U.S. ENVIRONMENTAL PROTECTION AGENCY

THE POTOMAC RIVER ESTUARY IN THE
WASHINGTON METROPOLITAN AREA
A HISTORY OF ITS WATER QUALITY PROBLEMS
AND THEIR SOLUTION

November 1972

Technical Report 57
Annapolis Field Office
Region III
Environmental Protection Agency

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THE POTOMAC RIVER ESTUARY IN THE WASHINGTON METROPOLITAN AREA
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Environmental Protection Agency

CONTENTS

CONTENTS (Continued)

CHAPTER I

INTRODUCTION

The Potomac River, more than any other, is the focal point of the American conscience in water quality control and has been the subject of extensive study since the middle of the nineteenth century.

While pollution problems have persisted in various areas throughout the basin, the most serious occur in the populated Washington metropolitan area and provide a classic example of the dilemma, present or imminent, faced by most of the large cities in the country. These cities have been situated on estuaries with their natural harbors and fisheries resources but where waste discharges from cities on free flowing streams readily transport the pollution problem downstream, cities like Washington find that the ebb and flow of the tides provide no dependable disposal of the liquid wastes during low river flow periods.

To compound the problem, development of water supply resources, and water power, flood control and recreational facilities as well, has resulted in the regulation of river flows to reduce the periodic flushing actions of past years that ameliorated to some extent the accumulation of pollutants both in the waters and bottom deposits near these large municipalities.

This, then, is the dilemma faced by Washington, D. C., by several other coastal and large inland lake cities and eventually by all similarly located cities as their population growth accelerates. Its resolution requires a multi-faceted approach involving social and economic, as well as scientific disciplines, to provide a viable course of action to preserve both the cities and the natural resources.

The author, as Director of the Annapolis Field Office, U. S. Environmental Protection Agency, has participated in a concentrated, interdisciplinary study of the water quality problems in the Potomac River metropolitan Washington area for the past seven years and offers the findings of this study as guides, not only to the solution to local water quality problems but also to similarly situated metropolitan areas.

Upon signing the Water Quality Act of 1965, President Lyndon B. Johnson said, "I pledge to *you that we are going to reopen the* Potomac for swimming by 1975". Later he stated "The river, rich in history and memory, which flows by our Nation's capital should serve as a model of scenic and recreational values for the entire country". These pledges can be realized since corrective action schedules adopted by the Potomac Enforcement Conference and subsequent actions by the agencies involved to implement construction programs promise completion by 1975.

This paper is concerned,primarily, with identification of the water quality problems, the sources and the corrective action required which have for all practical purposes been completed at the Annapolis Field Office. In a sense though, this work is never completed since it is subject to constant verification and refinement with scientific progress. Progress in improvement of the aquatic environment requires popular acceptance and financial support which have both been increasingly evident. It is the obligation of scientists, engineers and management to provide the most economical means of achieving this goal.

CHAPTER II

BASIN DESCRIPTION

A. History

Potomac, Patawomike, Patowomek, or in any of its historically spelled forms is the Algonkin word for "something brought" or more freely "place to which tribute is brought", singularly appropriate for the present day location of our national capital.

When explored by Captain John Smith in 1608 the river abounded in fish, the surrounding lands with game and the crude agriculture of the indigenous Indian tribes had little impact on the environment.

The upper estuary was developed rapidly as a shipping center from colonial times. Alexandria was then a bustling seaport, ocean-going ships docked as far upstream as Bladensburg on the Anacostia and Georgetown on the Potomac River. The area was intimately involved in the history of the nation, the westward expansion, the Civil War and the subsequent reconstruction and development of a strong central government in Washington which became increasingly involved in domestic and foreign affairs.

B. Geography

The historic source of the Potomac River is the Fairfax Stone at the headwaters of the North Branch in the rugged, forested Allegheny Mountains of the Appalachian chain at the Maryland-West Virginia border. The river flows first northeasterly, then southeasterly through several geophysical provinces some 400 miles to the Chesapeake Bay.

Above Washington, the river drains the Piedmont Plateau and, traversing the Fall Line, becomes tidal at the city where it is several hundred feet wide, draining the Coastal Plain and extending 114 miles to the Bay where it becomes six miles wide.

Though the average depth of the estuary is 18 feet, the upper reaches have become silted through poor land use practices so that regular dredging is required to maintain the 24 foot channel upstream to Washington.

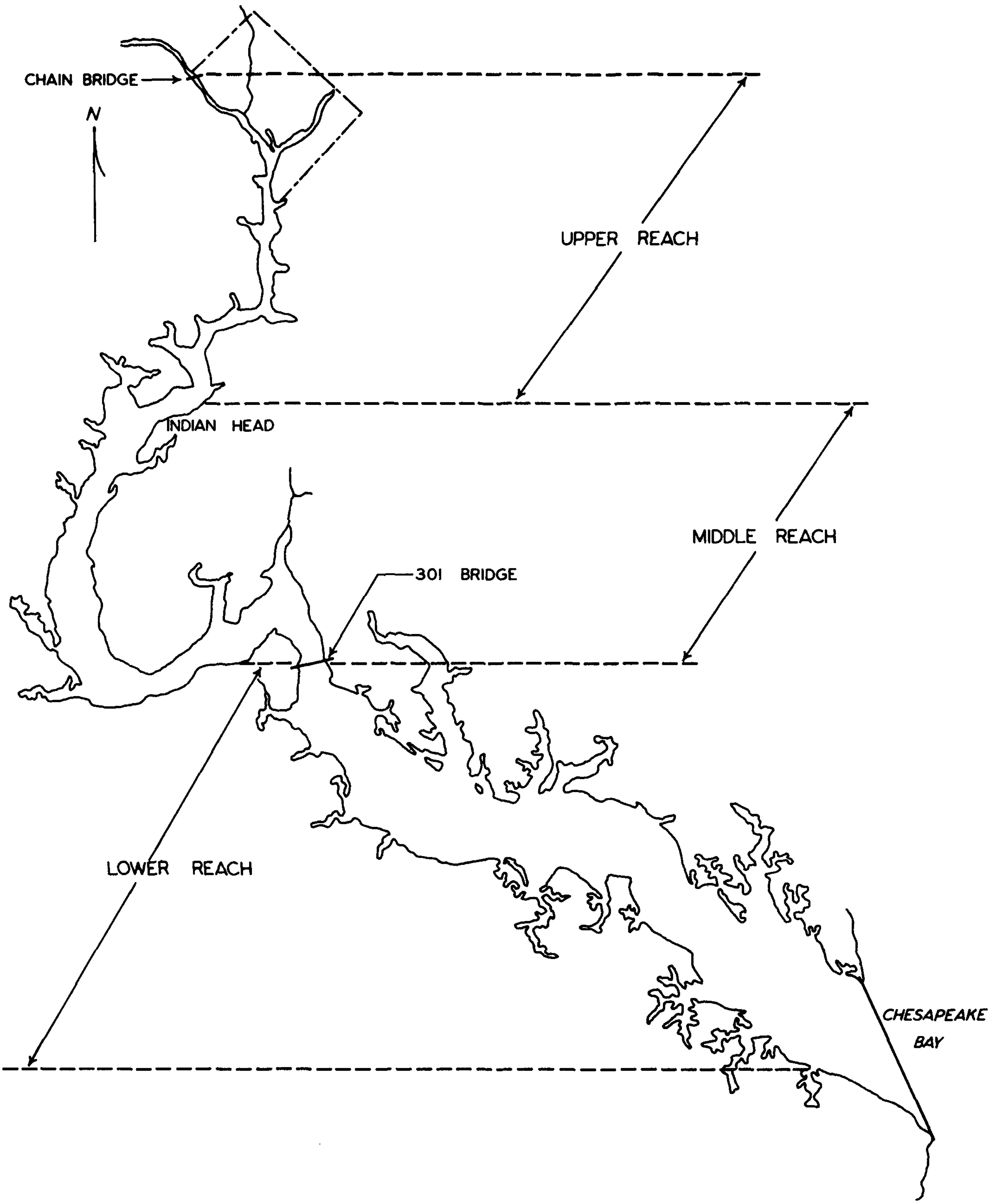
During low river flow periods in the summer, the upper estuary waters are fresh for approximately 30 miles downstream from Chain Bridge to above Indian Head, then brackish to the Potomac Bridge except during high river flows, then more or less saline to the mouth depending upon river flows. (Figure II-1)

Tidal ranges in the Washington area average 2.9 feet with an approximate 4.5 mile excursion.

