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TECHNICAL REPORTS

Volume 5

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NUTRIENT TRANSPORT AND DISSOLVED OXYGEN BUDGET STUDIES IN THE POTOMAC ESTUARY

October 1972

Technical Report 37
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Region III
Environmental Protection Agency

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NUTRIENT TRANSPORT AND DISSOLVED OXYGEN BUDGET STUDIES IN THE POTOMAC ESTUARY

Technical Report 37

October 1972

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PREFACE

The ability to simulate, mathematically, the historical dissolved oxygen (DO) distribution in a watercourse is quite an achievement, especially when most of the known components of the DO budget are quantitatively defined and incorporated in the analysis. This ability is in fact required to predict future changes, including standards compliance, in the dissolved oxygen content of a lake, stream, or estuary due to municipal or industrial growth.

While the classical Streeter-Phelps study of the Ohio River in 1924 initially established the basic relationships governing dissolved oxygen, the evaluation of the oxygen budget is no longer based solely on the biochemical oxyged demand (BOD) and reaeration. Sanitary engineers have intruded into the biologist's domain by attempts to determine in mathematical terms the effects of nutrient materials, specifically nitrogen and phosphorus, on the density and extent of algal blooms and the algae's subsequent effect on the DO budget. A strong interdependence exists among nitrogen, phosphorus, algae and dissolved oxygen, and although only a rudimentary approach was ventured, the Annapolis Field Office (AFO) of the Environmental Protection Agency (EPA) has mathematically modeled this interrelationship in the upper Potomac Estuary.

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CHAPTER I

INTRODUCTION

A. PURPOSE AND SCOPE

The importance of mathematical models as a water quality management "tool" is widely acknowledged. Models have evolved from the one dimensional steady-state type capable of simulating only relatively conservative constituents such as tracer dye or chlorides to time-dependent models linking BOD and DO and finally to multi-constituent models capable of (1) elaborate "feedback" linkage between the various constituents, (2) not only first-order kinetics but any mathematically describable reaction, and (3) incorporating tidal aspects to permit "real-time" hydraulic and quality predictions.

The purpose of this report is to present the approach taken by AFO to model a portion of the nitrogen cycle, phosphorus deposition, and the occurrence of algal blooms as measured by chlorophyll a; as well as the effects of carbonaceous, nitrogenous, and benthic oxygen demand; algal photosynthesis, respiration and decay; and reaeration on the dissolved oxygen resources in the upper Potomac Estuary. Basically, this approach entailed a feedback model similar to the one proposed by Thomann [1] and a procedure whereby individual reaction rates, based on a visual comparison of observed and simulated data, were estimated. Upon determining the appropriate rates, the models' reliability to predict DO distributions was investigated.

The EPA Dynamic Estuary Model [2] was modified to incorporate the necessary reactions describing nitrogen and phosphorus transport and most sources and sinks of dissolved oxygen. This model was used primarily to simulate short-term, pseudo-steady-state conditions. DECS III, an average tidal model, [3] was used to simulate nitrogen and phosphorus behavior over an annual cycle. Both of these models successfully simulated (1) a tracer dye distribution following a 13-day continuous release and (2) seasonal chlorinity changes in the Potomac Estuary [4] prior to the more complex modeling discussed in this report. In addition, the two models were used to investigate the role of nutrients in the eutrophication process and to establish maximum allowable nutrient and ultimate oxygen demand loadings for different zones of the Potomac Estuary [5].

The entire Potomac Estuary is included in the framework of the mathematical models. Since uncertainties arise when applying either model to the mesohaline portion of the estuary, most of the analyses will pertain to the freshwater region of the Potomac with the major emphasis placed on the critical area immediately downstream from Washington, D. C.

B. ACKNOWLEDGEMENTS

Special recognition has been given to the Steuart Petroleum Company, Piney Point, Maryland, for their extensive cooperation and assistance in performing all sampling during AFO's 1969-70 nutrient transport study of the Potomac Estuary. This report could not have been completed as promptly without such sampling assistance.

CHAPTER II

SUMMARY AND CONCLUSIONS

During 1970, the Annapolis Field Office embarked on a mathematical modeling study of the Potomac Estuary utilizing a 1965-70 data base to (1) predict nitrogen and phosphorus distributions during both a relatively short time period (steady-state) and over an annual cycle, (2) define the various reaction rates, including temperature effects, directly influencing nutrient transport, (3) evaluate the role of both nitrogen and phosphorus in the existing eutrophication problem and develop predictive capabilities for algal standing crop, (4) formulate a DO budget model incorporating algal effects in addition to biological oxidation and reaeration and (5) determine the maximum allowable loadings of nitrogen, phosphorus and carbon (BOD) that will maintain water quality commensurate with existing standards. The findings evolved during data analysis, model development and verification are as follows:

1) There are currently eighteen wastewater treatment facilities in the Washington Metropolitan Area that discharge total BOD_5, phosphorus (P) and nitrogen (N) loadings to the upper Potomac Estuary of 143,000 lbs/day, 25,000 lbs/day, and 60,000 lbs/day, respectively.

2) During the period from February 1969 to February 1970 the average nutrient contributions from the upper Potomac River Basin were, phosphorus (as P), 4,580 lbs/day, and nitrogen (as N), 59,000 lbs/day. These loadings correspond to an average freshwater flow of 6,900 cfs.

3) The median loadings contributed from urban and suburban runoff to the upper Potomac Estuary are given below:

Parameter	Loading (lbs/day)
BOD_5	12,500
Phosphorus (P)	850
Nitrogen (N)	4,070

4) Using weekly nitrogen data collected in the Potomac Estuary from February 1969 to July 1970 the following conclusions were drawn:

a) Maximum ammonia concentrations of 2.0 mg/l were observed on numerous occasions near the major wastewater discharges. A drastic reduction in ammonia, attributable to nitrification, occurred between the Woodrow Wilson Bridge and Indian Head under high temperature conditions.

b) The reduction in ammonia concentrations were accompanied by high levels of nitrate nitrogen, often approaching 2.0 mg/l. Farther downstream, between Indian Head and Smith Point, a significant decrease in nitrate, due to biological (algal) uptake, occurred during the summer and fall months.

c) Organic nitrogen concentrations were extremely high (3.0 mg/l) in the Potomac during the late summer and early fall when algal blooms were profuse.

5) Utilizing the EPA Dynamic Estuary Model and data from thirteen intensive sampling runs conducted under steady-state conditions, nitrification rates required for model verification varied from 0.005/day

to 0.4/day depending on temperature. At 20°C, the nitrification rate was 0.084/day (base e).

6) Reasonable agreement between the thirteen sets of observed nitrate data and model predictions was obtained when algal uptake rates varied from 0.01/day to 0.13/day with a 20°C value of 0.037/day (base e). A definite temperature vs algal uptake rate relationship was again indicated.

7) A modified version of DECS III that incorporated the verified reaction rates and temperature effects discussed above accurately simulated the basic seasonal trends and spatial distributions of ammonia and nitrate nitrogen observed during the period February 1969 to July 1970.

8) A modified version of the EPA Dynamic Estuary Model which converted losses of nitrate nitrogen to algal biomass based upon elemental composition ratios was used to predict bloom conditions in the Potomac as measured by chlorophyll a. Eight separate sets of chlorophyll data representing different flow and temperature conditions were simulated satisfactorily with this model, thus indicating the importance of inorganic nitrogen as a possible growth-rate-limiting nutrient.

9) Phosphorus data measured weekly in the Potomac Estuary during 1969-70 revealed the following:

a) The distribution of both inorganic and total phosphorus was markedly similar during the study period. Maximum concentrations of 2.0 mg/l and 4.0 mg/l, respectively, were recorded between Bellevue and Piscataway Creek with concentrations diminishing farther downstream.

b) Although high freshwater flow periods contributed an excessive phosphorus load, the adsorption of phosphorus onto silt particles accompanying these high flows and its eventual deposition actually reduced the phosphorus content in the upper Potomac Estuary.

c) During high temperature periods, inorganic phosphorus concentrations decreased appreciably downstream from Piscataway Creek as a result of biological uptake by phytoplankton and chemical deposition.

10) A modified version of the DEM having second order kinetics was utilized to simulate fourteen sets of prototype data and evaluate the phosphorus loss rate. Based on these simulation studies the loss rates required for model verification ranged from 0.005 gr/day to 0.04 gr/day, varying with temperature. The rate derived from a regression analysis for 20°C was 0.0218 gr/day.

11) A modified version of DECS III that again incorporated second order kinetics and the verified rates given above adequately simulated the interseasonal phosphorus distributions throughout the Potomac Estuary as observed between February 1969 and July 1970.

12) A series of model runs (DEM) that related phosphorus loss to algal productivity was made in order to delineate biological uptake from physical deposition of phosphorus and to acquire a better understanding of the significance of phosphorus as a possible growth-rate-limiting nutrient. Based on these runs, it appeared that only 10 to 20 percent of the phosphorus losses were attributable to uptake by algal cells whereas 80 to 90 percent represented deposition to the bottom sediments.

13) The DO budget model employed by AFO in its study of the Potomac Estuary consisted of the following five linkages:

a) oxidation of carbonaceous matter

b) oxidation of nitrogenous matter

c) oxygen production and respiration of simulated algal standing crops based upon the nitrogen cycle

d) benthic demand, and

e) atmospheric reaeration

14) The aforementioned DO model proved capable of simulating nine different observed conditions between 1965 and 1970 when fresh-water flows and temperature ranged from 185 cfs to 8800 cfs, and 19°C to 30°C, respectively. In order to achieve a meaningful verification of this model it was necessary to base all simulation runs on the following reaction rates and other related assumptions:

<u>Process</u>

a) Carbonaceous oxidation - 0.17 (base e - 20°C)

b) Nitrogenous oxidation - 0.084 (base e - 20°C)

c) Reaeration - O'Connor-Dobbins Formulation

d) Algal oxygen production rate - 0.012 mgO_2/hr/µg chloro <u>a</u>

e) Algal respiration rate - 0.0008 mgO_2/hr/µg chloro <u>a</u>

f) Euphotic Zone - 2 feet

g) Respiration Depth - full depth of water column

h) Algal oxygen production period - 12 hours

i) Algal respiration period - 24 hours

j) Benthic demand - 1.0 $grO_2/meter^2$/day

15) In order to determine the relative importance of the various rates incorporated in the DO budget model, a detailed sensitivity analysis was performed. The following conclusions were drawn based upon the results of this sensitivity analysis:

a) The predicted critical DO deficit is markedly sensitive to the carbonaceous oxidation rate assigned in the model. Since the mass of unoxidized nitrogen in the Potomac is considerably less than that of carbon, the model predictions for DO were not significantly affected when a comparable range in nitrification rates was inputted.

b) Increasing the algal photosynthesis rate or decreasing the respiration rate produced basically comparable results insofar as model predictions are concerned. Both the critical deficit and that portion of the predicted profile representing DO recovery were drastically affected when a change in either rate was instituted.

c) A displacement of the entire predicted DO profile by a substantial amount was noted when different benthic demand rates were used indicating significant model sensitivity.

d) Various expressions for computing the reaeration rate (i.e. O'Connor-Dobbins, Churchill and Langbein's Egs) were used in the model; however, no changes in predicted DO data were detected.

CHAPTER III

DESCRIPTION OF STUDY AREA

The Potomac River Basin, with a drainage area of 14,670 square miles, is the second largest watershed in the Middle Atlantic States. From its headwaters on the eastern slope of the Applachian Mountains near the historic Fairfax Stone, the Potomac flows first northeasterly then generally southeasterly some 400 miles to the Chesapeake Bay. The Potomac traverses the Piedmont Plateau until it reaches the Fall Line near Washington, D. C. Below the Fall Line, the Potomac is tidal, extending 114 miles southeastward and discharging into the Chesapeake Bay.

The tidal portion is several hundred feet in width in its uppermost reach near Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained upstream from the mouth to Washington. Except for this channel and a few short reaches where depths up to 100 feet occur, the tidal portion is relatively shallow with an average depth of approximately 18 feet. The mean tidal range is approximately 1.4 feet near the Chesapeake Bay and 2.9 feet in the vicinity of Washington. The lag time for the tidal phase between Chesapeake Bay and Washington is approximately 6.5 hours. The entire Potomac Estuary is characterized by numerous tidal embayments, generally less than 5 feet in depth, some of which are quite large in area.

