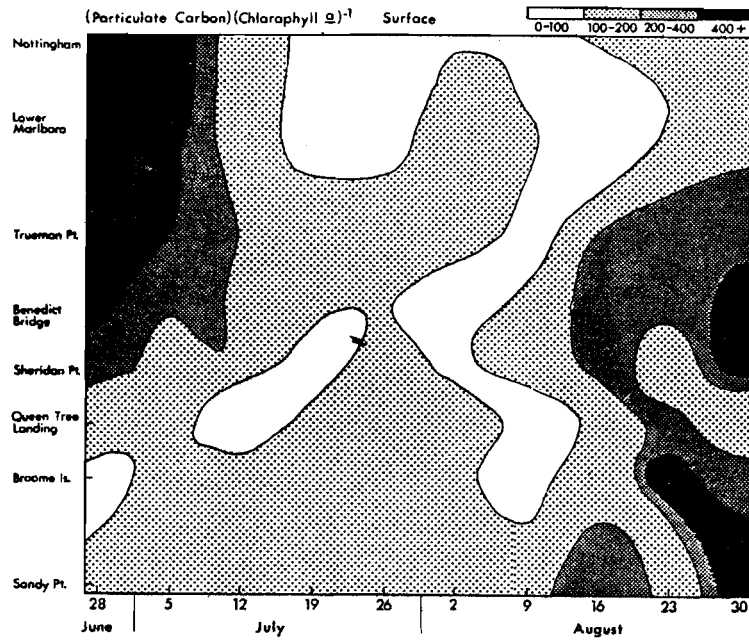(atomic) for the surface waters, Patuxent River
Post-Agnes study, Summer 1972.
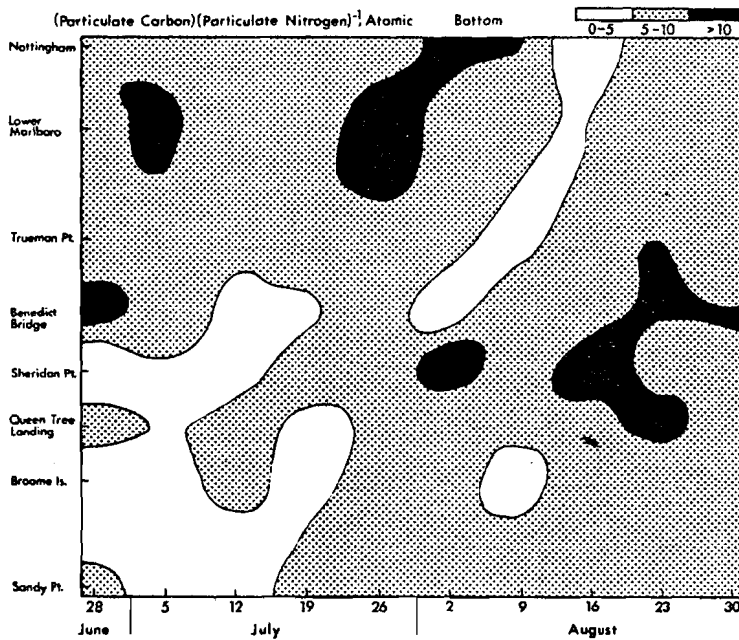
Figure 8b. The particulate carbon:particulate nitrogen ratio
(atomic) for the bottom waters, Patuxent River
Post-Agnes study, Summer 1972.

Figure 9a.   The particulate carbon: chlorophyll a ratio
for the surface waters, Patuxent River Post-
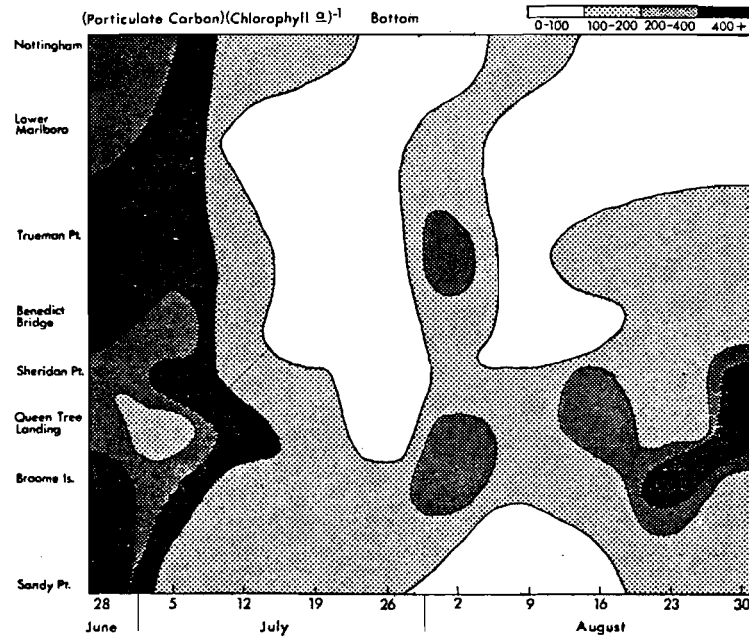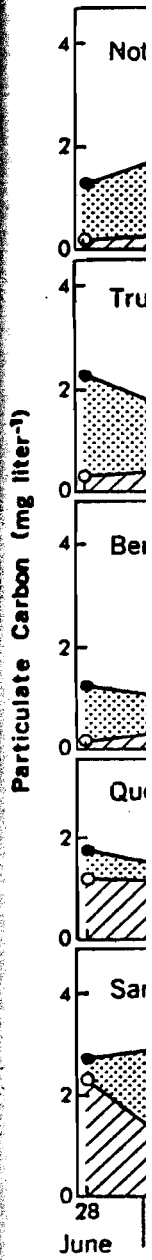Agnes study, Summer 1972.