The Potomac River, draining 14,670 square miles, may be classified as a "flashy" stream with an average annual flow of 11,340 cfs and recorded extremes of 484,000 and 800 cfs.

C. Water Quality

It was recorded that President Adams swam in the Potomac in the late 1790's, but by the 1860's the canals leading to the river often emitted such objectionable sewage odors that President Lincoln



POTOMAC RIVER TIDAL SYSTEM

1971

FIGURE II-1

was forced to leave the White House at night. Following the generally accepted practice of that time, the first sewers constructed in 1870 carried sanitary wastes to the river.

With the rapid population growth in Washington following the Civil War, river conditions became so bad that under President Harrison a system was devised to convey all sewage into the Potomac downstream from the city. By 1920 the need for sewage treatment was recognized but it was not until 1938 that a plant providing primary or settling type sewage treatment only was completed.

As the population continued to increase to over the 2.5 million mark currently in the area, some secondary or biological treatment was operating in 1958. While the efficiency of treatment by conventional methods has since been increased, the continued population growth has overloaded the sewerage facilities and until the additional capacity under construction is completed, water quality in the area will continue to deteriorate unless use, occupancy or other restrictive measures are taken.

Pollution in the upper river basin, while significant, is largely local and has only a minor role in polluting the estuary.

CHAPTER III

FRAMEWORK FOR ANALYSIS

A. Water Quality Investigations

1. Biochemical Oxygen Demand

The Annapolis Field Office (AFO) from the time of its establishment in 1965, first as the Chesapeake Field Station and later as the Chesapeake Technical Support Laboratory under successively the Federal Water Pollution Control Administration, the Federal Water Quality Administration and presently the U. S. Environmental Protection Agency, has expended a major effort on the Potomac River in general and the estuary in particular.

With the continuing degradation of water quality, AFO investigated the Potomac Estuary first in 1966 as part of the Presidential Task Force - Project Potomac and later for the reconvened Potomac Washington Metropolitan Area Enforcement Conference. The original session of the Conference in 1957-1958 had set an 80 percent five-day biochemical oxygen demand (BOD) removal as a minimum average performance standard for area sewage treatment plants (STP). A survey by AFO in 1966, using moving averages for dissolved oxygen (DO) data to cancel the effects of tidal excursion, showed that the major DO depression occurred immediately downstream from the major municipal discharge (Figures III 1 and 2) and was considerably below the minimum average DO standard of 5 milligrams per liter (mg/l).