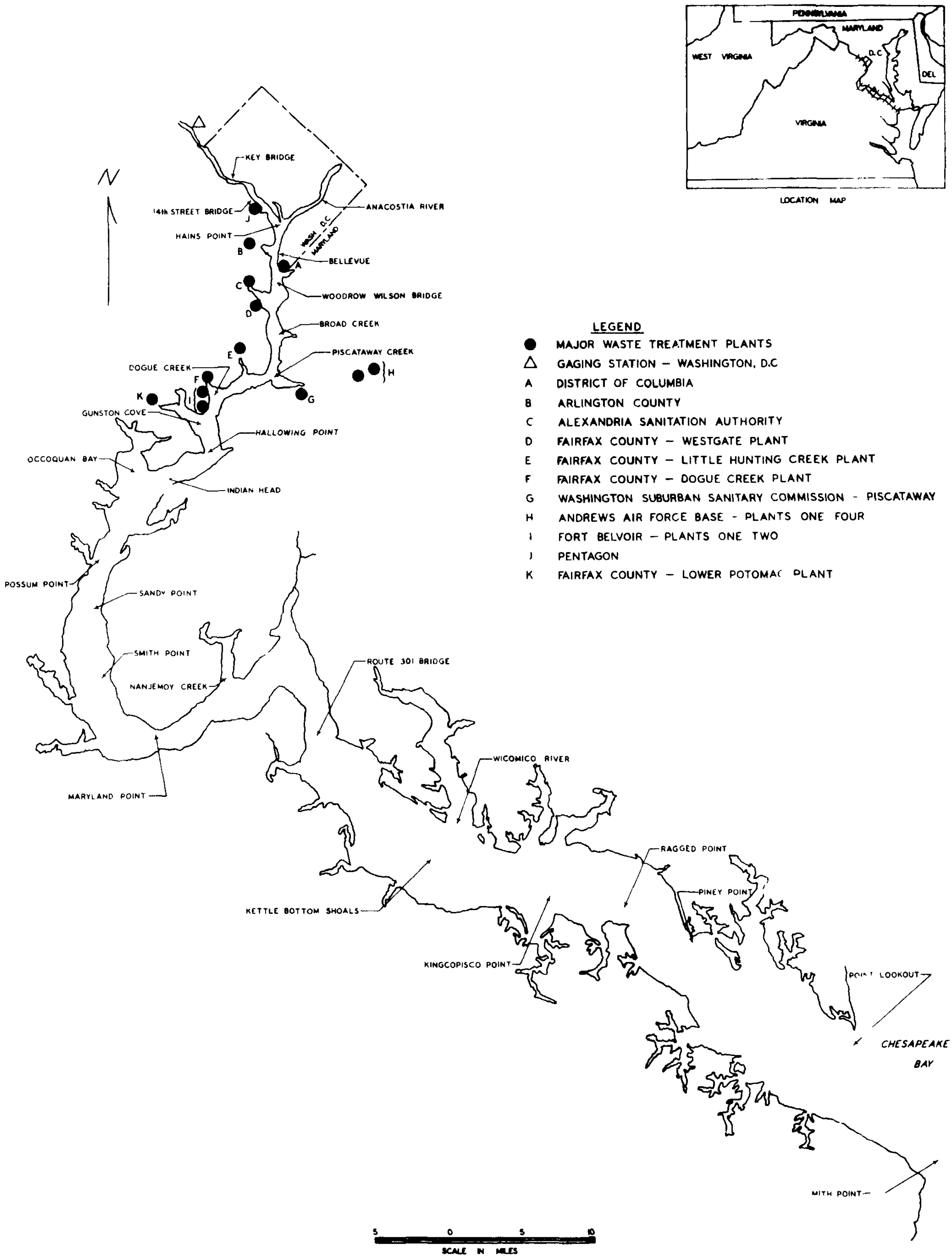
Of the 3.3 million people living in the basin, approximately

2.8 million reside in the upper portion of the Potomac Estuary within the Washington Metropolitan Area. The lower area of the tidal portion, which drains 3,216 miles, is sparsely populated.

The upper reach, although tidal, contains fresh water. The middle reach is normally the transition zone from fresh to brackish water. The lower reach is saline with chloride concentrations near the Chesapeake Bay ranging from approximately 7,000 to 11,000 mg/l.

Because of minimal regulation, the Potomac is characterized by flash floods and extremely low flows. The average freshwater flow of the Potomac River near Washington, before diversions for municipal water supply, is 10,800 cubic feet per second (cfs) with a median flow of 6,500 cfs.

Detailed physical data for the Potomac Estuary, including model segmentation geometry, have been presented in a previous report [6].



POTOMAC ESTUARY

FIGURE III -1

CHAPTER IV

SOURCES OF NUTRIENTS AND OXYGEN DEMANDING SUBSTANCES

A. WASTEWATER LOADINGS

A total domestic wastewater flow of approximately 337 mgd is discharged into the Potomac River tidal system upstream from Indian Head, Maryland. Nineteen facilities currently serve approximately 2.6 million people in the Washington Metropolitan Area with the largest facility being the Blue Plains plant of the District of Columbia. Of the 337 mgd, 40.0, 26.0, and 34.0 percent originate in Maryland, Virginia, and the District of Columbia, respectively. The current BOD and nutrient loadings from each treatment facility are presented in Table IV-1. The total loadings into the upper Potomac Estuary from wastewater sources are (1) BOD_5 - 143,000 lbs/day, (2) Total Phosphorus (P) - 25,000 lbs/day, (3) Total Nitrogen (N) - 60,000 lbs/day.

There are 82 wastewater point-source discharges in the Potomac Estuary between Indian Head, Maryland, and the Chesapeake Bay. The estimated BOD, phosphorus as P, and nitrogen as N loadings from these sources are 4,000, 500, and 1,000 lbs/day, respectively. Compared to the upper reach, with a population of approximately 2.6 million, the wastewater facilities in the middle and lower reaches serve a population of approximately 50,000 and consequently account for a small percentage of the total loadings to the Potomac Estuary. Most of the discharges in this area are into tributary or embayment waters.

Table IV-1

WASTEWATER LOADINGS TO THE UPPER POTOMAC ESTUARY AND TRIBUTARIES

Facility	Population Served	Flow	BOD_5 Untreated	BOD_5 Treated	Suspended Solids Untreated	Suspended Solids Treated	T. Phosphorus as P Treated	TKN Treated	$NO_2 + NO_3$ Treated
		mgd	(lbs/day)	(lbs/day)	(lbs/day)	(lbs/day)	(lbs/day)	(lbs/day)	(lbs/day)
Pentagon	10,600*	1,060	2,100	360	2,100	310	65	290	20
Arlington	247,000	19,390	33,500	5,460	37,400	14,300	1,650	1,020	1,465
Sewer Overflows D. C. System	18,300**	2,516	3,740	3,740	3,700	3,700	170	460	20
Naval Laboratory White Oaks, Md.	950*	0.095	25	7	32	12	7	25	1
District of Columbia	1,830,000	251.660	373,700	103,800	369,900	102,000	17,300	46,200	2,000
Alexandria	190,000	23.300	38,000	13,000	36,200	12,600	2,300	3,690	20
Fairfax-Westgate	124,400	11.570	11,500	10,900	9,600	8,200	1,280	1,830	40
Piscataway, WSSC	55,000	5.810	6,300	540	7,300	1,310	320	630	100
Andrews AFB No. 1	8,200*	0.820	1,200	110	770	110	45	50	30
Andrews AFB No. 4	860*	0.086	104	16	80	10	5	3	3
Naval Comm. Station Cheltenham, Md.	670*	0.067	110	15	140	14	3	2	1
Fairfax-Hunting Cr.	25,000	3.260	4,060	1,390	3,890	1,130	380	620	15
Fairfax-Dogue Cr.	20,000	2.441	4,048	915	4,010	760	270	365	20
Fort Belvoir No. 1	3,600	0.600	1,100	120	110	70	30	25	25
Fort Belvoir No. 2	18,400	2.340	3,500	380	3,800	325	175	430	20
Fairfax-Lower Potomac	100,000	11.700	16,860	2,140	19,490	3,120	760	***	***
Naval Ordnance Station Indian Head, Md.									
Site I	2,500*	0.250	155	90	200	160	12	25	1
Site II	3,600*	0.360	355	140	430	80	8	5	1
Site III	60*	0.006	2	1	2	1	1	1	1
Site IV	10*	0.001	2	1	2	1	1	1	1
TOTAL		337.332	500,361	143,125	499,146	148,213	24,782	55,672	3,784

* Based on 100 gcpd

B. CONTRIBUTIONS FROM THE UPPER POTOMAC RIVER BASIN

During the period of February 1969 to February 1970, the following average concentrations of BOD_5 and nutrients in the freshwater flow entering the upper Potomac Estuary were measured.

Parameter	Concentration (mg/l)
BOD_5	2.60
TKN as N	0.61
NO_2 + NO_3 as N	1.00
Phosphorus as P	0.13

Detailed analyses of the freshwater inflows from the upper Potomac River Basin at Great Falls were conducted during 1969 and 1970. The observed data, as shown in Figure IV-1, indicate the wide range of nutrient concentrations for the period of June 1969 to July 1970. The river discharge was considerably higher during the 1970 period of the study than it was for the 1969 thus resulting in higher NO_2 + NO_3 concentrations. Concentrations of TKN and phosphorus appeared to decrease during periods of high flow, except during periods of intense runoff.

The monthly nutrient contributions from the upper basin during the period of February 1969 through February 1970 are presented in Table IV-2. For this 13-month period, the average daily contributions of nutrients are given below:

Parameter	Contribution (lbs/day)
Total Phosphorus as P	4,580
Inorganic Phosphorus as P	2,650
TKN as N	22,410
NH_3 as N	4,590
NO_2 + NO_3 as N	36,700

