REGION III
ANNAPOLIS FIELD OFFICE

CURRENT NUTRIENT ASSESSMENT
UPPER POTOMAC ESTUARY*

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WORKING FOR A BETTER ENVIRONMENT

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ABSTRACT

In order to assess the current nutrient impact on the upper Potomac Estuary, 1973-74 data from major wastewater sources were compared to previous data to note possible trends. A comparison of recent water quality data with 1969-70 data at three control sampling stations shows reductions of inorganic phosphate in the upper estuary, particularly at the historical bloom area for blue-green algae. The absence of massive algal blooms since 1972 is noted, together with a discussion of the framework necessary to develop the predictive capability to quantitatively identify the cause-effect relationships in the estuary.

Types of Nutrients

Plant growth requires nutrients. Plant physiologists classify nutrients into two categories. Macro-nutrients are those chemical elements required by plants in large amounts. The macro-nutrients are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, iron, and magnesium. Micro-nutrients include molybdenum, boron, manganese, zinc, and sometimes, even iodine and chlorine. They are just as essential to plant growth as the macro-nutrients, but, as their name implies, they are required by plants in minute quantities. Their abundance in nature relative to plant needs is evidenced by the lack of case histories on micro-nutrients as rate limiting growth factors.

Of the various nutrients, carbon, nitrogen, and phosphorus have received more attention in the field of water pollution biology. These three elements have life cycles in which they undergo changes in chemical composition as they interact with various components of their immediate environment. Concerning the life cycles, only the phosphorus is not open to the atmosphere for replenishment purposes. In the case of carbon, a constant diffusion rate from the atmosphere into the water column exists at normal pH and temperature ranges. In fact, the oceanic carbonate system is, in most cases, in equilibrium with the atmospheric CO_2. Changes in the partial pressure of CO_2 in the atmosphere or changes in the aquatic carbonate cycle can effect changes in the rate of CO_2 dissolution into water bodies.

As with carbon, there exist natural source factors which influence the abundance of nitrogen in the aquatic environment. The atmosphere

is composed of approximately 80 percent nitrogen, which is roughly the equivalent of 148,000 tons of nitrogen in the atmosphere for every acre of land area [1]. Literature values show nitrogen from rain water and airborne particulate matter contribute 480 lbs/mi^2 per year [2]. In addition, atmospheric nitrogen being so inert in the free state allows certain groups of soil bacteria and blue-green algae to fix nitrogen.

The literature pretty much establishes the fact that certain groups of blue-green algae can fix nitrogen directly from the atmosphere. The literature, however, is split on the ability of Microcystis sp. and Anacystis sp. (blue-green algae) to fix nitrogen [2,3]. These are the pollution tolerant phytoplankton identified as being prevalent during massive blooms in the freshwater portion of the Potomac Estuary. The basic point to be made, is that it is imperative to establish as soon as possible the nitrogen fixation abilities of Microcystis sp. and Anacystis sp. in the freshwater estuarine environment of the Potomac.

Phosphorus enters the aquatic environment from the erosion of soils and from man induced inputs such as human and industrial wastes. Because of the nature of its sources, it makes sense that phosphorus can be controlled to the extent that it could be made the rate limiting nutrient to curb and hopefully reverse an accelerated eutrophic condition.

Impact of Nutrients

Let us turn our attention to the impact of nutrients. We can probably say, in general, that nutrients are present in sufficient concentration in most water bodies to provide for the needs of aquatic organisms. In the presence of light, photosynthesis occurs and plant biomass is created. In a healthy environment the plant biomass is grazed on by zooplankton, which is followed by an ordered series of events to complete the food chain.

When there exists an overabundance of nutrients in a system, massive algal blooms of an undesirable nature can occur. This condition first presented itself in August-September 1959, when blooms of the nuisance blue-green algae *Anacystis* sp. were reported in the Anacostia and Potomac Rivers near Washington. Chlorophyll *a* at Indian Head and Smith Point for 1965-66 and 1969-70, as shown in Figures 1 and 2, indicate that algae had not only increased in density but became more persistent over the annual cycle. The figures also show a decrease in chlorophyll *a* concentrations during the 1973-74 sampling cruises. The exact nature of this decrease has yet to be determined.

When algae is not consumed by higher trophic forms, which is the apparent case with the blue-greens in the Potomac Estuary, the effects of massive blooms can be quite devastating. Jaworski, *et al.* [4], estimated that the combined ultimate oxygen demand of nitrogen and carbon resulting from the death of algal cells during intense summer bloom conditions in the estuary is approximately 490,000 lbs/day, if exerted. For comparison purposes, this load would be greater than the