POTOMAC RIVER ESTUARY
WASTEWATER TREATMENT PLANTS
ANNAPOLIS FIELD OFFICE EPA
1971

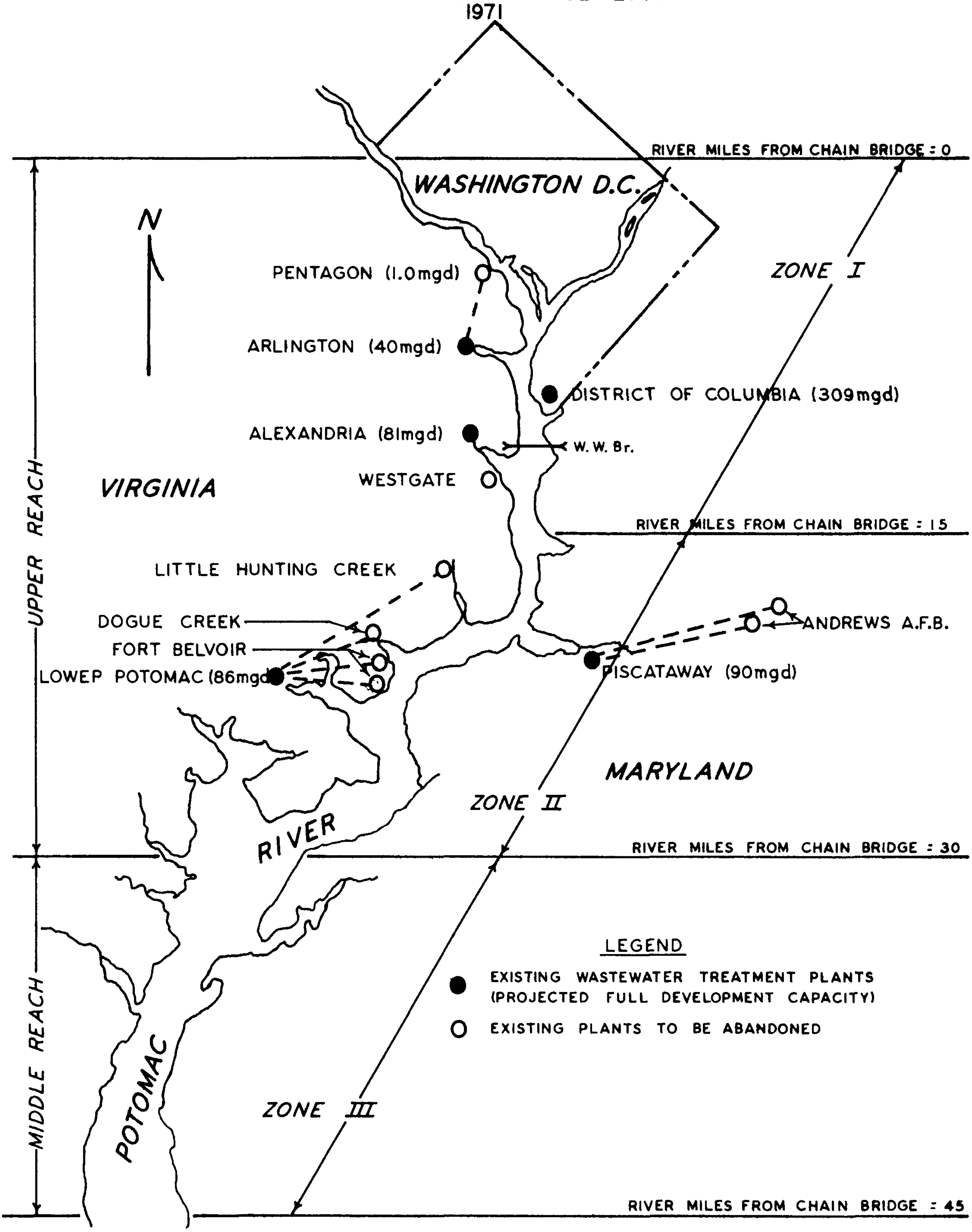


FIGURE III - 1

POTOMAC RIVER ESTUARY

BOD_5 CONTRIBUTIONS FROM SEWAGE TREATMENT PLANTS

ANNAPOLIS FIELD OFFICE EPA

1966

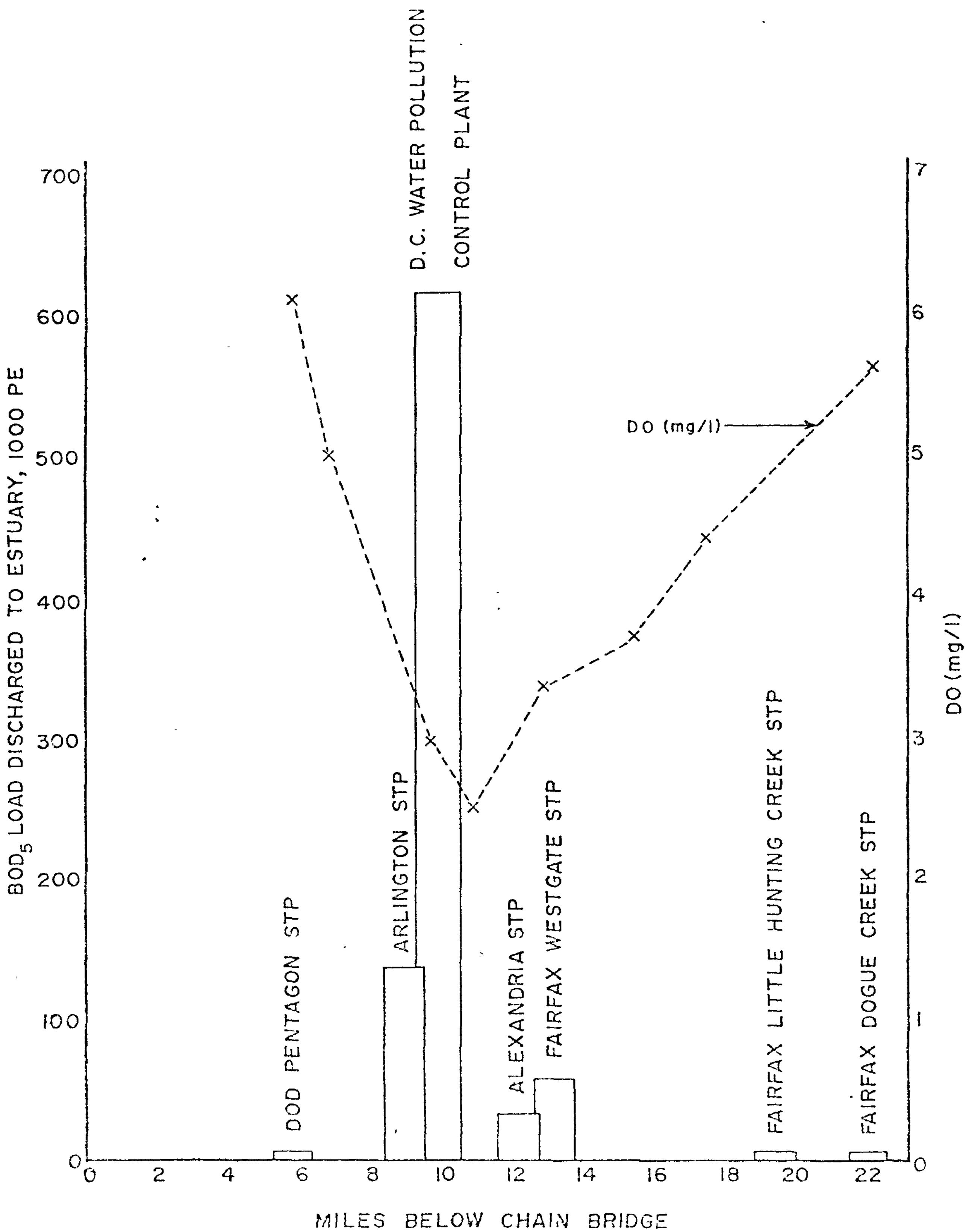


FIGURE III-2

It soon became evident that the 80 percent BOD removal requirement agreed upon at the Conference would no longer be adequate to meet the adopted DO standards and when reconvening of the Conference was proposed, AFO began a detailed investigation of the sources of oxygen-demanding wastes. The first of several waste inventories, the latest of which was in 1969 [2], established the significant waste sources. A study of the estuary [3] completed in 1965 showed not only that a BOD removal nearer 95 percent was currently required but that oxygen demands far greater than that measured by 5-day BOD were exerted in the estuary.

2. Other Oxygen Demands

Specifically, there were two sources of the demand on dissolved oxygen not previously considered, the first, a nitrogenous demand by ammonia and organic nitrogen in the discharges, as measured by total Kjeldahl nitrogen (TKN), and the second, a secondary carbonaceous and nitrogenous oxygen demand from the excessive algae whose growth had been stimulated by nutrients, primarily nitrogen and phosphorus, in the treated waste discharges. Figure III-3 shows the relative demands as measured in the estuary from the above sources.

3. Nutrient-Phytoplankton Relationships

Since nutrient concentrations were not enforceable water quality parameters though the relationships between both

5 DAY BOD DELINEATION & TOC-DO PROFILES

POTOMAC ESTUARY

AUGUST 19-22, 1968

ANNAPOLIS FIELD OFFICE EPA

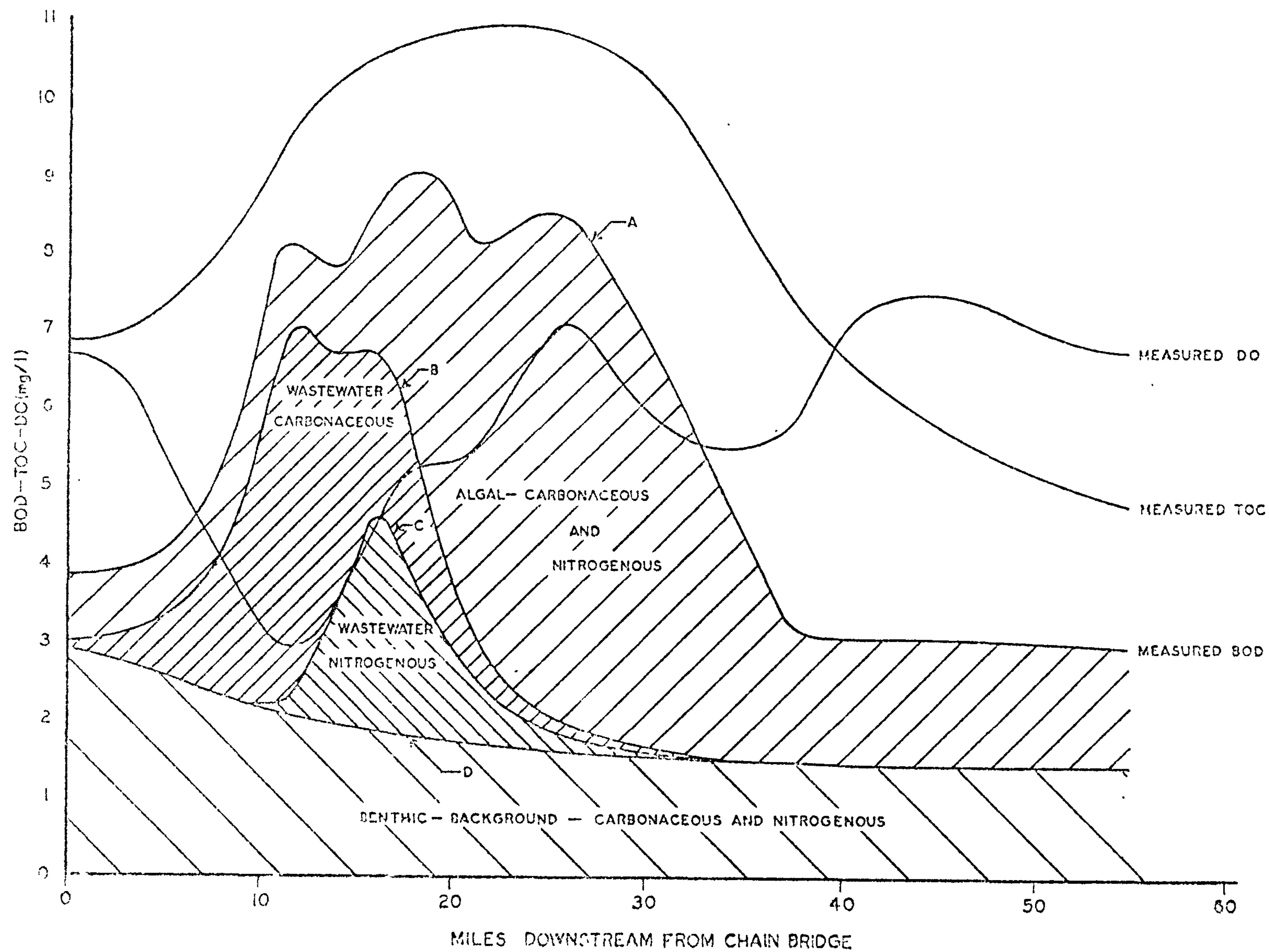


FIGURE III-3

nitrogen and phosphorus and the standing crop of algae (as measured by chlorophyll a) had been established (Figures III-4 & 5), it became necessary to determine a relationship between nutrients in their role of stimulating algal growth and excessive standing crops of algae in depressing dissolved oxygen levels by respiration and decay. These relationships were reported [3] and became the basis for fixing the maximum allowable loadings of BOD and the nutrients nitrogen (N) and phosphorus (P), that could be discharged into the estuary and still maintain the adopted water quality standards.