NUTRIENT CONCENTRATIONS
POTOMAC RIVER AT GREAT FALLS

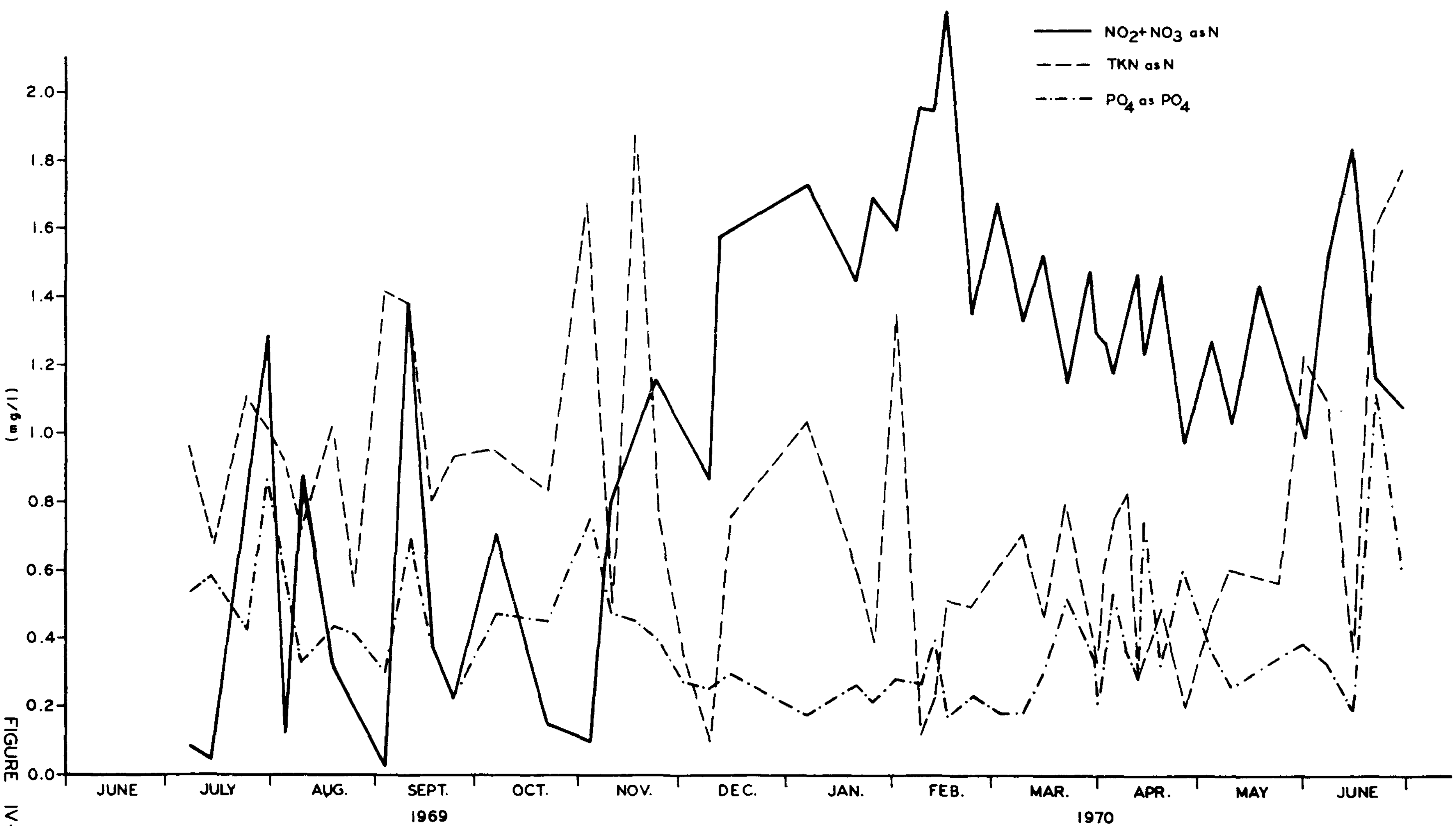


FIGURE IV-1

Table *IV-2*
UPPER POTOMAC RIVER BASIN CONTRIBUTIONS
(Above Great Falls)
February 1969 through February 1970

Month	Flow (cfs)	T. Phosphorus as P (lbs/day)	Inorganic Phosphorus as P (lbs/day)	TKN as N (lbs/day)	NH_3 as N (lbs/day)	$NO_2 + NO_3$ as N (lbs/day)
February	6,700	4,495	2,070	22,180	4,670	23,080
March	8,400	5,500	3,270	26,360	5,300	45,370
April	7,000	4,740	2,120	22,700	5,080	21,750
May	3,900	2,730	900	11,680	3,750	7,910
June	2,200	1,560	430	7,630	2,070	2,890
July	2,400	1,700	540	8,460	2,190	4,970
August	8,000	5,310	2,700	26,260	5,290	32,030
September	4,300	2,920	1,050	14,680	3,370	10,040
October	2,300	1,680	420	8,200	2,240	3,160
November	3,600	2,540	810	11,800	3,070	6,980
December	7,900	5,230	2,980	25,890	5,100	39,400
January	11,900	7,830	5,600	38,870	6,950	86,980
February	21,400	13,360	11,550	66,610	10,590	191,910
Average	6,900	4,580	2,650	22,410	4,590	36,700

C. SUBURBAN AND URBAN RUNOFF

A regression analysis of the river discharge and contributory loadings was applied to data from the Rock Creek and Anacostia River watersheds in the District of Columbia. Based on these regression studies and flow duration curves, yield rates in terms of lbs/day/sq mi were determined. These rates were used for the suburban areas in Virginia and Maryland as shown in Table IV-3. For the District of Columbia, additional data on stormwater and urban runoff were obtained from a study of Washington overflows [7].

The median loadings contributed from urban and suburban areas to the upper Potomac Estuary (Table IV-3) are tabulated below:

Parameter	Loadings (lbs/day)
BOD_5	12,500
TKN as N	2,560
$NO_2 + NO_3$	1,510
T. Phosphorus as P	850

The total lbs/day loadings of BOD and nutrients from suburban and urban runoff were fairly low when compared to those contributed from the upper Potomac Basin. However, the yield rates, except for nitrites and nitrates, were significantly higher for the urban and suburban area than for the upper Potomac Basin. This indicates that as an area becomes more populated, the amount of BOD, phosphorus, and TKN contributions will probably also increase.

Table IV-3
URBAN AND SUBURBAN RUNOFF CONTRIBUTIONS TO UPPER POTOMAC ESTUARY
(Great Falls to Indian Head)

	Area	Duration* Yield Rate	T. Phosphorus as P		$NO_2 + NO_3$ as N		TKN		BOD_5	
	sq mi	(percent)	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day
Maryland	352	5	3.30	1,200	15.65	5,500	30.40	10,700	64.0	22,500
	352	50	1.00	350	1.71	600	3.20	1,100	9.6	3,400
	352	95	0.10	35	0.20	70	0.60	210	1.2	420
Virginia	300	5	3.30	1,000	15.65	4,700	30.40	9,100	64.0	19,200
	300	50	1.00	300	1.71	510	3.20	960	9.6	2,900
	300	95	0.10	30	0.20	60	0.60	180	1.2	360
District of Columbia	62	5	17.74	1,100	27.42	1,700	41.90	2,600	62.9	3,900
	62	50	3.23	200	6.45	400	8.10	500	10.0	6,200
	62	95	0.40	25	0.40	50	1.50	90	4.8	300
Total	714	5	4.62	3,300	16.66	11,900	31.37	22,400	63.86	45,600
	714	50	1.20	850	2.11	1,510	3.58	2,560	17.50	12,500
	714	95	0.12	90	0.25	180	0.67	480	1.51	1,080

* The percent of time of which a given duration of yield in lbs/day/sq mi was equaled or exceeded

CHAPTER V

FRAMEWORK FOR ANALYSIS

A. WATER QUALITY DATA

Since 1965, the Annapolis Field Office has conducted water quality sampling in the Potomac Estuary. Initially, most of the data were collected in the critical upper reach near Washington, D. C., but the area of concern has progressively lengthened to include the middle reach, where the most serious algal problems occur, and more recently the almost continuously saline lower reach.

The frequency and duration of sampling generally followed one of two patterns: (1) an intensive type survey, hopefully performed during steady-state conditions, composed of multiple sampling runs carried out each day for approximately a week's duration or (2) weekly or bi-weekly sampling over an annual cycle. The importance of the first sampling method is that relatively short-term intensive data can be employed to obtain reaction rates and, thus, be used for model verification during a period of somewhat constant temperature and freshwater flow. The EPA estuary model, due to its hydraulic solution, particularly lends itself to steady-state flow analysis. In order to verify a mathematical model over a larger time scale, to predict seasonal variations in the nitrogen and phosphorus transport mechanism, and to investigate the effects of seasonal wastewater treatment requirements, AFO with the cooperation of Steuart Petroleum Company conducted a weekly nutrient sampling program of the entire Potomac Estuary from February 1969 to May 1970. These data will be discussed in a later section of this report. All of the intensive data have been published in separate reports [8] [9] [10].

In addition to AFO sampling, data collected by the District of Columbia's Department of Sanitary Engineering in weekly cruises in the upper Potomac Estuary were also evaluated. Certain data, which were collected during appropriate steady-state periods, were used in the rate determination and model verification studies presented in this report.

B. CHEMICAL, PHYSICAL, AND BIOLOGICAL REACTIONS

1. Nitrogen

Figure V-1 schematically shows the major reactions of the nitrogen cycle in an aquatic environment. Organic nitrogen derived primarily by biological action has many forms, with the more common being proteins, amines, purines, and urea. While certain forms (fibrous proteins) are resistant to biological degradation, others may be decomposed by biological action or, in the case of urea, hydrolyzed enzymatically into ammonia and carbon dioxide.

Ammonia nitrogen can be introduced into natural waters by sewage effluents or agricultural runoff. In addition, ammonia is released by biological decomposition of organic matter. Since it is extremely soluble in water, ammonia concentrations can become quite large. Ammonia is characterized by significant sorption (physical and chemical) properties, but more important is the fact that it can be resynthesized to organic nitrogen by aquatic plants or oxidized to nitrites by autotrophic bacteria (nitrosomonas). This latter reaction, known as nitrification, is highly dependent on temperature and pH and will proceed only under aerobic conditions. It has been reported [11] that this phase of nitrification requires 3.43 grams of oxygen for 1 gram of ammonia nitrogen to be oxidized to nitrite.

In addition to the oxidation of ammonia, nitrites are also formed by the reduction of nitrates. Further reduction by heterotrophic bacteria (denitrification) results in the release of nitrogen gas. Nitrite nitrogen is very unstable since it can be readily oxidized by Nitrobacter bacteria to nitrates. Consequently, high concentrations of nitrite are not normally found in surface waters. Approximately 1.14 grams of oxygen are required to oxidize one gram of nitrite nitrogen.

Nitrate nitrogen represents the completely oxidized form of nitrogen in the nitrogen cycle. Its major external sources in a watercourse are wastewater effluents and agricultural runoff. The nitrate form is quite soluble in water and concentrations can reach high levels, particularly since it does not adsorb on particulate matter and is chemically relatively nonreactive. In addition to the reduction of nitrate by heterotrophic bacteria at low DO levels (0-2 mg/l), it may also be used by phytoplankton as a nutrient source. The assimilated nitrate nitrogen is converted to organic nitrogen in the plant's cells. Upon death, the cellular material releases organic nitrogen which completes the nitrogen cycle.

From the standpoint of mathematical modeling the Potomac Estuary, there are two aspects of the nitrogen cycle that deserve special attention: (1) the reduction in dissolved oxygen by bacterial oxidation of unoxidized nitrogen forms (ammonia + organic nitrogen)* and (2) the assimilation of inorganic nitrogen forms by phytoplankton during their growth phase.