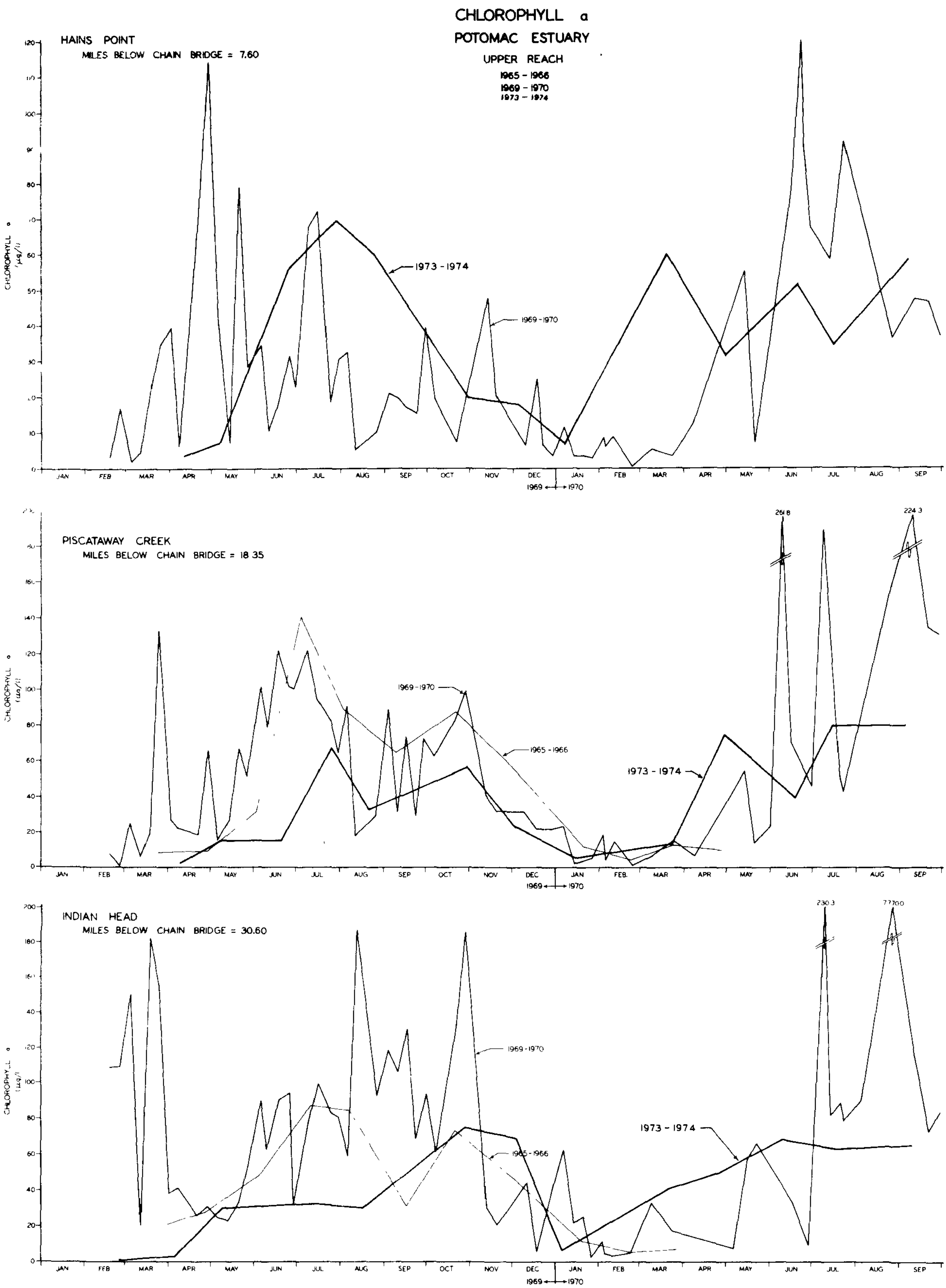

CHLOROPHYLL a
POTOMAC ESTUARY
UPPER REACH
1965 - 1966
1969 - 1970
1973 - 1974
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
CHLOROPHYLL a μg/l
1973 - 1974
1969 - 1970
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
1969 1970
PISCATAWAY CREEK
MILES BELOW CHAIN BRIDGE = 18.35
1969 - 1970
1965 - 1966
1973 - 1974
261.8
224.3
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
1969 - 1970
1965 - 1966
1973 - 1974
230.3