The investigations (Figures III-4 & 5) showed the direct relationships existing between the algal standing crop (as measured by chlorophyll a) and nitrogen and phosphorus. It is interesting to observe that while no emphasis was placed on a specific responsible nutrient at that early date, the algal standing crop was found to be directly proportional to the nitrogen concentrations while the response rate changed abruptly for phosphorus concentrations exceeding approximately 0.5 milligrams per liter (0.5 mg/l) or parts per million. At that time a phosphorus concentration of 0.1 mg/l had been selected as the maximum to prevent excessive algal growth in the estuary based upon field observations.

B. Mathematical Modeling Activities

Mathematical methods of evaluating the effects of waste loadings had been in use for several decades but were readily applicable to free flowing streams. The problems of dilution and dispersion by tidal excursion in estuaries such as the Potomac required application of more

CHLOROPHYLL - INORGANIC NITROGEN CONCENTRATIONS

POTOMAC ESTUARY

INTENSIVE SURVEYS - 1966 & 1968

ANNAPOLIS FIELD OFFICE EPA

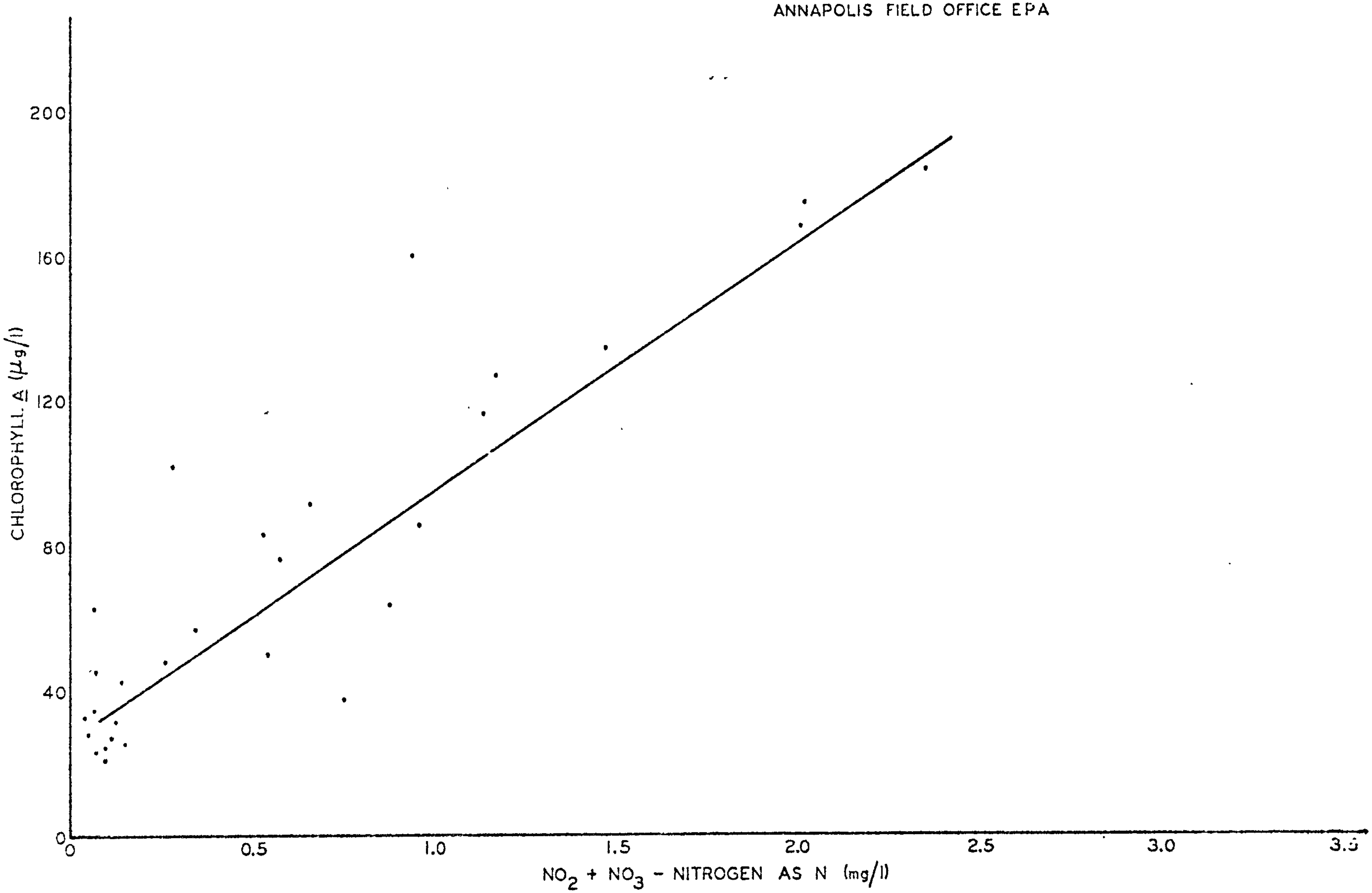
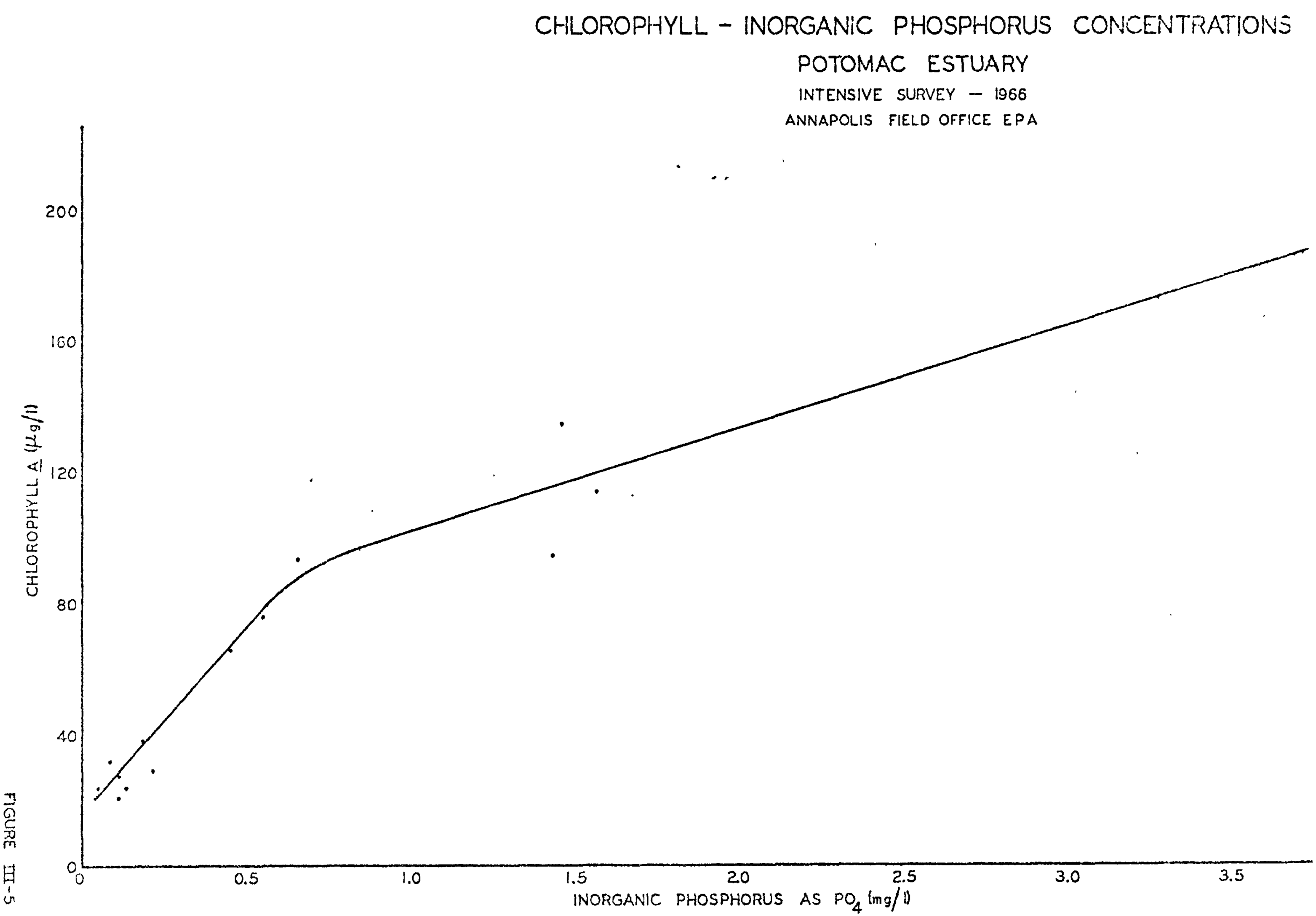