* Commonly measured as total Kjeldahl nitrogen

SIMPLIFIED NITROGEN CYCLE

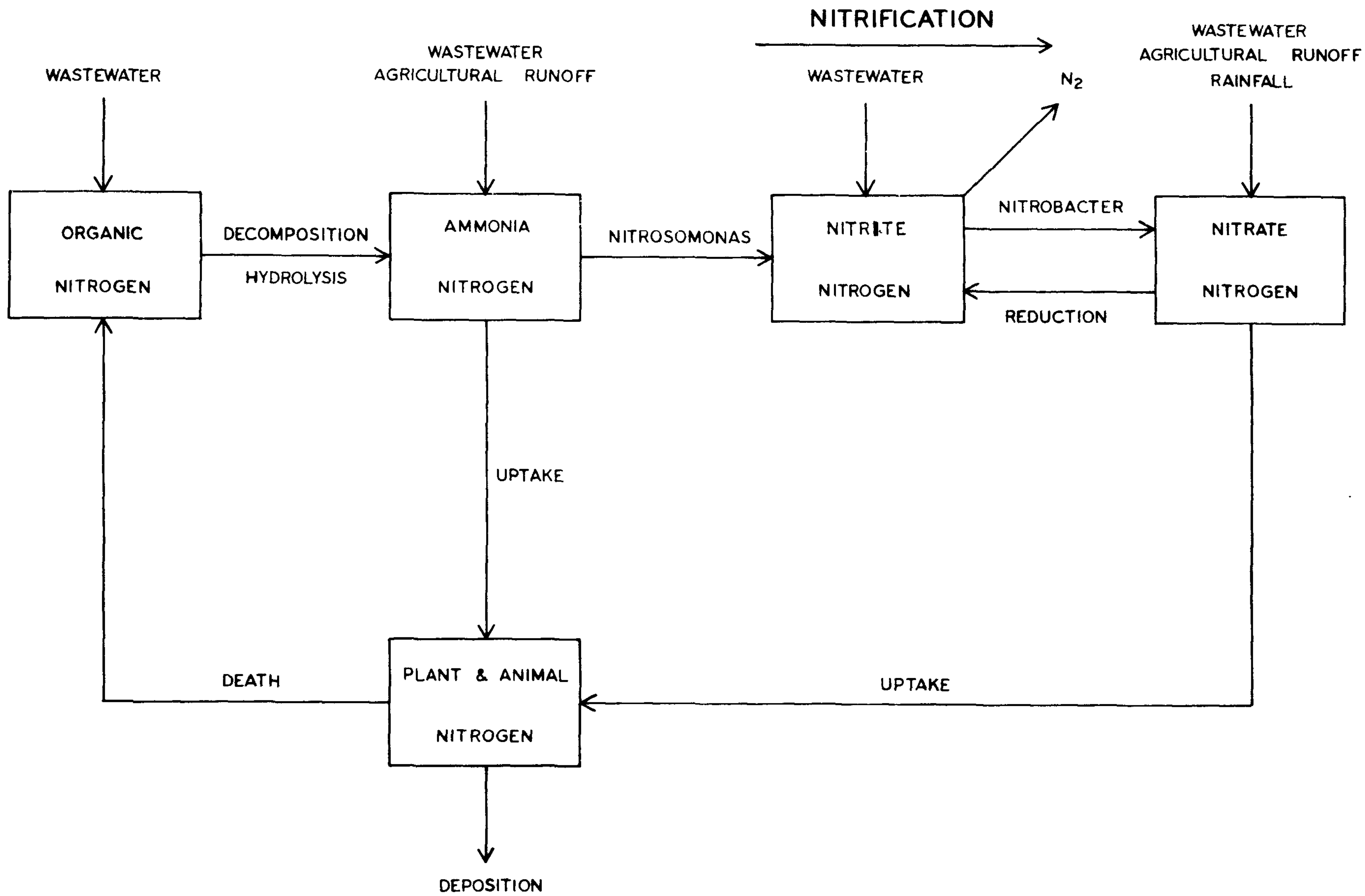


FIGURE V-1

2. Phosphorus

Since the advent of synthetic detergents, phosphorus levels in the natural environment have increased drastically and its role in the eutrophication process has received considerable attention. Shown in Figure V-2 is a schematic representation of a simplified phosphorus cycle with pertinent chemical, physical, and biological reactions. Although large quantities of mineral phosphates are present on the earth's surface, they are relatively insoluble in water.

Phosphorus in the aquatic environment can basically be categorized as either inorganic or organic. As shown in Figure V-2, inorganic phosphorus can be subdivided into: (1) particulate, (2) soluble ortho, and (3) soluble poly and pyro. The major contributor of soluble inorganic phosphorus is wastewater effluents. Prior to the inception of synthetic detergent use orthophosphate constituted most of the total phosphorus present in sewage, with the remainder being primarily dissolved and suspended organic compounds. Since that time, however, the cleansing agents polyphosphate and pyrophosphate have become predominant factors in water quality management. In addition to sewage sources, both inorganic and organic phosphorus (soluble and particulate) may be contributed in much smaller quantities by agricultural and other types of land runoff.

Polyphosphate and pyrophosphate are readily hydrolyzed to the orthophosphate form. Various sorption phenonmena can convert soluble orthophosphates to a particulate form or vice versa. Of the different forms of inorganic phosphorus, only soluble orthophosphate can be biologically assimilated by phytoplankton. A portion of the particulate phosphorus is deposited in the bottom sediments. A quantitative appraisal of phosphorus recycling has not been undertaken, but it appears that the sediment adsorbs more phosphorus than it releases.

The organic phosphorus component also contains soluble and particulate phosphorus which undergo chemical and physical reactions similar to their inorganic counterparts. The oxidation of organic soluble phosphorus into an inorganic form is a relatively minor sink of DO. The cells of plants and animals convert inorganic phosphorus to an organic form; when these cells die, a certain portion is probably deposited. Biological decomposition of the remainder results in additional soluble and particulate organic phosphorus, and because of "luxury" uptake, some soluble inorganic phosphorus.

Phosphorus cycle factors of special concern in mathematical modeling studies are the gross deposition rate and the quantity biologically taken up by algae. While other aspects are also important, they are not as easily defined.

SIMPLIFIED PHOSPHORUS CYCLE

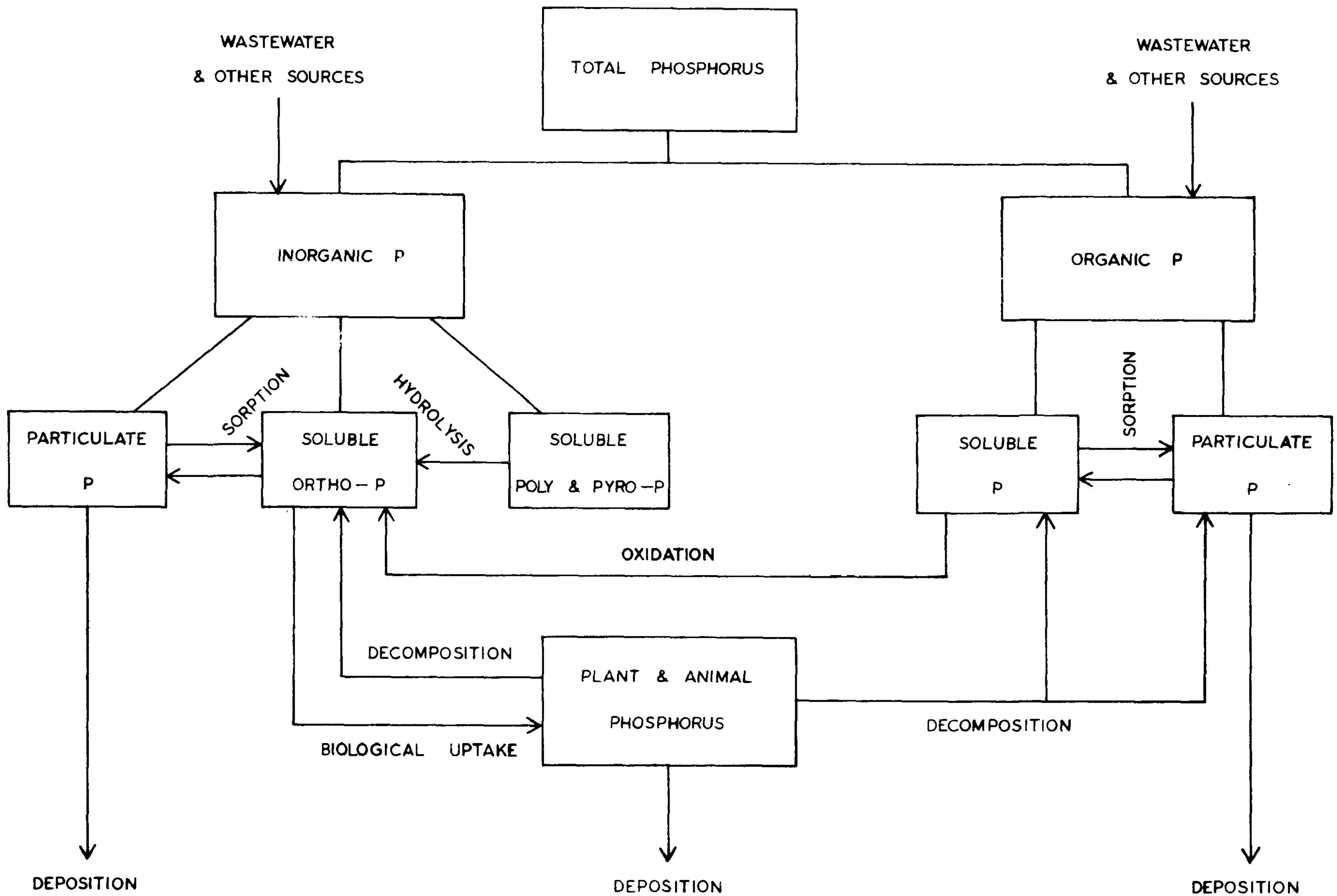


FIGURE V – 2

C. MATHEMATICAL MODELING TECHNIQUES

Water quality simulations discussed in this report were made using the EPA Dynamic Estuary Model (DEM) and DECS III (Thomann Model). Relatively steady-state conditions over a 2 or 3 week period were simulated with the DEM, whereas DECS III was used to simulate inter-seasonal conditions. The DEM is a real time system incorporating hydraulic and quality components. Both of these components utilize the same two-dimensional network of interconnecting junctions and channels. The hydraulic solution describes tidal movement, while the quality solution considers the basic transport mechanisms of advection and dispersion as well as the pertinent sources and sinks of each constituent. The DEM can concurrently simulate six different constituents. They may be either conservative or nonconservative and may be interrelated in any mathematical linkage. A detailed description of this model is available from EPA [2]. The application and verification of the DEM in simulating dye and chloride data in the Potomac Estuary and a detailed sensitivity analysis of the various input parameters have also been documented [4].

Several modifications were made to the DEM in order to simulate nutrient transport and historical dissolved oxygen distributions. A schematic diagram of the basic feedback linkage employed by the DEM to predict algal growth based on the nitrogen cycle and the effects of algae and other sources and sinks on the DO budget are shown in Figure V-3. One version of the DEM included five nitrogen reactions: (1) bacterial nitrification of ammonia to nitrite and nitrate, (2) phytoplankton utilization of inorganic nitrogen, (3) release of organic nitrogen by the death of phytoplankton, (4) deposition of organic nitrogen, and (5) decomposition of organic nitrogen to ammonia. Moreover, the following DO budget linkages were included in a separate model: (1) oxidation of carbonaceous matter, (2) oxidation of nitrogenous matter (ammonia and organic), (3) oxygen production by photosynthesis and utilization by respiration of simulated algal standing crops based upon the nitrogen cycle, (4) benthic demand, and (5) reaeration from the atmosphere.

All model reactions were based on a mass balance basis. The mass conversion factors (nitrogen to chlorophyll a) were determined by algal composition analyses performed in the laboratory [5]. The rates used in the DO budget analysis were obtained primarily from field studies. Besides changing the various reaction rates temporally, a modification was made in the DO model to allow for spatial variations in the photosynthetic, respirational and benthic rates as well as the depth of the euphotic zone.

Simulations of phosphorus transport in the Potomac Estuary were based on second-order reaction kinetics. As will be discussed in a subsequent section of this report, adequate agreement between observed and predicted phosphorus profiles could not be obtained using a first-order system for deposition rates. Consequently, the DEM was modified to handle second and other order reactions. Linkage between algal growth and phosphorus loss in the model was performed similarly to that of the nitrogen cycle, e.g., mass balance analysis.

SIMPLIFIED D O BUDGET
FOR
DYNAMIC ESTUARY MODEL

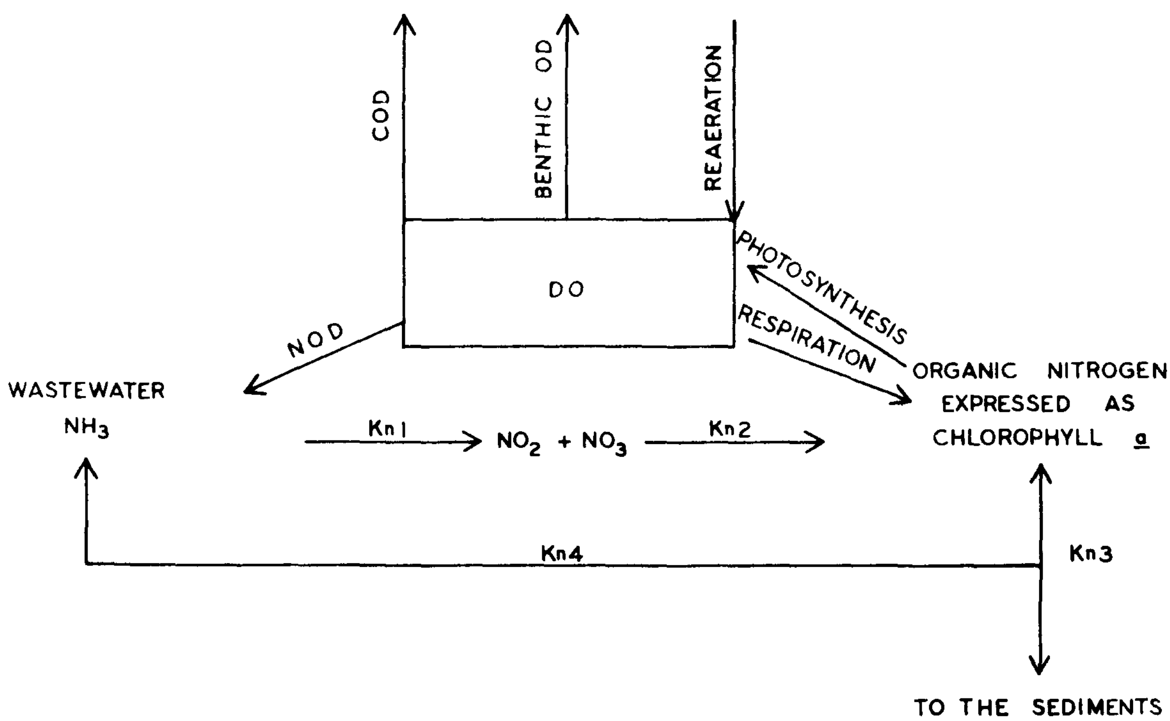


FIGURE V-3

The DECS III model is based on a tidal average time-dependent solution of the basic mass balance equations as originally developed by Thomann [12]. These equations are expressed in finite difference form by segmenting the estuary under study. Since this model is nontidal, a dispersion coefficient is introduced to account for tidal dispersion and advection in addition to eddy and molecular diffusion. The quantitative appraisal of this coefficient becomes extremely difficult. AFO's experience in verifying DECS III for historical dye and chloride data and the estimation of dispersion coefficients for several reaches of the Potomac Estuary as a function of freshwater inflow is available in another report [4].