FIGURE - I

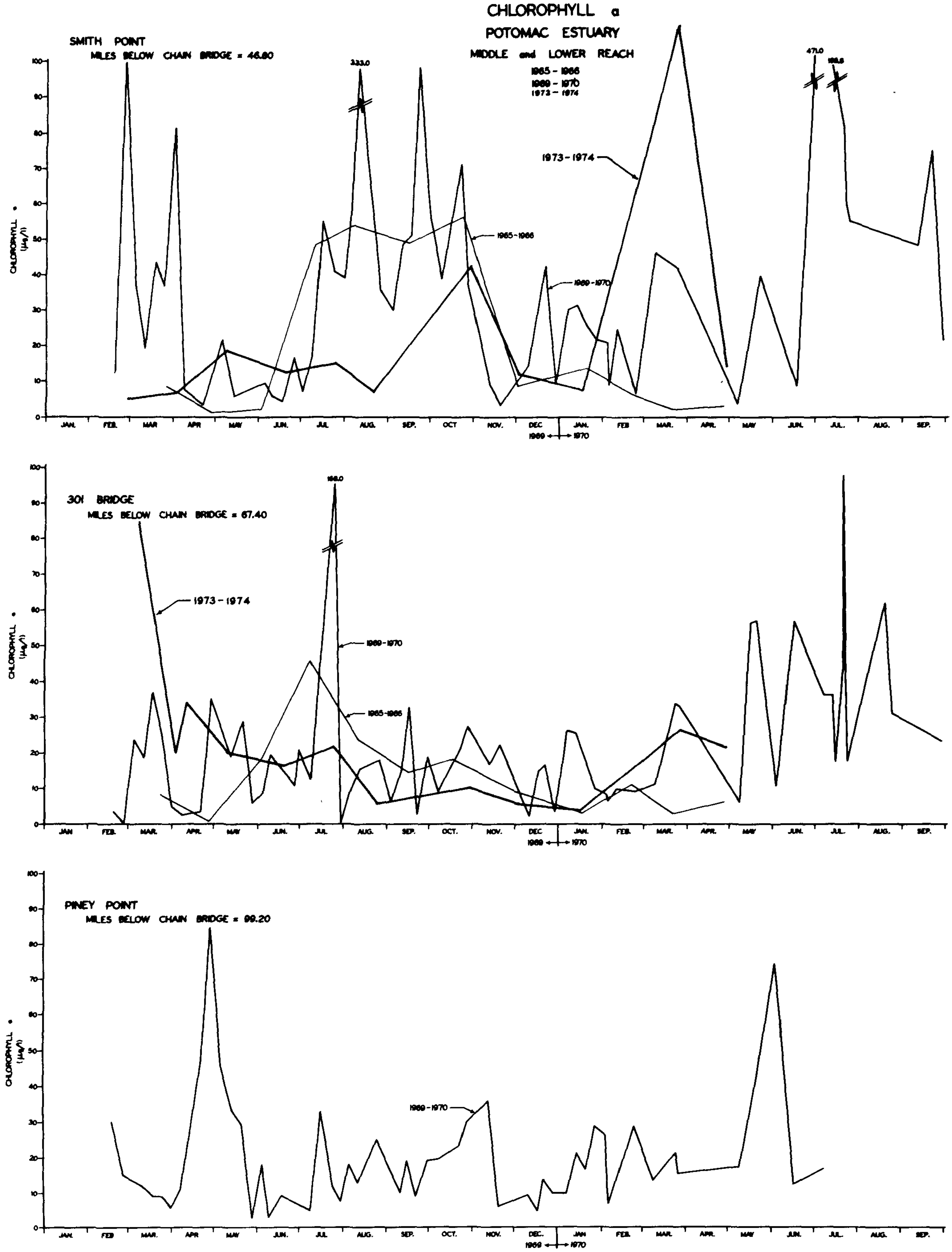

CHLOROPHYLL a
POTOMAC ESTUARY
MIDDLE and LOWER REACH
1965 - 1966
1969 - 1970
1973 - 1974
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.80
233.0
471.0
1973 - 1974
1965-1966
1969-1970
CHLOROPHYLL a (µg/l)
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP.
1969 ← → 1970
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
168.0
1973 - 1974
1969-1970
1965-1966
PINEY POINT
MILES BELOW CHAIN BRIDGE = 99.20
1969-1970

FIGURE - 2

total oxygen demand by all wastewater discharges into the upper estuary. Other undesirable effects of accelerated eutrophication include decreases in the dissolved oxygen budget caused by algal respiration, creation of nuisance and aesthetically objectionable conditions, and possible toxic effects on other aquatic organisms.

Major Sources of Nutrients

The major sources of nutrients to the upper Potomac Estuary can be categorized as follows: wastewater treatment plants within the Washington Metropolitan Area, contributions from the upper freshwater basin, and stormwater runoff from the highly urbanized area of Washington, D.C.

Figures 3 and 4 present wastewater nutrient enrichment trends and ecological effects on the upper Potomac Estuary. The loadings represent the major wastewater treatment plant sources within the Washington Metropolitan Area. With respect to Figure 3, Jaworski, et al.[4], hypothesized that the nuisance plant conditions did not develop linearly with an increase in nutrients. Instead, the increase in nutrients appeared to favor the growth and thus the domination by a given species. As nutrients increased further, the species in turn was rapidly replaced by another dominant form. For example, water chestnut was replaced by water milfoil which in turn was replaced by blue-green algae.

Figure 4 is a presentation of the current wastewater treatment plant loadings to the upper estuary. The loadings show a gradual decrease in total phosphorus (as P) from 24,000 lbs/day at the end of 1969 to 16,310 lbs/day as an average for 1974. BOD_5 loadings have shown a downward trend from a high of 154,000 lbs/day in 1971 to the current rate of 119,870 lbs/day (1974). Total nitrogen loadings were also lower in 1972 and 1973, but showed a slight increase during 1974, the average being 59,710 lbs/day.