FIGURE III-4



CHLOROPHYLL - INORGANIC PHOSPHORUS CONCENTRATIONS
POTOMAC ESTUARY
INTENSIVE SURVEY - 1966
ANNAPOLIS FIELD OFFICE EPA
CHLOROPHYLL A (μg/l)
200
160
120
80
40
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
INORGANIC PHOSPHORUS AS PO4 (mg/l)

FIGURE III-5

sophisticated mathematical modeling techniques. These were adapted by AFO to fix maximum allowable loading limits for BOD, nitrogen (N) and phosphorus (P) in 15 mile zones of the estuary beginning at Chain Bridge and proceeding downstream. The zonal length was selected since it approximated the segments of similar quality and conveniently placed the major waste discharges near the center of each zone. This concept allowed the technical allocation of maximum loads for each zone without the need to make management decisions on individual load allocation by discharge or geographical subdivision, a political responsibility more properly assumed under an interstate compact or by the conferees. In order to apply the mathematical model, however, it was necessary to assume future loadings which were based upon population projections and projected waste discharge locations arrived at after consultation with the various involved agencies. In addition, it was assumed that all discharges were to be made to the main channel to assure maximum dispersion and dilution of the discharges and that a uniform treatment policy would be adopted within each zone.

The first application of the model, previously verified by dye and salinity studies, provided maximum loadings to Zone I of BOD = 16500 lbs/day, N = 8000 lbs/day and P = 740 lbs/day, which incidentally represented a 96 percent removal of BOD and P for existing treatment plant loadings and were adopted by the Potomac Enforcement Conference as discussed later.

C. Upper Basin Investigations

At the third session of the Conference investigation of upstream pollution contributions to the Conference (estuarine) area was recommended for investigation. AFO prepared a report (4) which gave the results of the physical, chemical, biological and bacteriological studies in the upper basin and their effects on water quality in the estuary. The pertinent findings were that:

1. No thermal problems existed.

2. High acidity from mine drainage in over 40 miles of the North Branch was a local problem only. The measurable effects did not extend beyond another 10 miles downstream.

3. Pesticides were a sporadic minor local problem and required additional surveillance.

4. Low dissolved oxygen levels on certain reaches of tributaries including the North Branch but did not occur in the main river.

5. BOD concentrations discharging to the estuary were low, ranging from 2 to 4 mg/l.

6. Nutrient concentrations were high in localized reaches of tributaries.

7. Only local bacterial problems existed, with complete recovery only short distances downstream.

CHAPTER IV

WATER QUALITY CONTROL ACTIVITIES

A. Governmental Agencies

The upper Potomac Estuary is geographically in the states of Maryland and Virginia and in the District of Columbia (Figure III-1). The situation is further complicated by the historical fixing of the Maryland state boundary, and consequently that of the District of Columbia as well, along the Virginia shoreline. Since discharges from all three jurisdictions were the causes of the water quality degradation, an interstate cooperative activity was essential for corrective action.

1. Potomac Enforcement Conference

Since there was no appropriate authoritative interstate agency in existence, it was mutually agreed that a Conference on Pollution of Interstate Waters of the Potomac River in the Washington Metropolitan Area could be called by the U. S. Department of Health, Education and Welfare under provisions of Section 8 of the Federal Water Pollution Control Act, Public Law 660, 84th Congress.

The Conference was initially in two sessions in 1957 and 1958 and resulted in a remedial action program requiring a minimum wastewater treatment to achieve 80 percent BOD removal, disinfection when required and control of stormwater overflows by 1966.

By 1969 water quality conditions had become progressively worse and the recommended actions had not been implemented according to the agreed schedule. Moreover, AFO studies [3] had clearly established the present inadequacy of the proposed actions.

It was agreed by the conferees that a third session of the Potomac Enforcement Conference be held to review the existing situation and progress made to date. Since the initial sessions, the Federal Water Pollution Control Act of 1965 had been passed resulting in the adoption of water quality standards for all interstate waters.

The third session on May 8, 1969 recommended the loading limits developed by AFO, expanded by fixing specific load limits at existing treatment plants in Zone 1 representing 96 percent BOD removal, 96 percent phosphorus removal and 85 percent nitrogen removal. Construction schedules to achieve these levels of treatment at all wastewater treatment plants in Zones I and II by 1977 were also recommended. Of the several other recommendations four are deserving of special note, the first, that the effect of upstream discharges on the estuary be evaluated, the second, that public progress meetings be held every six months to review the status of compliance with the several recommendations, the third, that continuous disinfection of all treated sewage effluents be practiced and the fourth, that a joint study of the entire Potomac River basin be made to determine the controls required to protect the river and the estuary.

At the reconvened third session on October 13, 1970 a "Memorandum of Understanding" among the jurisdictions involved; Maryland, Virginia, and the District of Columbia was submitted and adopted. Essentially, it limited the capacity of the Blue Plains facility to 309 mgd because of inadequate space for further expansion primarily to serve areas outside the District of Columbia. These areas would be served at a new regional plant to be located at a site selected by the Washington Suburban Sanitary

Commission (WSSC). The load limitations at Blue Plains applied to Virginia areas as well, which retained as in the case of Maryland, basic load limits as provided in the original Blue Plains agreement.

The progress meeting of December 8-9, 1970 in response to dissatisfaction with the 1977 completion schedule, moved up the agreed completion date to 1974. While this accelerated schedule posed many construction and financing problems, this too was agreed upon.

2. District of Columbia Government

The Conference thus placed the primary burden of corrective action on the District, understandably so, since the loading was greater and degree of treatment lower than that of other major discharges. The District is less able to fund expansion of facilities since it is dependent upon Congressional action for financing major projects. Considerable progress was made in (1) reduction of bacterial pollution by institution of full-time adequate chlorination (2) raising the BOD removal efficiency by addition of flocculants and (3) reduction of raw and combined sewer overflows by provision of more adequate sewerage capacity. Construction is under way to increase the capacity at the Blue Plains treatment plant. When the first stage of increasing primary treatment capacity to 309 mgd is completed, most incoming sewage will receive at least some treatment.

3. Washington Suburban Sanitary Commission

This agency has the responsibility of providing water and waste services to Montgomery and Prince George's Counties in Maryland immediately adjacent to the District of Columbia. Most of the sanitary sewage is treated at Blue Plains at present but in accordance with the Conference agreement, other treatment plant location sites must be agreed upon. An

STP at Piscataway provides a higher degree of treatment to about 8 mgd of sewage from southern Prince George's County and the facility is presently being expanded to a 30 mgd capacity. Further expansion to 90 mgd in the same area is under study. Since Piscataway discharges to an embayment of the Potomac Estuary, advanced waste treatment (AWT) for the removal of nutrients will ultimately be required for the present facility as determined in an AFO study [5]. The expanded facility will require AWT and discharge to the main channel of the Potomac.