The major disadvantage of using DECS III is its limitation to a two-constituent linkage. Therefore, neither the complete nitrogen cycle nor the DO budget could be simulated. To help alleviate this problem, ammonia nitrogen and nitrate nitrogen replaced BOD and DO, respectively, in the original version of the model. The reaeration component sign was changed; it thus behaved as a sink of NO_3 instead of a source of DO. This loss would, of course, correspond to the biological uptake of NO_3 by algae. In such a manner, two nitrogen fractions could be properly represented.

Two other modifications were made to DECS III to permit the simulations given in this report: (1) the inclusion of second-order reaction kinetics for the analysis of phosphorus transport and (2) the inclusion of a mathematical expression relating dispersion coefficient to freshwater flow. This latter addition was necessary since the simulation period was long in duration and was characterized by extreme flow differences.

CHAPTER VI

NITROGEN ASSIMILATION AND TRANSPORT

A. TEMPORAL AND SPATIAL DISTRIBUTION

The concentrations and forms of nitrogen in the Potomac Estuary are dependent upon wastewater loadings, temperature, freshwater inflow, and biological activity. The weekly nitrogen data collected by AFO from February 1969 to July 1970 are presented in isopleth form in Figure VI-1 (Ammonia Nitrogen), VI-2 (Nitrite + Nitrate Nitrogen), and VI-3 (Organic Nitrogen).

As shown in Figure VI-1, ammonia concentrations of 2.0 mg/l were fairly common in the upper estuary in 1969 as a result of wastewater discharges. The rapid decrease in concentrations between the Woodrow Wilson Bridge (River Mile 12) and Indian Head (River Mile 31) is indicative of nitrification or the conversion of ammonia nitrogen to nitrite and nitrate nitrogen. Based upon the data shown in Figure VI-1, the rate of this reaction appears to be definitely related to temperature.

During the warm summer months, for example, ammonia concentrations in the vicinity of Dogue Creek (River Mile 22) were about 0.5 mg/l, whereas concentrations during winter and spring periods averaged 1.0 - 1.5 mg/l. The almost immediate effects of nitrification would indicate that the upper Potomac Estuary behaves as a "continuous-culture system." It should also be noted that changes in freshwater flow rates had a relatively minor effect on the ammonia nitrogen levels upstream from Hains Point (River Mile 7.6).

The concentrations of nitrite and nitrate nitrogen at any given time will be a function of (1) nitrification rate and (2) nitrate uptake by algal cells. Figure VI-2 shows maximum nitrite and nitrate nitrogen concentrations (1.5 - 2.0 mg/l) throughout much of the summer and fall of 1969 and again in January 1970. These high levels generally prevailed between Woodrow Wilson Bridge and Indian Head where rapid reduction in ammonia levels was observed. Besides the conversion of ammonia from wastewater effluents, a considerable amount of nitrate nitrogen enters the upper Potomac Estuary during periods of high freshwater flow. This contribution would account for the high concentrations in January 1970, a low-temperature, minimal nitrification period.

The significant decrease in nitrite and nitrate nitrogen between Indian Head and Smith Point (River Mile 46) in the summer and early fall of 1969 was caused by algal uptake of nitrogen. This reaction, like nitrification, appears to be related to temperature as evidenced by the greater persistence of nitrate nitrogen during colder periods.

From a water quality management standpoint, the virtual disappearance of inorganic nitrogen in the critical algal growing areas suggests that this nutrient may become the major factor in limiting algal growth in the middle reach of the Potomac Estuary.

The distribution of organic nitrogen in the Potomac Estuary during 1969-70 is shown in Figure VI-3. These iso-concentration lines were based on differencing the total Kjeldahl nitrogen (TKN) and ammonia nitrogen data. As shown in Figure VI-3, organic nitrogen is quite plentiful in the Potomac Estuary, especially during the late summer and early fall of 1969. Maximum concentrations, exceeding 3.0 mg/l, were observed in the middle estuary throughout most of September 1969 with the lower reach having levels nearer 2.0 mg/l. These extremenly high levels of organic nitrogen resulted from the profuse algal blooms which were visually observed and measured at greater than 100 μg/l chlorophyll a. The maximum recorded chlorophyll value during this critical period was 445 μg/l. Algal composition studies conducted by AFO [5] indicate that water with an algal bloom of 100 μg/l chlorophyll a contains about 1.0 mg/l of organic nitrogen.

Relatively high organic nitrogen concentrations (1.5 - 2.0 mg/l) continued in the upper and middle estuary through October 1969. Similar concentrations were again observed in June and July 1970 when a reappearance of algal blooms occurred.

It would appear from a comparison of the ammonia nitrogen and organic nitrogen data that the rate of decomposition of organic nitrogen is much slower than the rate of bacterial nitrification, since organic nitrogen is the predominant form of nitrogen in the middle and lower estuary.