WASTEWATER NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS

UPPER POTOMAC TIDAL RIVER SYSTEM

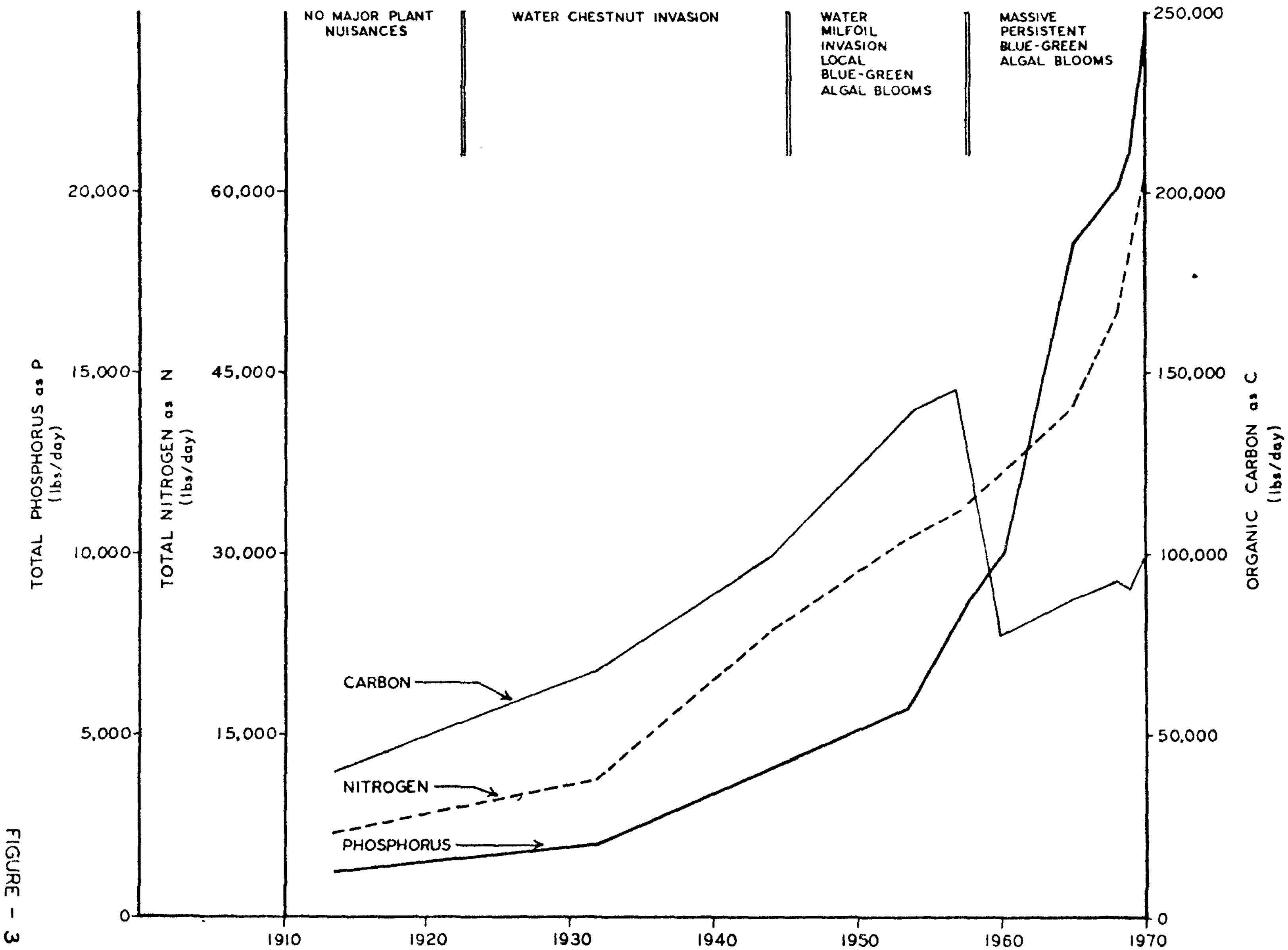


FIGURE - 3

RECENT WASTEWATER NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS

UPPER POTOMAC TIDAL RIVER SYSTEM

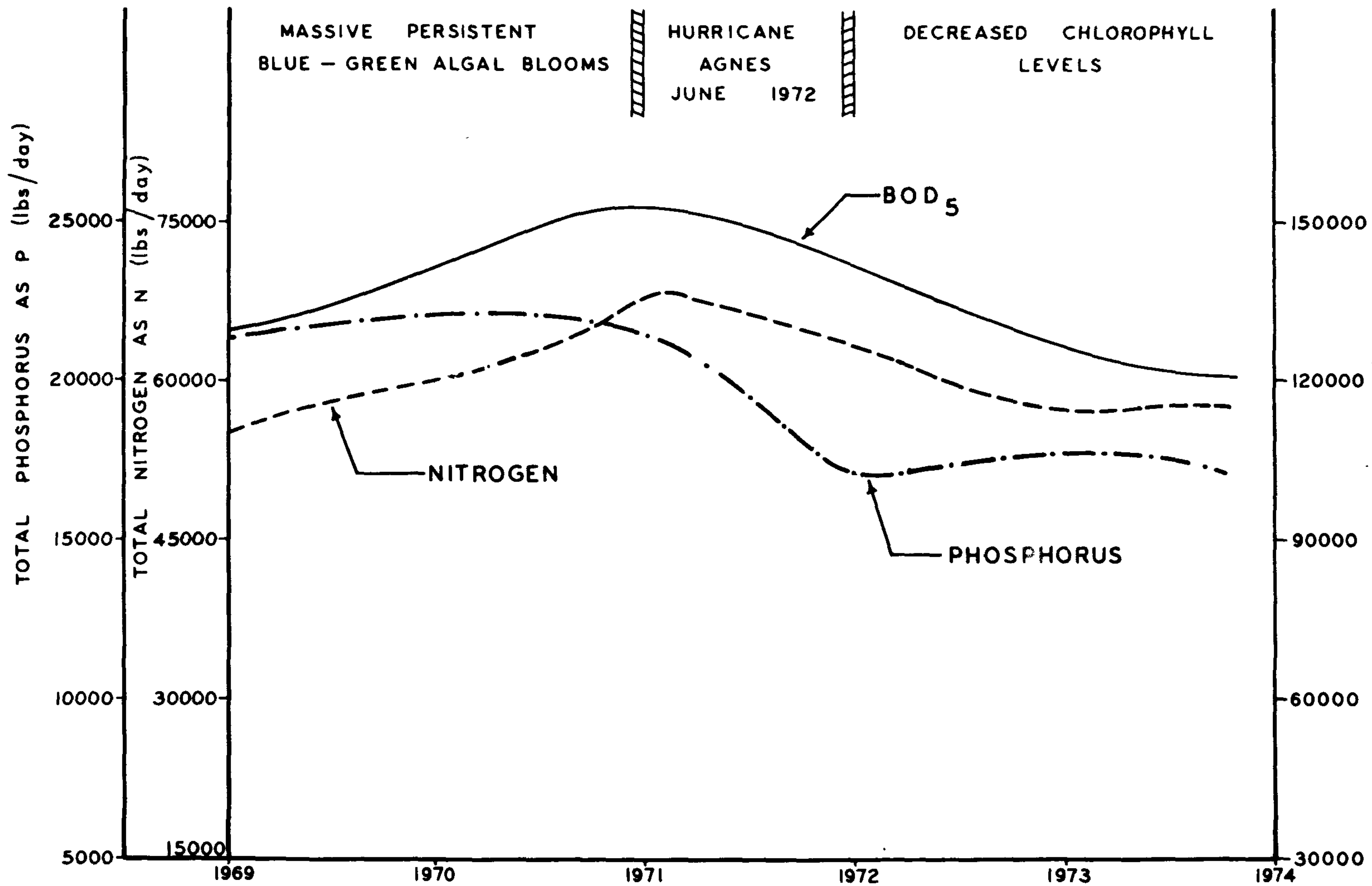


FIGURE – 4

Since 1972 there has been a noticeable absence of dense blue-green algal blooms of any duration in the upper estuary. In the historical bloom area near Indian Head (30.6 miles below Chain Bridge), chlorophyll a levels were observed in range of 25-70 μg/l and 40-78 μg/l during the 1973 and 1974 summer seasons, respectively. (See Figure 1.) In contrast, during the 1969 and 1970 summer months, chlorophyll a approached and on two observed occasions, in July and August 1970, exceeded 200 μg/l.