In the meantime the Piscataway plant has been upgraded in efficiency by the addition of two lagoons or polishing ponds after secondary treatment and disinfection before discharge into the embayment. BOD removal regularly exceeds 95 percent and a substantial degree of phosphorus removal is sporadically achieved. Considering that the primary source of nutrients and organic loading to the embayment is the Potomac River, operating efficiency at this plant shows progress well ahead of other facilities in the area [5].

There are present plans for at least another sewage treatment plant for Montgomery County to take care of sanitary waste discharges from the area west of the District. This has been tentatively determined to be the answer to the building moratorium required because of inadequate existing sewerage and the long delay before such sewerage could be constructed, even if economically feasible. No investigation of such location had been made previously because (1) the AFO mathematical model was applicable to the estuary only, (2) a policy of no treated waste discharges upstream of the water supply intake had been in effect for several years and, (3) no maximum capacity had previously been set at Blue Plains.

4. Fairfax County

Upgrading performance of the sewage treatment plants discharging directly to the Potomac: Westgate, Dogue and Little Hunting Creek had been accomplished partly by the use of flocculants in the existing plants.

The new Lower Potomac STP (Gunston Cove) will ultimately be expanded to eliminate these three plants and part of the Fairfax County sewerage load will be treated at Alexandria.

5. Other Governmental Agencies

The City of Alexandria will expand their STP facility not only to serve the expanding population but parts of Fairfax County by agreement as well.

Arlington County will expand their facility.

B. Federal Activities

There are several Federal activities providing their own waste treatment facilities which will be phased out as soon as other treatment plants can provide adequate capacity (Figure III-1).

The Pentagon will be served by Arlington, Fort Belvoir by the Lower Potomac STP and Andrews Air Force Base by the Piscataway STP.

At present two Federal activities, the Naval Ordnance Station at Indian Head and the Marine Corps Schools at Quantico provide their own adequate secondary treatment but are outside the Conference Area.

C. Annapolis Field Office - EPA

Since the activities (Chapter III) which had provided the technical basis for the administrative actions just outlined, AFO has continued more detailed investigations to refine the previous allowable load figures.

With advances in the state of the art in mathematical modeling, a dynamic model was developed and verified providing a surprisingly close confirmation of the loadings previously determined. It was realized that because of the approximate three week residence time of discharge components in the estuary under low flow conditions, that five day BOD figures did not accurately reflect the organic carbon nor nitrogenous oxygen demands. These were now combined in an ultimate oxygen demand (UOD) factor which was achieved by use of the classical relationship:

$$UOD = 1.45\ BOD + 4.57\ TKN$$

where TKN (total Kjeldahl nitrogen) represents the unoxidized nitrogen, organic nitrogen and ammonia [6].

Extensive field studies by AFO on nutrient-phytoplankton relationships gave more precise allowable nutrient loadings to control the algal standing crop. These figures now vary by zones, being lower downstream where turbidities are lower because of settlement and dilution. This has posed a dilemma in water quality control in the upper estuary, a brown (turbid) water versus a green (algal) one. Control of both is possible but cost considerations may defer such a solution until more urgent water quality problems are resolved.

The previous maximum figures for nutrients (N = 0.3 mg/l, P = 0.1 mg/l) become [6]:

Zone I	N = 0.5	P = 0.067
II	N = 0.4	P = 0.03
III	N = 0.3	P = 0.03

As a result of these AFO investigations loading figures developed from the 1969 report [3] were reconciled with those of the 1971 report [6], prepared for Zone I and submitted to the Conference progress meeting in November 1971 as follows:

1971	1969 (page III-11)
UOD = 75000 lbs/day	BOD = 16500 X 1.45 = 24000 lbs/day
	TKN = 8000 X 4.57 = 36500 lbs/day
	UOD (equivalent) = 60500 lbs/day
N_i = 3400 lbs/day	N = 8000 lbs/day
P = 900 lbs/day	P = 740 lbs/day

Except for the nitrogen loadings the agreement is reasonably close with distinct benefits resulting from the more recent figures, (1) phosphorus and ultimate oxygen demand controls are much more feasible that nitrogen control and (2) there is a choice between degrees of BOD and TKN control to arrive at a net UOD figure. This "trade-off" lends a substantial flexibility in selection of a treatment process.

The lower nitrogen loading figures are a result of better understanding of the relationship between nitrogen availability and phytoplankton growth and not to its role in the DO budget. In addition, a strict comparison cannot be made between the 1969 and 1971 N figures since the former is unoxidized and thus includes organic N while the latter is inorganic only. The figures are probably much more nearly in agreement. Practical nitrogen control methods on a large scale are yet to be demonstrated so that the drastically reduced loading figure makes the solution less formidable.

CHAPTER V

OTHER WATER QUALITY CONSIDERATIONS

A. Water Quality Parameters

1. Bacteriological

Probably the most important parameter from the point of view of beneficial public use is bacteriological - the continuing incidence of high coliform bacterial populations which indicate the probable presence of pathogens. The sources are known in (1) inadequately treated sewage overflows, (2) urban runoff and (3) discharge from boats.

Since 1969, all treated waste discharges from sewage treatment plants in the area have been continously disinfected and this source has been virtually eliminated. Upstream treatment plant discharges are not a problem because of inability of the pathogens to survive the time of travel to the estuary.

The primary coliform bacterial sources are the overflows of raw sewage from inadequate sewerage and from combined sewers after storms. The former are the result of excessive population growth with corrective actions obvious, zoning and restriction of building permits pending construction of adequate sewerage and treatment facilities. A continuing program of sewer separation and additional interceptor capacity will ultimately eliminate the combined sewer overflow sources.

Urban runoff has always provided a significant coliform source especially during the first few minutes of heavy rainfall. The indicated solutions are (1) a high standard of urban sanitation, (2) storage of at least the early runoff for later treatment in the system when flows subside or (3) installation of screening and disinfection equipment at all storm water outfalls.

The effects of sanitary waste discharges from pleasure boats have been investigated by AFO. The contribution was found to be insignificant in comparison with land based pollution sources. Only when large congregations of boats occurred as during a regatta could any coliforms be measured and then only in areas of low background pollution. This potential pollution source cannot be neglected however, since proposed regulation by requiring onboard sanitation devices in a few years would be effective at about the time when effective shore pollution control should be realized and boat sources then become more significant.

2. Heavy Metals

Certain metals, notably mercury, lead, chromium and cadmium, are toxic to marine life in small concentrations especially in warm weather, during spawning periods and to shellfish which, being filter feeders, readily concentrate the metal to potentially toxic levels.

There is relatively little industry in the area to provide major metals sources and their discharges are invariably to municipal sewerage systems. Periodic analyses of discharges by AFO have failed to show heavy metals content above minimum detectable limits. Samples of bottom sediments in the vicinity of outfalls, however, show varying heavy metals content. These were determined by hot acid extraction and would not normally be taken up by the overlying water [6].

3. Pesticides

Infrequent AFO sampling has shown no significant incidence of pesticides in the estuary [6]. It is known, however, that pesticides have been found on occasion upstream. The sources could be industrial as well as agricultural and a precautionary monitoring program is suggested.

4. Thermal

Heated water discharges from electric power plants occur in several areas upstream and downstream as well as in the metropolitan area itself [6]. The thermal effects contribute directly to low DO by lowering the saturation with higher temperatures and stimulating algal growth rates. Adverse effects upstream may result with increases in power generation and a present downstream discharge is the cause of an unacceptably high temperature rise in Quantico Creek. A potential problem discharge exists in the Anacostia River but any adverse biological consequences are effectively masked by existing gross pollution.

5. Sediments

A severe sediment problem has its sources throughout the basin and though sediments are transported to the estuary during the relatively few high flow periods of the year, they cause serious silting of navigation channels as well as excessive turbidity in the upper estuary for most of the year. The metropolitan area sedimentation rate is seven times that from the upper basin and yields over 1.3 million lbs/sq. mi./yr. [6].

The adverse effects include the obvious cost of dredging for navigation, the covering of fish spawning beds and the obvious aesthetic objections in the national capital area.