AMMONIA NITROGEN ISOPLETH

POTOMAC ESTUARY

1969 - 1970 DATA

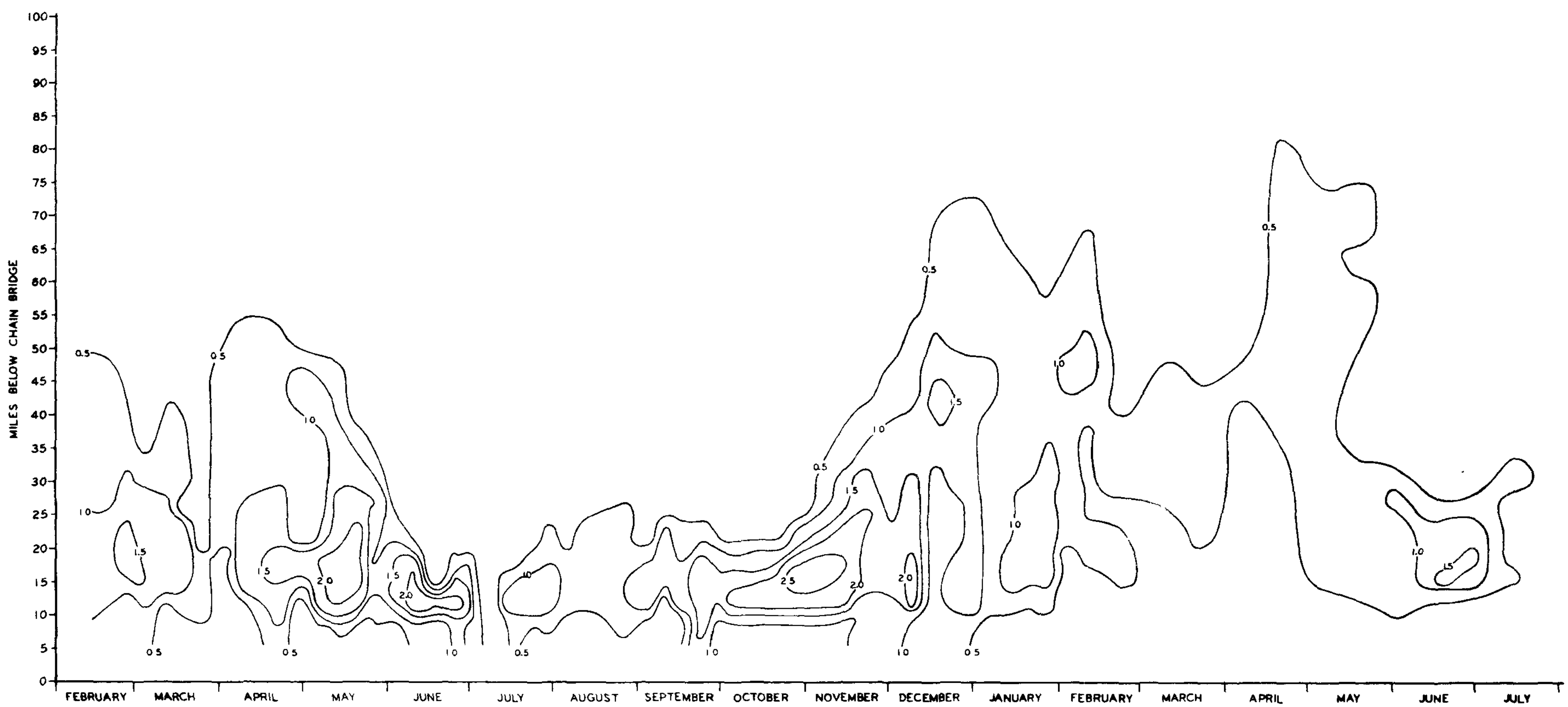


FIGURE VI-1

NITRITE + NITRATE NITROGEN ISOPLETH
POTOMAC ESTUARY
1969–1970 DATA

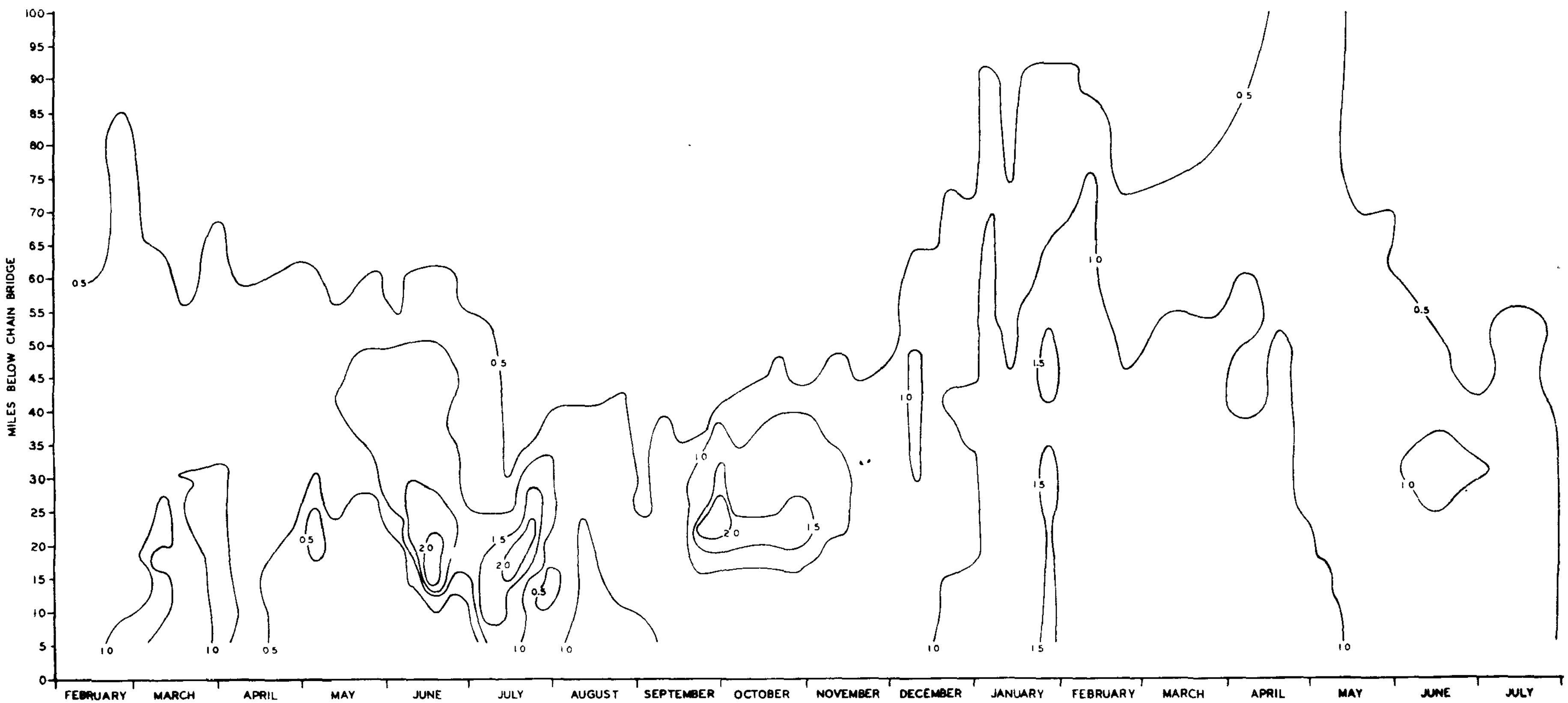


FIGURE VI-2

ORGANIC NITROGEN ISOPLETH

POTOMAC ESTUARY

1969–1970 DATA

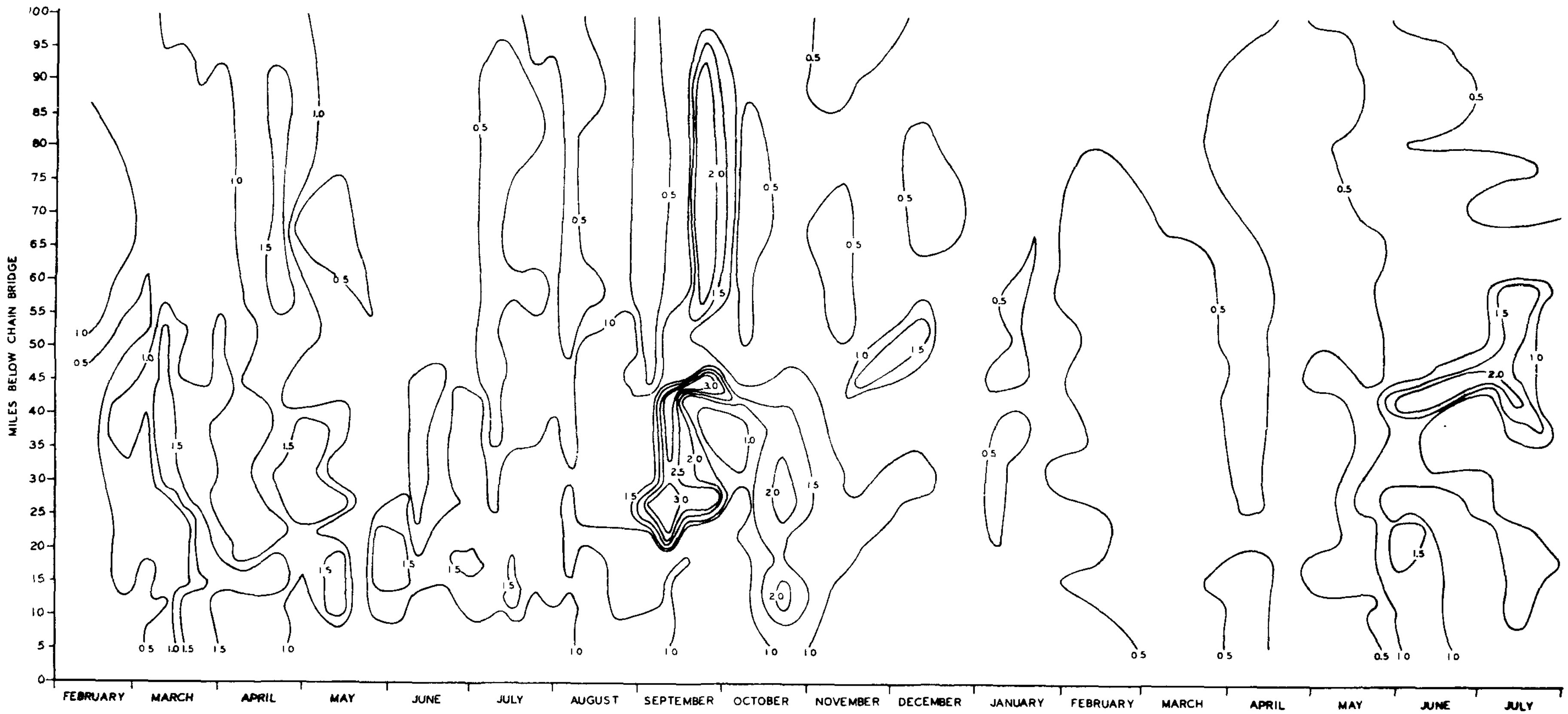


FIGURE VI-3

B. DETERMINATION OF REACTION RATES AND TEMPERATURE EFFECTS

1. Nitrification

The rate at which ammonia nitrogen (NH_3) is biochemically oxidized to nitrite and nitrate nitrogen (NO_2 + NO_3), commonly referred to as the nitrification rate, was determined for the Potomac Estuary by using the aforementioned version of DEM to simulate numerous observed conditions representing a variety of temperatures and freshwater inflows. The prototype behavior was established using intensive-type sampling data collected during relatively steady-state flow periods. These data indicated that ammonia was being rapidly depleted, especially when high temperatures prevailed, and that a subsequent increase in nitrate concentrations could be expected. Because of this and the fact that maximum depletion occurred upstream from the major algal blooms, it was apparent that nitrification, and not biological uptake by phytoplankton, was primarily responsible for the loss of ammonia.

Various reaction rates were inputted to the Dynamic Estuary Model until a reasonable simulation of each of the observed ammonia profiles was achieved. The final profiles obtained with the model along with the appropriate nitrification rates are shown in Figures VI-4 through VI-16. As can be seen in the figures, peak ammonia concentrations and spatial gradients were generally simulated satisfactorily.

In order to establish a relationship between nitrification rate and temperature, a regression analysis was performed utilizing the thirteen separate sets of data discussed above. The linear relationship resulting from this analysis is presented in Figure VI-17. At 20°C, the nitrification rate is 0.084/day (base e).