It is premature to hypothesize that the absence of massive blooms is a direct result of reduced wastewater loadings in the Washington Metropolitan Area. If there are no massive blooms this summer and in subsequent years, and if wastewater loadings continue to decline, a more definitive cause-effect relationship would be established between nutrient concentrations and algal populations. Also, the relative merit of Hurricane Agnes as a cleansing mechanism must be viewed as a transient phenomenon. After all, Hurricane Camille provided a flushing of the estuary in August 1969 which did not appear to significantly reduce the algal populations. The essence of this brief discussion is, at this time, we do not know all the causitive agent or agents that trigger massive blue-green algal blooms in the Potomac Estuary. This point will be developed later in this paper.

The relative contribution of nutrients to the Potomac Estuary from its upper basin has been documented by the Annapolis Field Office, EPA, in Technical Report Nos. 15 and 35 [4,5]. In summary, this previous work established that during a selected low-flow of 1200 cubic feet

per second (cfs), at which the loadings will be equaled or exceeded 95 percent of the time, the total phosphorus contribution from the upper basin is 3.7 percent of the total phosphorus load to the estuary. In contrast, the load from the wastewater treatment plants in the Washington Metropolitan Area constitutes 96 percent of the total phosphorus load. The disparity in loadings is similar for total nitrogen.

With regard to the upper basin nutrient contributions, Technical Report 35 [4] concluded that a 50 percent reduction in the phosphorus load from the upper Potomac River, together with the recommended phosphorus reductions in the Washington Metropolitan Area, is required if the recommended phosphorus criteria are to be achieved in the upper estuary. In order to realize the 50 percent reduction, it was concluded that the wastewater contribution from point sources of 6,100 lbs/day must be reduced to 700 lbs/day. Should this recommendation be implemented, point sources of phosphorus would have to be reduced by 90 percent.

During August 1973, and again on three separate occasions during the summer of 1974, the Annapolis Field Office carried out intensive surveys in the upstream reach from Chain Bridge to just above the confluence of the Monocacy River with the Potomac, a distance of approximately 38 miles. The purpose of these studies was to assess current water quality conditions. The revealing finding of the surveys was the significant biological activity taking place in the reach. Chlorophyll a had not been measured previous to the surveys. During August 6-9, 1973, chlorophyll a levels of 150 μg/l were observed between river miles 17 and 26, or the area from Seneca Creek upstream

to the mouth of Goose Creek. From June 18-20, 1974, chlorophyll averaged about 60 μg/l in the same reach, while during the period July 16-18, 1974, the levels averaged about 40μg/l. On September 3, 1974, a chlorophyll concentration of 310 μg/l was observed about one mile above Seneca Creek. During this observation dramatic decreases in nitrate nitrogen and inorganic phosphorus were noted suggesting that these compounds were being utilized by the algae.

A review of earlier chlorophyll a data (1966-70) indicates that upstream algal activity was not occurring to the extent recently observed. For example, just below the fall line at Key Bridge, chlorophyll a levels in 80-90 μg/l range were recorded in July-August 1973, with a historically high value of 171 μg/l observed on September 5, 1974. The previous levels in this vicinity were around 30 μg/l. This indicates a carry over or upstream contribution of chlorophyll a or algal biomass to the upper estuary. But, this condition does not persist down the estuary. The impact of the freshwater algae on estuarine biological communities has not been evaluated. Extensive analyses of all available upstream water quality data will be carried out by the Annapolis Field Office in order to establish any significant changes in upstream loadings as well as the species identification and significance of the recently observed algal blooms.

With respect to the impact of nutrients from stormwater runoff on water quality of the estuary, a few general conclusions can be drawn at this time. The significance of stormwater nutrients on the eutrophication process will depend on the magnitude, intensity, and duration of the storm event, the time of occurrence of the storm, and whether

or not the nutrients reach the critical growth zone in a readily available form. To date, the actual impact of stormwater on water quality in the estuary has not been evaluated. As part of its NPDES permit for Blue Plains, the D. C. Department of Environmental Services is required to monitor stormwater loadings.

Based on earlier work of Roy Weston Associates and Philip Graham, Council of Governments, on water quality aspects of stormwater, the Annapolis Field Office has, based on rainfall records of 1973-74, calculated the relative pollutant loadings from combined and separate storm sewers within the Washington, D.C., Beltway for different rainfalls, including the frequency of the rainfalls. These estimates, with appropriate updating to reflect forthcoming monitoring data, will be useful in future modelling efforts where the ability to predict diurnal fluctuations on a real time basis will be developed.

Water Quality Data Trends

Data presented earlier in this paper showed marked reductions in wastewater loadings from the major sources in the Washington Metropolitan Area. In order to evaluate the effects of the reduced loadings, a comparison is made of the 1973-74 and 1969-70 nutrient data from three representative sampling stations in the upper estuary.

The Hains Point sampling station is located 7.6 miles below Chain Bridge, the fall line. Hains Point can be considered the control point, i.e., the area located above the influence of the Blue Plains Wastewater Treatment Plant. The inorganic phosphorus (as PO_4) concentrations (Figure 5) show a general decrease over those of 1969-70, while nitrate nitrogen concentrations (Figure 6) between the periods of 1969-70 and 1973-74 appear to have remained unchanged. Ammonia nitrogen (Figure 7) did not exhibit the high peaks shown in 1969, yet the recent data show no dramatic decline over 1970 concentrations.