There are beneficial effects as well. The previously mentioned light interference to retard algal growth is an example. Another benefit is the reduction of some 40 percent in phosphorus concentration by adsorption to silt particles most of which becomes unavailable for uptake either by burial or transport seaward during flood periods [6 & 7].

B. Special Problems

1. Water Supply

In 1966 and again in 1969 flow of Potomac water so approached water supply use that emergency plans were required. The Potomac River is the primary potable water source for the metropolitan area and implementation of long term plans for increasing this resource by upstream storage in multi-purpose reservoirs has been delayed by environmental objections.

An AFO investigation [6] confirmed a previous study that use of water from the estuary could provide not only an emergency source but also provide an adequate supply of potable water almost to the year 2000. Beyond that year upstream storage would be required in any case. Without being involved in what is essentially a political decision, AFO investigated the effects of water withdrawals from the estuary on salinity buildup through reuse as well as movement upstream of the salt wedge with various rates of withdrawal for a 7-day-10 year low flow. This water could be used on short notice whereas the lead time for construction of a storage reservoir is approximately ten years after the project is approved and funded.

It was found that any substantial increases in waste discharge quantities downstream from Zone I would rapidly preclude any contemplated use of estuarine waters for water supply purposes by accelerating movement of salinity to the intake. This would also be the case where substantial wastewater quantities are diverted out of the basin for treatment or disposal.

2. Discharges to Embayments

The AFO mathematical model was developed and loadings determined for discharges to the main channel only. Most existing treatment plants discharge to embayments of the Potomac, the Blue Plains plant being the notable exception. Special model studies were made for Piscataway Creek and Gunston Cove (Lower Potomac STP) and allowable maximum loadings established [6]. The Piscataway STP cannot exceed a 15 mgd discharge into the embayment without contravening adopted water quality standards unless an unusually high degree of AWT is provided.

Since it is anticipated that Fairfax County treatment plants at Westgate, Dogue and Little Hunting Creek will be taken out of service and the sewage treated at the Lower Potomac STP, no further loading figures are needed. Recently, however, it has appeared that for political or economic reasons the Arlington and Alexandria STP's propose to continue discharges to embayments instead of to the main channel. These locations will require independent determinations of allowable load limits and the inevitably high degrees of AWT.

3. Noxious Plant Growth

An interesting serendipitous corollary to the nutrient-phytoplankton investigations by AFO was the historical aquatic plant succession in the Potomac Estuary recorded by various observers (Fig. V-1). It appears that as nutrient concentrations increased, there was an increase in nuisance plant infestations starting with rooted aquatic plants in the 1920's gradually being displaced by drifting microscopic plants (phytoplankton), first the green algae and finally the blue-green algae (Anacystis).

WASTEWATER NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS

UPPER POTOMAC TIDAL RIVER SYSTEM

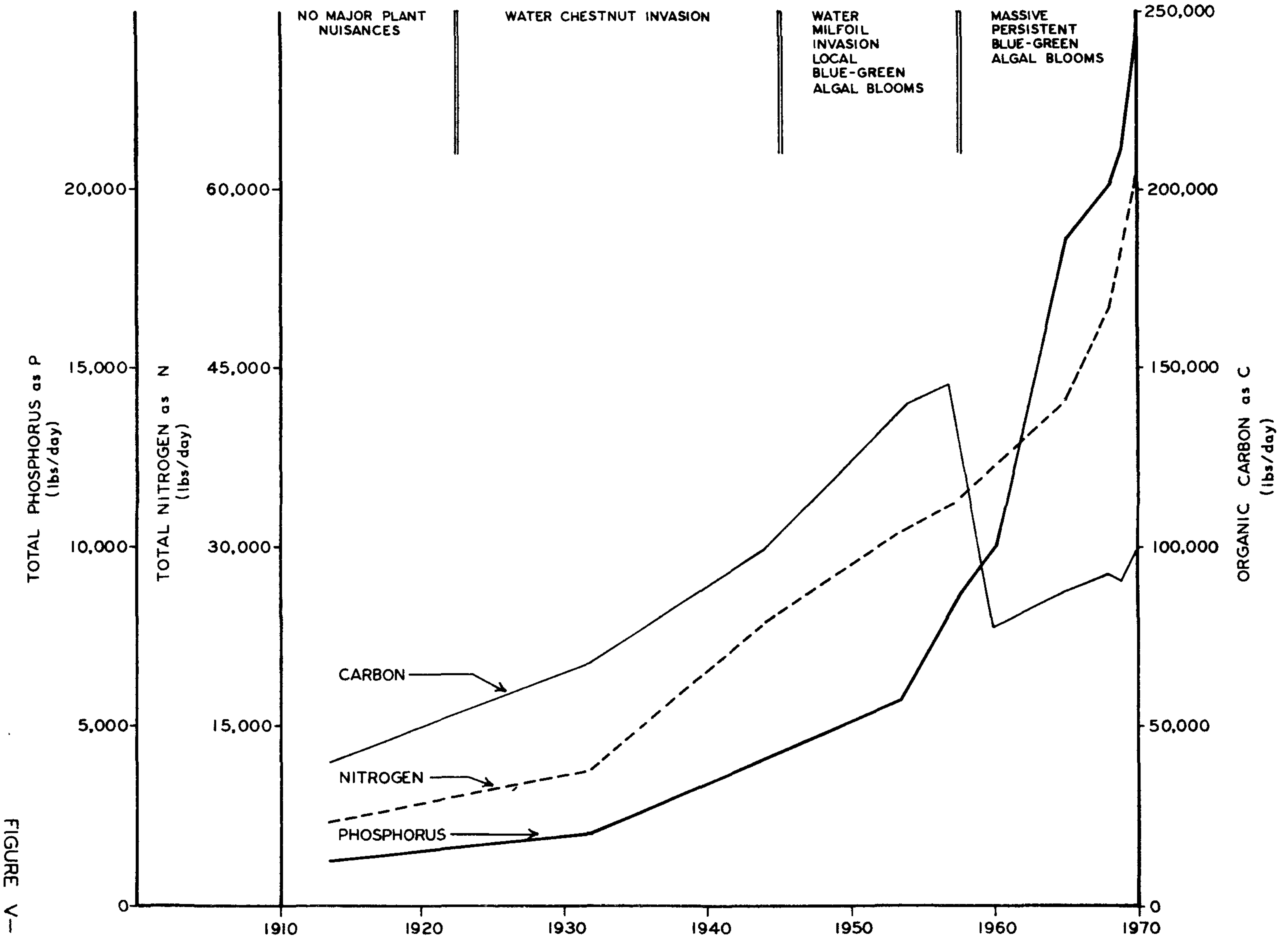


FIGURE V-1

Each historical stage provided a balanced ecological system where the nutrients stimulated the plant growth that was naturally controlled either by nutrient limits or grazing by aquatic animals, the phytoplankton by the zooplankton, the zooplankton by successively higher trophic levels with return of the nutrients by their waste discharges, death and decay. The blue-green algae, however, assume toxic forms and proliferate rapidly when no longer grazed by the zooplankton accelerating the demand on dissolved oxygen, in effect creating an unbalanced ecological system and an odorous, unsightly mass as well [6].

It has been demonstrated that reduction in nutrients will reverse this biological succession notably in the cases of Lake Washington in Seattle and the Thames River in London.

Considerable controversy has arisen regarding which of the major constituents of algae should be controlled to inhibit growth. AFO has proceeded on the basis of controlling all three: carbon, nitrogen and phosphorus where possible. Since the approximate composition of algae is in the ratio of 100:16:1 of C, N and P respectively, it would appear that the order of importance is the same. Controllability, however, is a major factor [6].

In the Potomac, carbon exists in large amounts in the bicarbonate form as well as in the organic form associated with treated sanitary waste discharges. The latter can be fairly well controlled in the treatment process but substantial reduction of the large bicarbonate quantities from the upper basin could not be achieved without treating the entire flow. In addition, carbon can be fixed by algae from the carbon dioxide in the air with even higher rates of fixation when carbon starved [6].