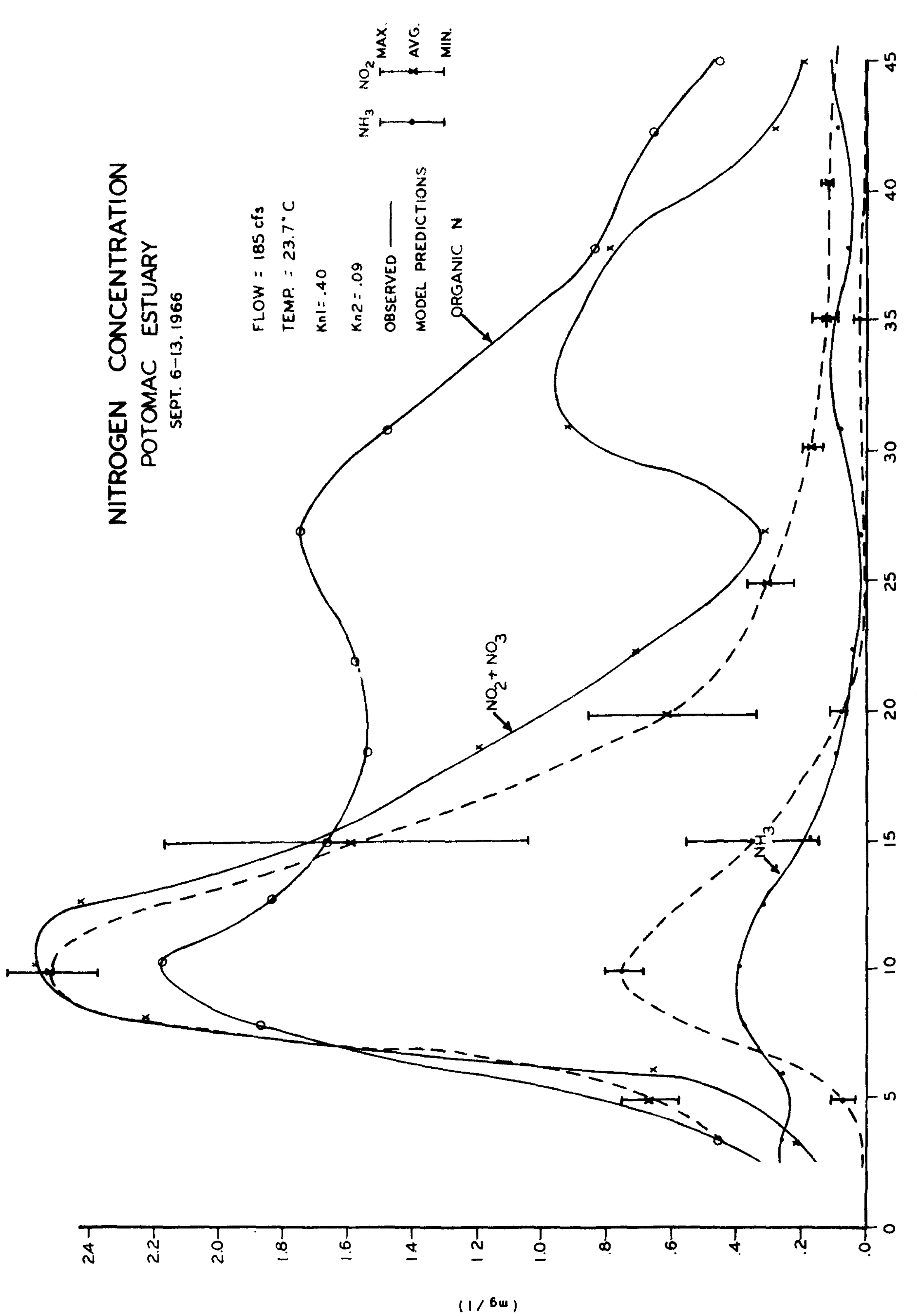
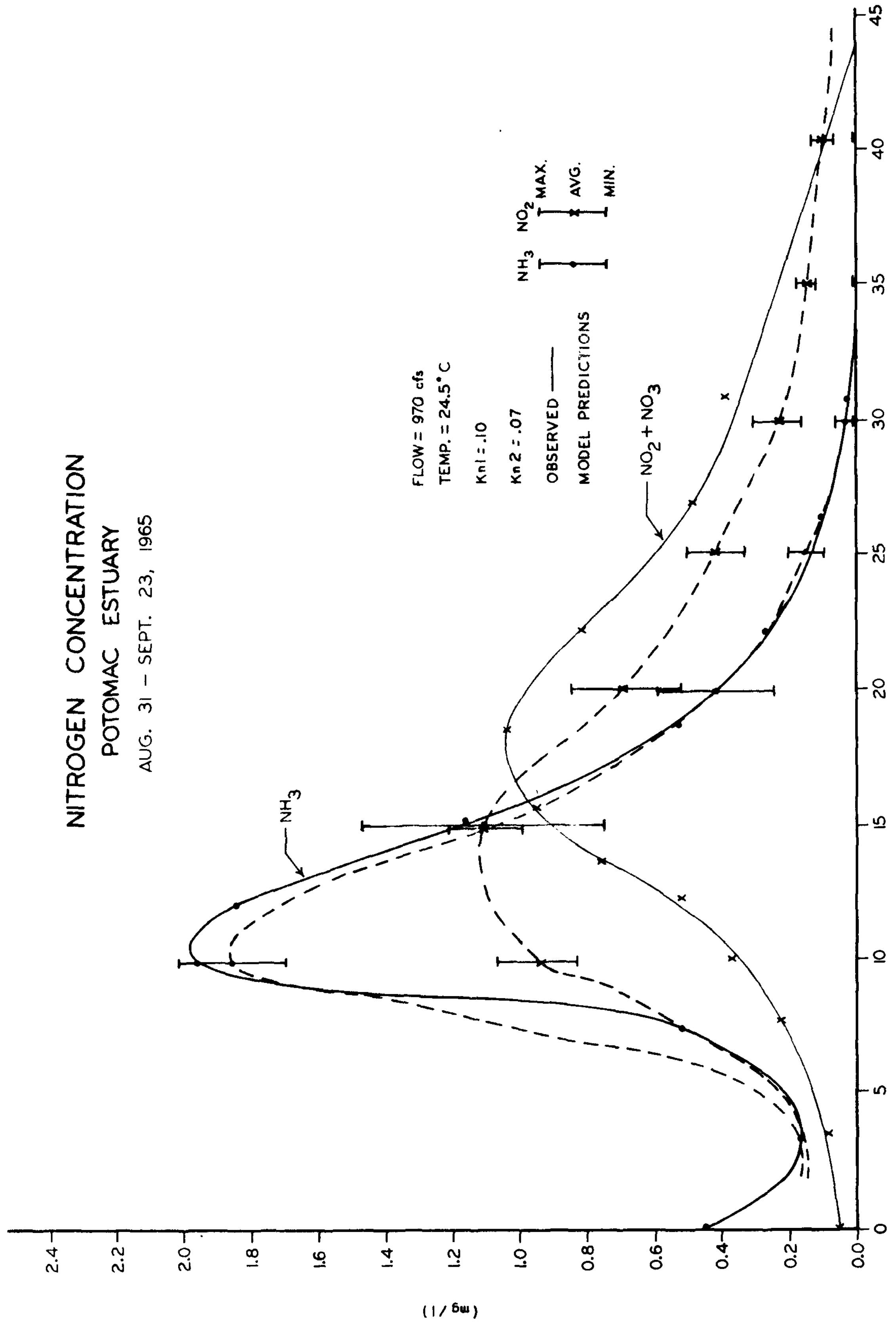
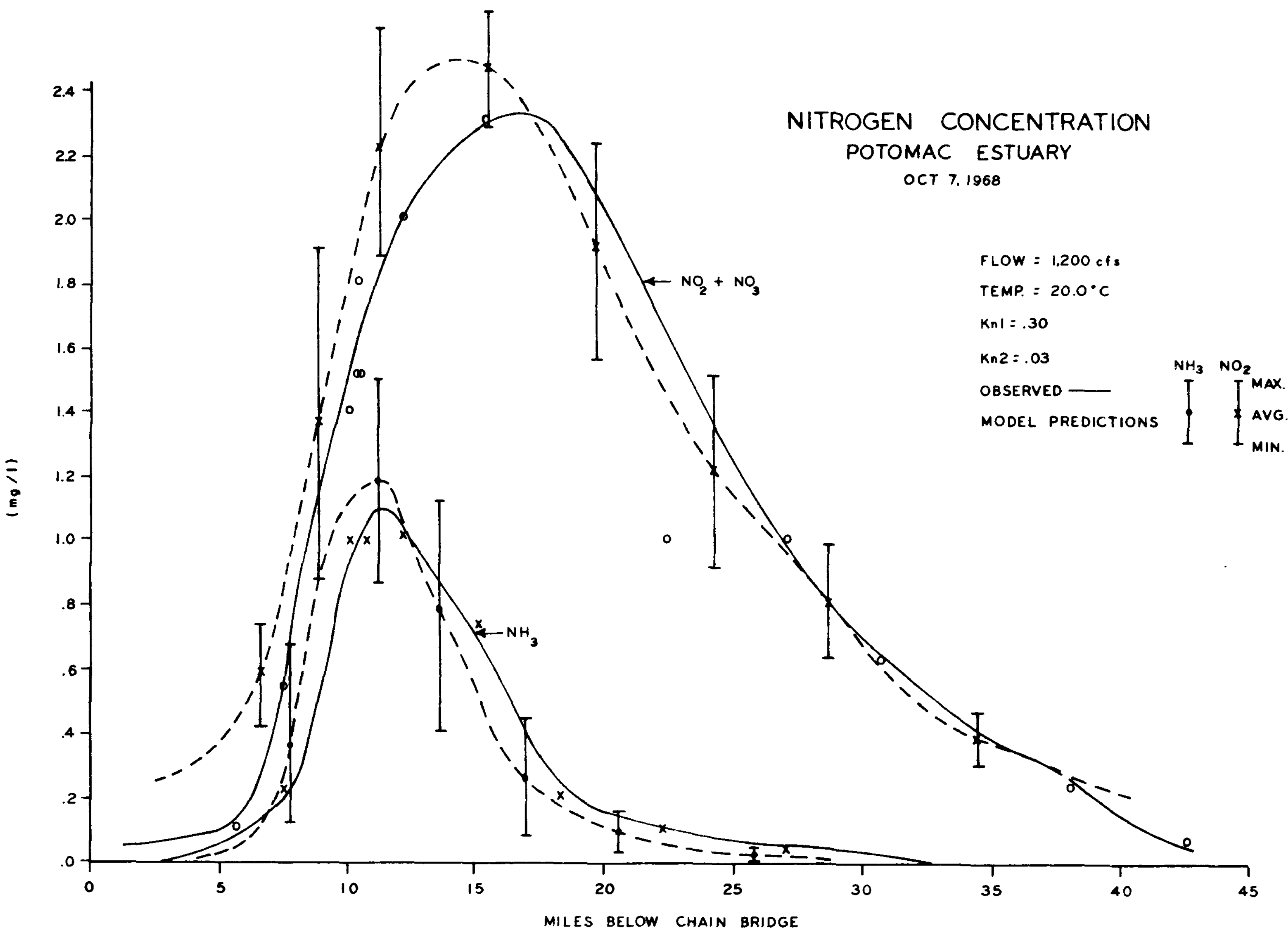

NITROGEN CONCENTRATION
POTOMAC ESTUARY
SEPT. 6-13, 1966
FLOW = 185 cfs
TEMP. = 23.7° C
Kn1 = .40
Kn2 = .09
OBSERVED
MODEL PREDICTIONS
ORGANIC N
$NO_2 + NO_3$
NH_3
NH_3 NO_2
MAX.
AVG.
MIN.
MILES BELOW CHAIN BRIDGE
(mg/l)
0
5
10
15
20
25
30
35
40
45
0.
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

FIGURE VI-4



NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUG. 31 – SEPT. 23, 1965
FLOW = 970 cfs
TEMP. = 24.5°C
Kn1 = .10
Kn2 = .07
OBSERVED
MODEL PREDICTIONS
NH3
NO2
MAX.
AVG.
MIN.
NH3
NO2 + NO3
(mg/l)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-5



NITROGEN CONCENTRATION
POTOMAC ESTUARY
OCT 7, 1968
FLOW = 1,200 cfs
TEMP. = 20.0°C
Kn1 = .30
Kn2 = .03
OBSERVED
MODEL PREDICTIONS
NH3
NO2
MAX.
AVG.
MIN.
NO2 + NO3
NH3
(mg/l)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-6

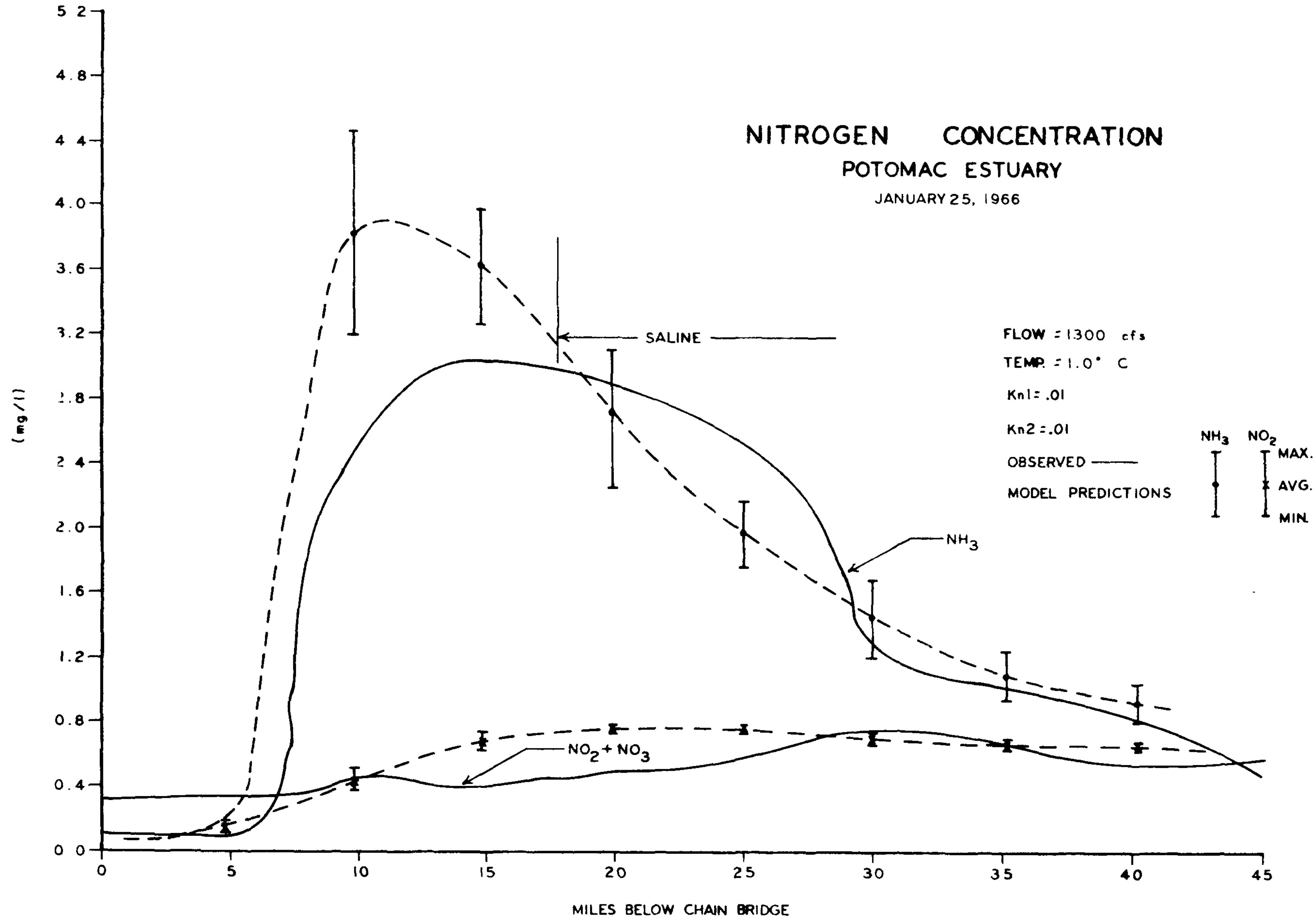
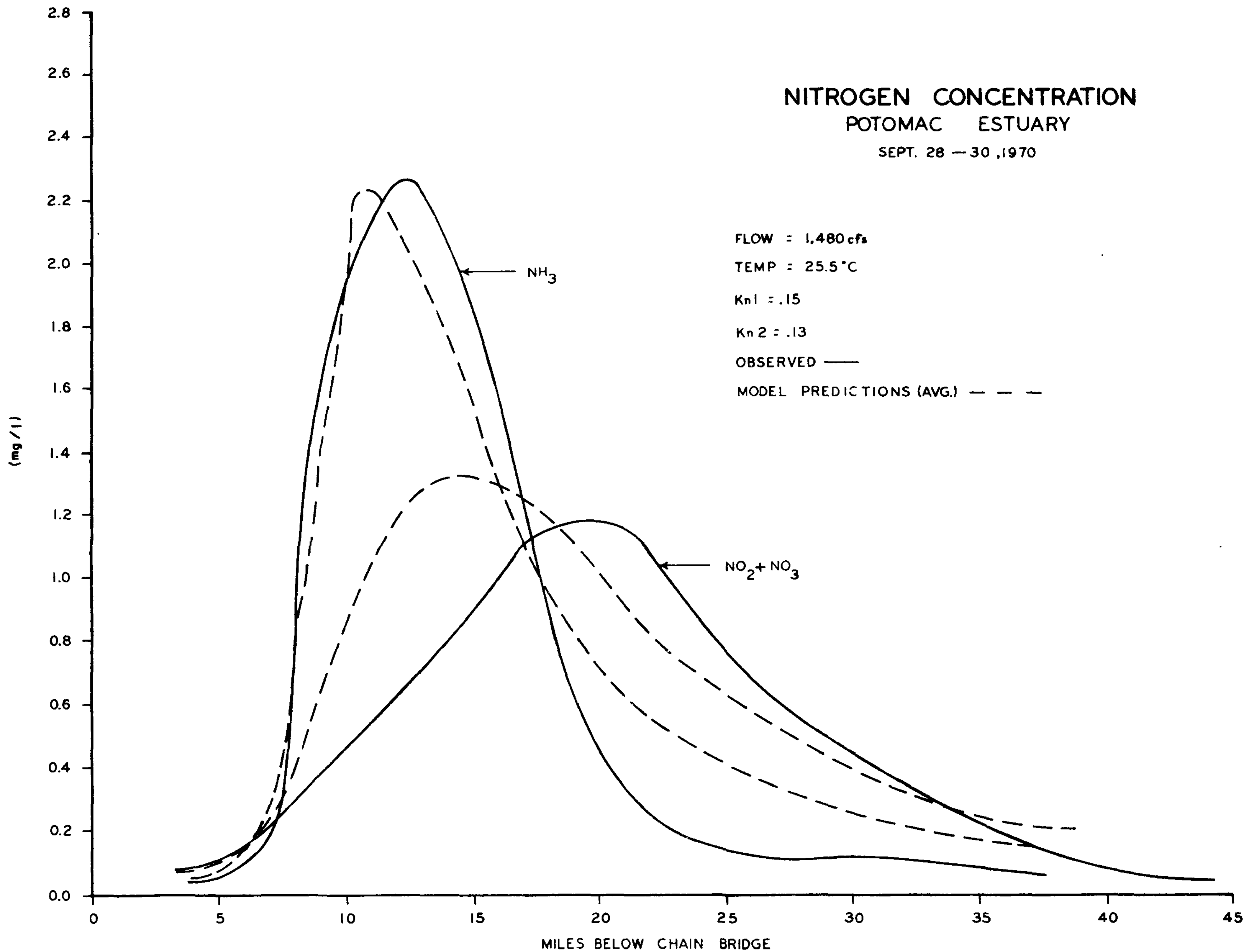