The Woodrow Wilson Bridge sampling station is expected to show the effects of the major wastewater discharges. A comparison of the ammonia and nitrate nitrogen data show no significant changes for the periods of comparison. The inorganic phosphorus appears to have dramatically declined. On close examination, however, the high peak in May-July 1969 could be due to the low flow conditions (3000 cfs) and the buildup of phosphorus from the discharges. During August 1969 Hurricane Camille and higher flows (8000 cfs) flushed the estuary, as can be seen by the sharp drop in phosphorus concentrations. Likewise, the high peak of 3.4 mg/l inorganic phosphorus (as PO_4) in September 1970 is associated

INORGANIC PHOSPHATE CONCENTRATION as PO_4

POTOMAC ESTUARY

1969 - 1970

1973-1974

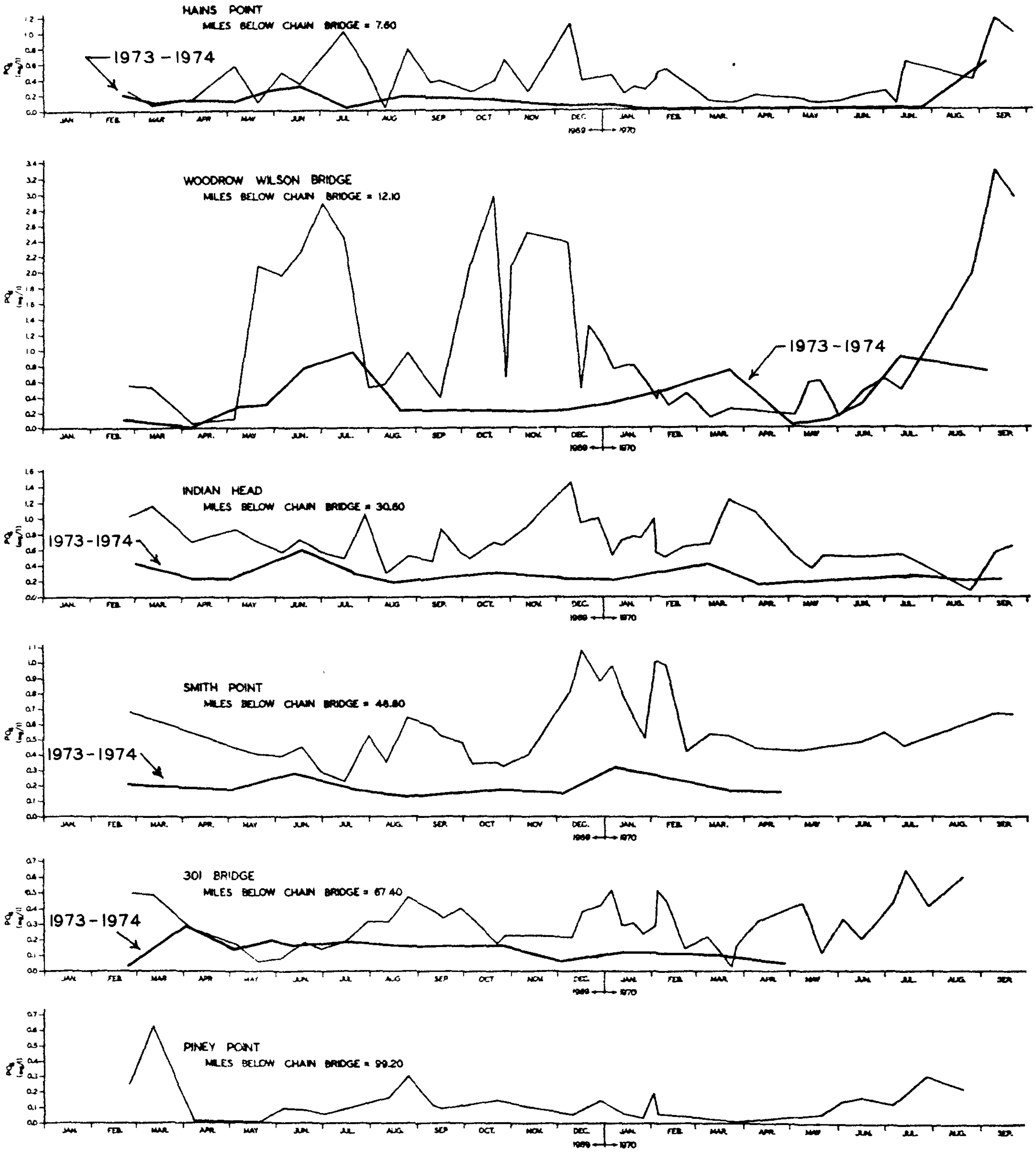
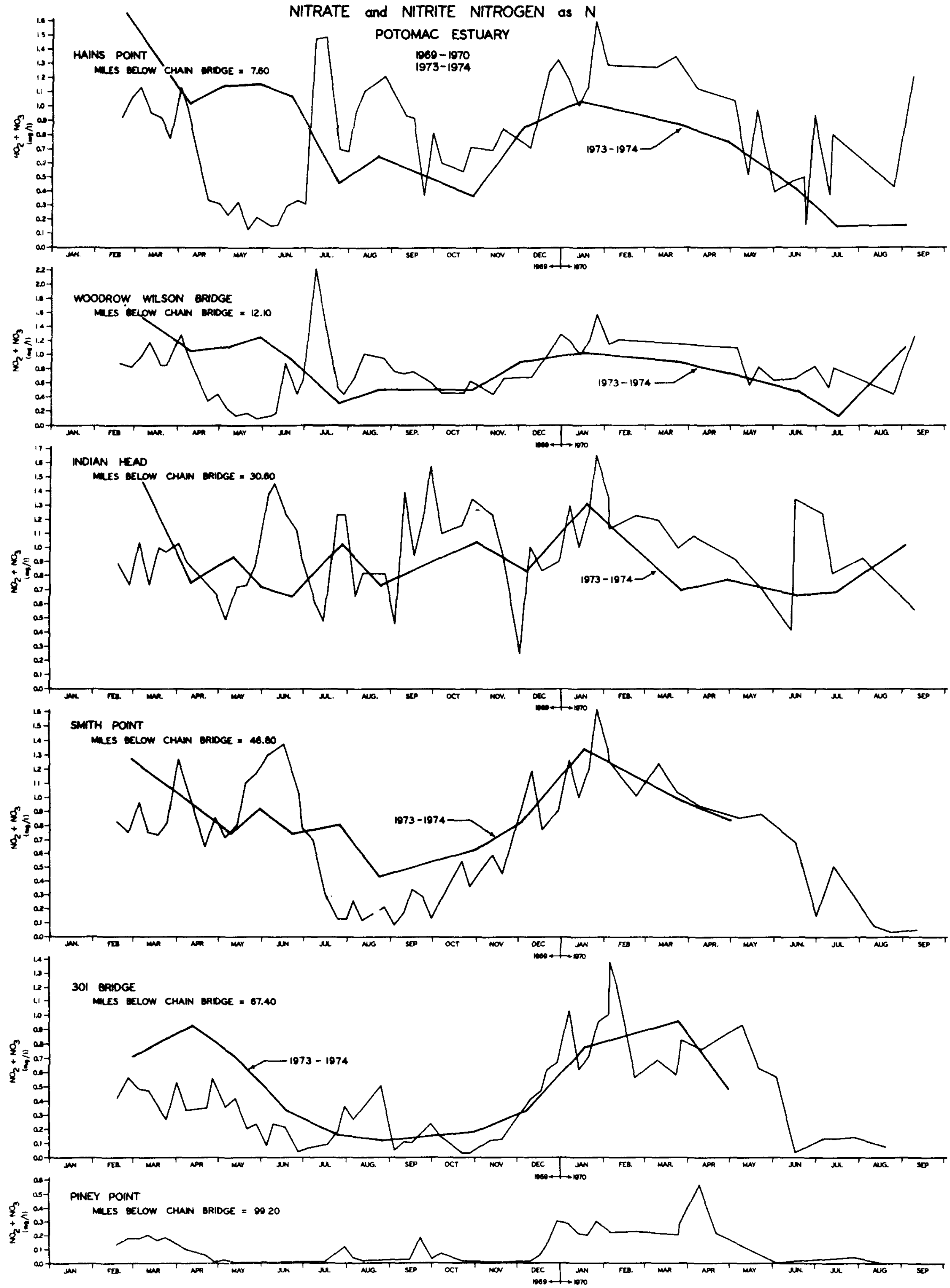