Nitrogen control is a problem because large scale application of laboratory and pilot plant methods have yet to be demonstrated as economically feasible. Nitrogen also can be fixed from the air by algae especially when nitrogen starved but the rate appears to be negligible compared with the promising removal methods. Nitrogen probably is the algal growth rate-limiting nutrient in the upper estuary according to AFO data. These showed carbon and phosphorus levels adequately high during periods of heavy algal bloom whereas the inorganic nitrogen had almost disappeared, a certain indication that it had been taken up in algal growth. An approximate evaluation of the growth limiting potential of N and P may be made by comparing Figures III-4 and III-5. The nutrient-phytoplankton (as measured by chlorophyll a) relationships are clearly shown but the rate of increase in chlorophyll a drops noticeably in the case of P* concentrations over 0.5 mg/l. Nitrogen plays a minor role in the dissolved oxygen budget at low temperature so that removal is not required whenever water temperatures are below 15 degrees Centigrade, or approximately six months of the year for the Potomac [6].

Phosphorus is the most readily controllable of the nutrients. Well-tried, economical processes not only remove 95 percent and better but most of them make possible an additional 5 percent removal of carbon as well. Moreover, phosphorus starved algae cannot find it in the atmosphere.

The conclusion to control both nitrogen and phosphorus is based upon the findings by AFO as given above.

* P is approximately one third of PO_4 values or 0.17 mg/l

CHAPTER VI

GUIDELINES FOR CORRECTIVE ACTION

A. The Surrogate Model

Here then is the upper Potomac River estuary the Washington Metropolitan area which has provided a model for a corrective action program for other coastal cities. The methodology developed here can be applied equally well to cities on the large inland lakes.

Some cities are fortunately located near enough to extend their treated waste discharges well offshore but most are on major estuaries that provided them with the natural harbors about which they grew, with present or prospective pollution problems as populations continue to grow. Except for serious industrial waste discharge, the Potomac Estuary has them all and has already reached a critical stage. The conditions which now exist are:

1. Little or no freshwater flow to the estuary to provide seaward transport of treated wastes during low flow seasons.

2. Inadequacy of conventional wastewater treatment methods to control oxygen demanding loads resulting in dissolved oxygen depression below adopted concentrations.

3. Stimulation of excessive algal growths resulting in unsightly and noxious masses further depressing oxygen levels.

4. Waste discharges primarily from point source discharges of treated municipal effluents with relatively minor agricultural or forested non-point-source discharges.

5. Urban or suburban tributary area to provide pollution

from street washing or urban storm runoff. This may include combined sewer overflows that are characteristic of older cities.

6. Rapid present and future population growth not already controlled by zoning or other regulatory measures.

7. Where applicable, a gradual transition from a freshwater to a marine environment with accompanying biological considerations such as fish spawning areas, shellfish habitat, aquatic plant growth and related recreational use.

B. The Water Quality Control Program

Using the program developed for the upper Potomac Estuary as a guide the suggested sequence of investigations could be as follows:

1. Identify the problem areas, usually the city and its urban area but often including industrial areas.

2. Locate sources of pollutants; municipal, industrial and agricultural. Determine qualitatively and quantitatively those parameters affecting water quality both point and non-point sources.

3. Evaluate the relative contributions of conservative and non-conservative parameters as functions of flow, distance from problem areas and temperature. Generally, the critical conditions occur during high-temperature, low-flow periods but for some parameters, seasonal population concentrations, agriculture and its incidental food processing and certain industrial operations may require special investigation at certain times of the year.

4. Determine the maximum loading of each critical parameter at its source to realize the maximum total loading in the problem area. This is not a technical consideration alone since political or manage-

ment decisions are required. In the case of the Potomac Estuary the zone loading concept was used with the apportionment of loadings deferred to the Conference. For the purpose of estimating future effects of population growth, certain assumptions were made and made definite conditions for the individual discharge loadings. They were:

a. Uniform treatment at all facilities within each zone.

b. Populations served were in their natural drainage basins with no interbasin transfers.

c. Population projections used were acceptable.

d. The seven-day ten-year low flow was used as the critical flow.

e. Location of major sanitary discharges were substantially as indicated in the report (Figure III-1).

5. Develop an area plan for the most feasible distribution of treatment units. Design should be such that each construction stage be compatible with a 50 year plan and meet water quality standards.

6. Eliminate all raw sewage overflows by separation of storm and sewage systems where existing and provide adequate capacity in the sewerage system.

7. Initiate measures to reduce pollution by urban runoff by screening and disinfection or storage for later treatment when flows subside.

8. Upgrade treatment methods for industrial wastes and reduce quantities by process improvements, whether discharged directly or into a municipal system, to meet adopted water quality standards and Federal laws.

C. Future Study Needs

1. Improved Advanced Waste Treatment Processes

Conventional waste treatment methods, physical solids separation (primary), biological actions (secondary) and disinfection of the discharge is presently the minimum treatment required for municipal wastewater. Where this degree of treatment is inadequate to achieve approved water quality standards in the receiving water as in the case of the upper Potomac River estuary, advanced waste treatment is required. This has generally included modular facilities to remove additional carbon, nitrogen and phosphorus. Continuing studies to develop economical new processes are required especially in the case of nitrogen where large scale adaptions of laboratory processes have not yet been applied.

2. Nutrient-Phytoplankton Relationships

a. Algal Productivity

The use of algal standing crop as a factor in evaluating the effects of excessive nutrients has been practical in determination of allowable loading limits because it is readily measurable as the chlorophyll a parameter. This has been applicable in the case of the Potomac because the upper estuary is fairly well mixed. Even so there is some question of the relative effect of heavy algal mats inhibiting photosynthetic activity to an extent where the effect of nutrient stimulation is not fully realized.

A more accurate relationship may be made using algal productivity rates for specific nutrient concentrations if a practical methodology can be developed.

b. Marine Phytoplankton

While AFO investigations to date have been in freshwater quality problem areas of the Potomac Estuary and in Chesapeake Bay, freshwater algae do thrive in more saline waters of the transition zone between the fresh and salt waters. While freshwater algae do persist in this transition zone there has been a noticeable increase in marine species in recent years. The "red tides" (gymnodinium) have been found in quantities not only in the lower Potomac Estuary but during 1971 in the Chesapeake Bay north to the Bay Bridge for the first time. It appears that a nutrient-marine phytoplankton relationship exists in saline as well as in freshwaters and this should be quantitatively established. The threat of depressed dissolved oxygen loads may exist in areas where population centers exist on saline estuarine waters. Probably a greater potential danger is in the species shift to a toxic dinoflagellate such as that which poisoned the shellfish off the New England coast late in 1972.

3. Embayment Studies

It seems obvious from investigations of discharge locations in the Potomac Estuary that however desirable discharges to the main channels of bays and estuaries may be for dispersion and dilution, major discharges will be continued at the heads of embayments for economic or political reasons. Because they are generally shallower, have lower transport rates and offer less mixing, separate mathematical model studies are required in each case since hydrographic characteristics are rarely similar. The greater photosynthetic action and lower transport rates increase nutrient efficiency in algal productivity and the degree of AWT above that for discharges to main estuary channels. Here again is an economic "trade-off" between the cost of a long outfall against that of the higher degree of AWT required.

D. Recapitulation

The Potomac River upper estuary is an appropriate surrogate model to be used as a guide in corrective water quality action programs, present or future, for similarly situated coastal cities. It offers, in fact, an unparalleled study situation because (1) as the site of the national capital it has received the higher priority as a demonstration project for water quality control, (2) the combination of high population-low flow characteristics offer a prototype solution without the complexities of industrial or agricultural waste discharges which are better resolved separately and (3) as the federal center it can demand the maximum share of federal funds.

Upon signing the Water Quality Act of 1965, President Johnson said, "I pledge to you that we are going to reopen the Potomac for swimming by 1975".

The technical requirements have been determined as outlined in this paper.

A suitable interstate institutional vehicle, the Potomac Enforcement Conference, has succeeded in bringing all involved state agencies to agreement on treatment requirements and construction schedule.

Construction is presently in progress.

The pledge can be fulfilled subject only to provision of adequate funds for construction.

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