Figure 9b.   The particulate carbon: chlorophyll a ratio
for the bottom waters, Patuxent River Post-
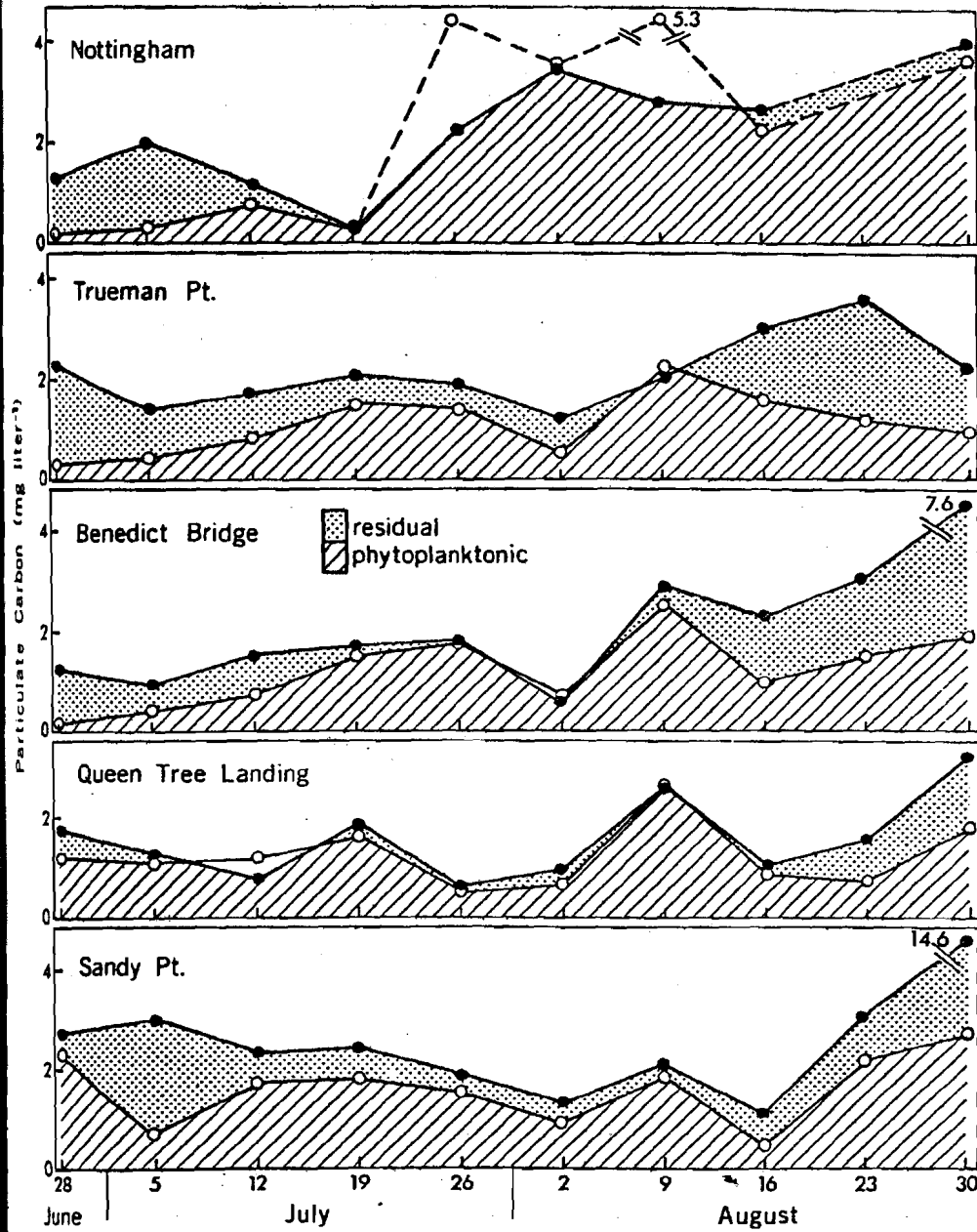Agnes study, Summer 1972.

Figure 10. The distribution of particulate carbon (PC)(top line)
and the estimated living phytoplanktonic carbon (bottom
line) for selected stations, Patuxent River Post-Agnes
study, Summer 1972. The residual PC is indicated.