FIGURE - 5



NITRATE and NITRITE NITROGEN as N
POTOMAC ESTUARY
1969-1970
1973-1974
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
WOODROW WILSON BRIDGE
MILES BELOW CHAIN BRIDGE = 12.10
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.80
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
PINEY POINT
MILES BELOW CHAIN BRIDGE = 99.20
1973-1974
NO2 + NO3 (mg/l)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
1969 1970

FIGURE - 6

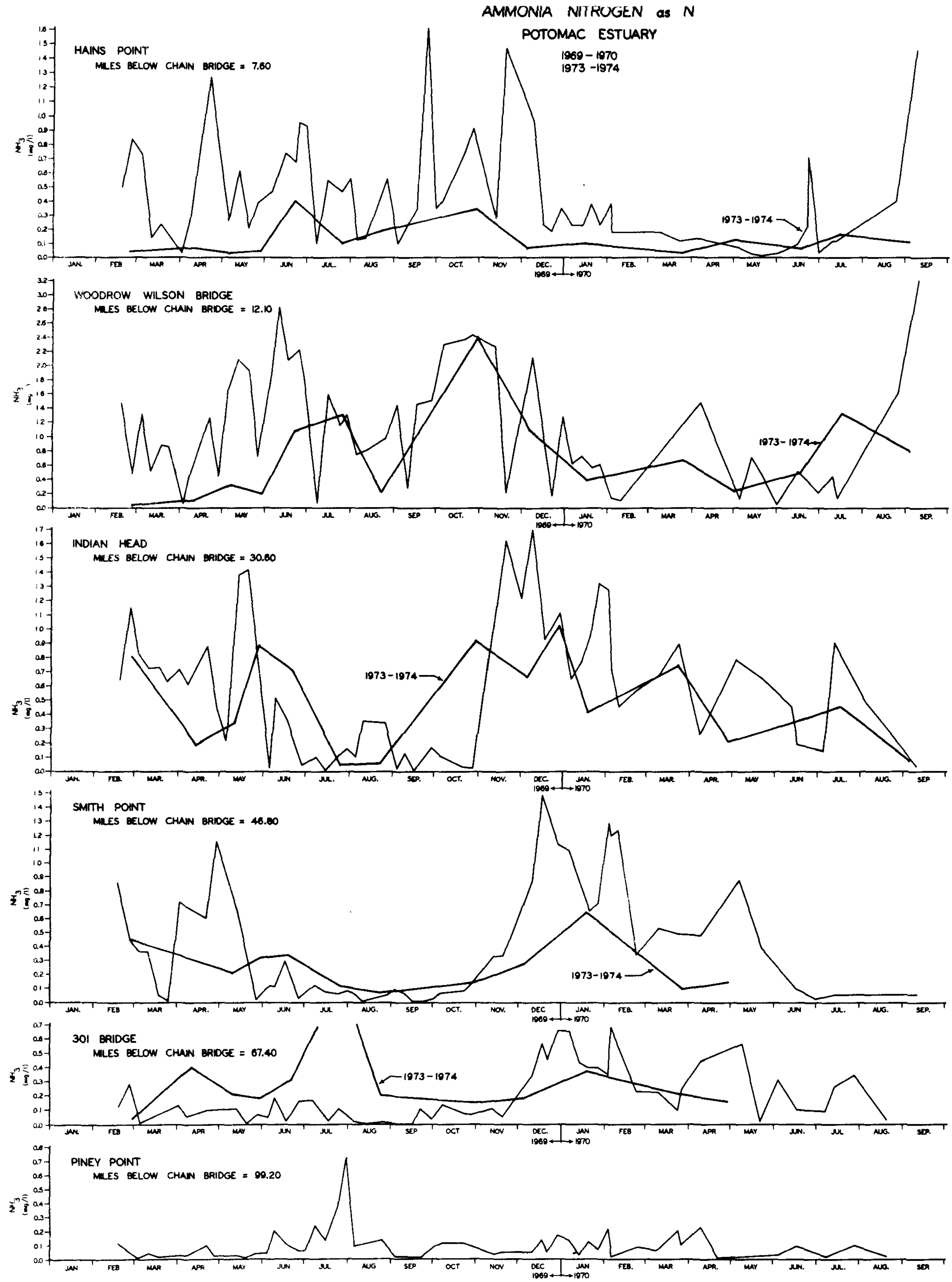

AMMONIA NITROGEN as N
POTOMAC ESTUARY
1969 – 1970
1973 – 1974
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
WOODROW WILSON BRIDGE
MILES BELOW CHAIN BRIDGE = 12.10
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.80
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
PINEY POINT
MILES BELOW CHAIN BRIDGE = 99.20
1973 – 1974
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP.
1969 ← → 1970
NH3 (mg/l)

FIGURE - 7

with the low flow condition (1600 cfs). It was during this period of low flow and high temperatures that algal mats encroached into the Tidal Basin.

The Indian Head sampling station, 30.6 miles below the fall line, is located in the historical bloom area of the blue-green algae. The nitrate and ammonia nitrogen have remained fairly constant as was noted at the two upstream stations. The 1973-74 inorganic phosphorus (as PO_4) concentrations were consistantly lower at Indian Head when compared to the 1969-70 concentrations. While 1969 was a low-flow year, the freshwater inflows for 1970 (10,500 cfs) and 1974 (11,500 cfs) were similar. This would infer that the differences in comparative phosphorus levels for 1970 and 1974 were not greatly effected by freshwater flows.

The literature states that an average N/P ratio, by atoms, is about 15 or 20 to 1. In general, if the ratio is less than 10:1 the system can be considered nitrogen deficient. If it is greater than 25:1 the system may be phosphorus deficient. At the Indian Head sampling station the N/P ratios for inorganic nitrogen versus inorganic phosphorus on a yearly average basis for the comparative study periods are as follows: 14.0:1, 1969; 16.9:1, 1970; 32.3:1, 1973; and 31.4:1, 1974. In the same order the ratios for the summer seasons (May-September) were: 21.4:1, 15.9:1, 31.3:1, and 28.0:1. (It should be noted that the data sets for 1973 and 1974 summer seasons were limited to 6 and 7, respectively.)

It is quite evident that in this particular area of the estuary the system has switched from nitrogen deficient to nitrogen abundant.

It should be stated that atomic ratios cannot be taken as an absolute, but they can serve as a useful tool to evaluate the respective relative shifts in the abundance of nutrients.

It is most important to point out that while intense algal populations were not observed in the last couple of years in the upper estuary, there were sufficient concentrations of nutrients to support algal growth. According to the literature, 10 μg/l (.01 mg/l) of inorganic phosphorus can stimulate an algal bloom [6]. During the critical summer months of 1973 and 1974, at Indian Head, concentrations of inorganic phosphate were measured at .35 and .27 mg/l, respectively. Why there were no major blooms is not fully understood.

Water Quality Predictions

Finally, because of current economic considerations, the role of nitrogen in the eutrophication process of the Potomac Estuary has to be defined. The Dynamic Estuary Model of the Potomac Estuary has been modified by the Annapolis Field Office so that the yield of algae is determined either by phosphorus or nitrogen; the nutrient that produces the least growth in any given time or place is the controlling factor. Model runs have been made using the nitrogen and phosphorus limitations set forth in the Blue Plains NPDES permit, as well as nutrient limitations recommended for the other major discharges to the estuary, and freshwater inflows to the estuary of 9000, 3000, and 1000 cfs.

Preliminary results show that chlorophyll production is fairly uniform with both N and P control and P control only, at the higher flow (9000 cfs). At the 1000 and 3000 cfs flows the reduction of chlorophyll with N and P control is in the range of 10-20 μg/l. It could be expected that at high flow conditions an ample supply of nutrients from sources other than treatment plants would be available for algal growth.

In order to answer the phenomena of why blooms occur and why blooms do not occur, the Annapolis Field Office has begun to lay out the framework of a new model that represents the state-of-the-art in the area of eutrophication dynamics. The model should have the predictive capability to assess the function of light, temperature, and nutrients as rate limiting factors in the eutrophication process in the Potomac Estuary.

Coupled with the modelling effort, an extensive monitoring effort is being planned. The purposes of the monitoring program are:

1. To provide data for model calibration and verification.
2. To perform specialized field and lab studies (e.g., algal bioassays) to assist in identifying limiting nutrients and algal growth characteristics.
3. To assess both the seasonal and long term water quality trends in the estuary.

The combined information from the modelling and monitoring programs should provide the information necessary to quantitatively identify the cause-effect relationships in the estuary.

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