NITROGEN CONCENTRATION
POTOMAC ESTUARY
JANUARY 25, 1966
FLOW = 1300 cfs
TEMP. = 1.0° C
Kn1 = .01
Kn2 = .01
OBSERVED
MODEL PREDICTIONS
NH3
NO2
MAX.
AVG.
MIN.
SALINE
NH3
NO2 + NO3
(mg/l)
MILES BELOW CHAIN BRIDGE
0
5
10
15
20
25
30
35
40
45
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2

FIGURE VI-7



NITROGEN CONCENTRATION
POTOMAC ESTUARY
SEPT. 28 — 30, 1970
FLOW = 1,480 cfs
TEMP = 25.5°C
Kn1 = .15
Kn2 = .13
OBSERVED ——
MODEL PREDICTIONS (AVG.) — — —
NH3
NO2+NO3
(mg/l)
MILES BELOW CHAIN BRIDGE

FIGURE VI-8

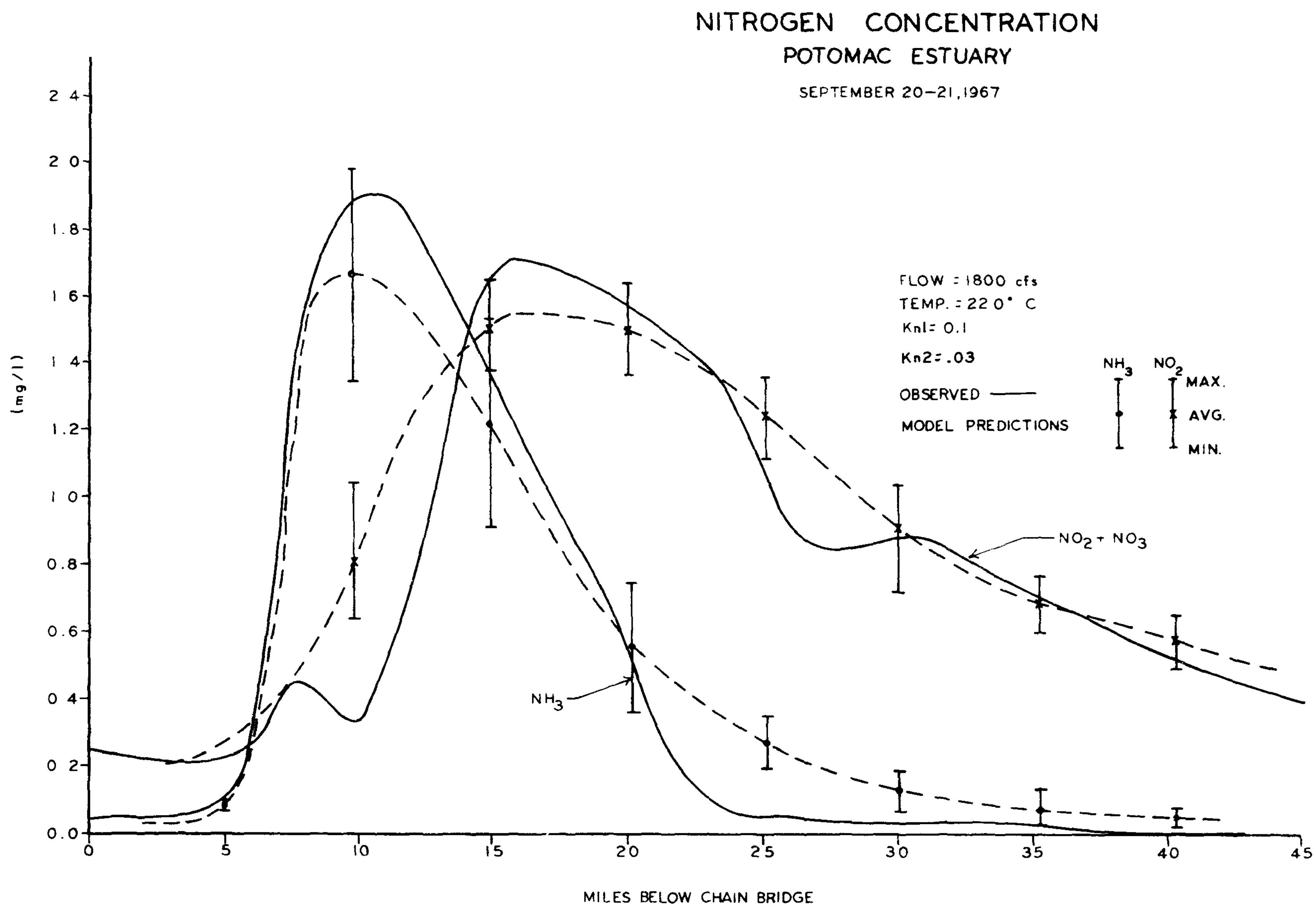

NITROGEN CONCENTRATION
POTOMAC ESTUARY
SEPTEMBER 20–21, 1967
FLOW = 1800 cfs
TEMP. = 22.0° C
Kn1 = 0.1
Kn2 = .03
OBSERVED
MODEL PREDICTIONS
NH3
NO2
MAX.
AVG.
MIN.
NO2 + NO3
NH3
(mg/l)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.4
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-9

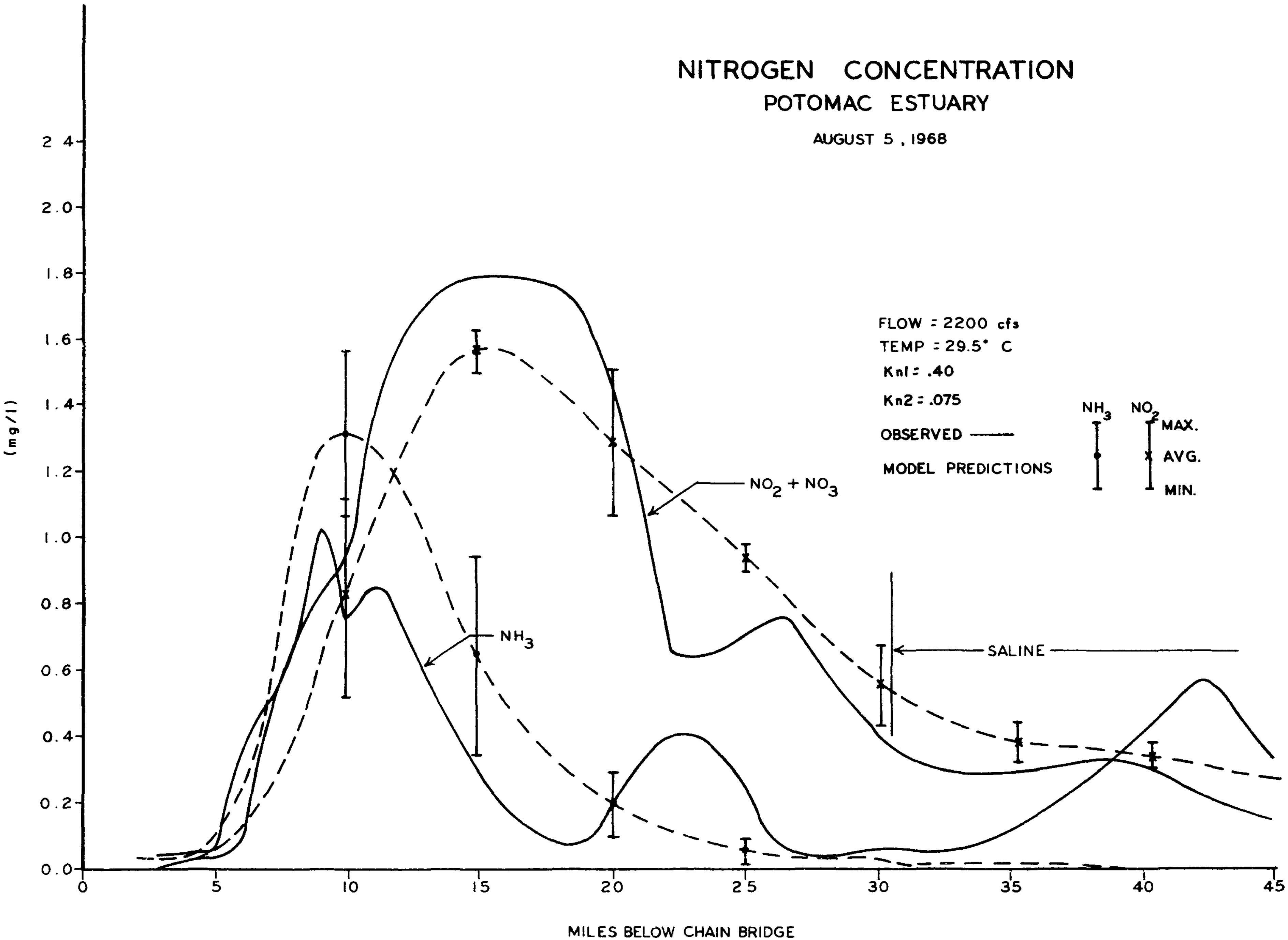

NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUGUST 5, 1968
FLOW = 2200 cfs
TEMP = 29.5° C
Kn1 = .40
Kn2 = .075
OBSERVED
MODEL PREDICTIONS
NH_3
NO_2
MAX.
AVG.
MIN.
$NO_2 + NO_3$
NH_3
SALINE
(mg/l)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2 4
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-10

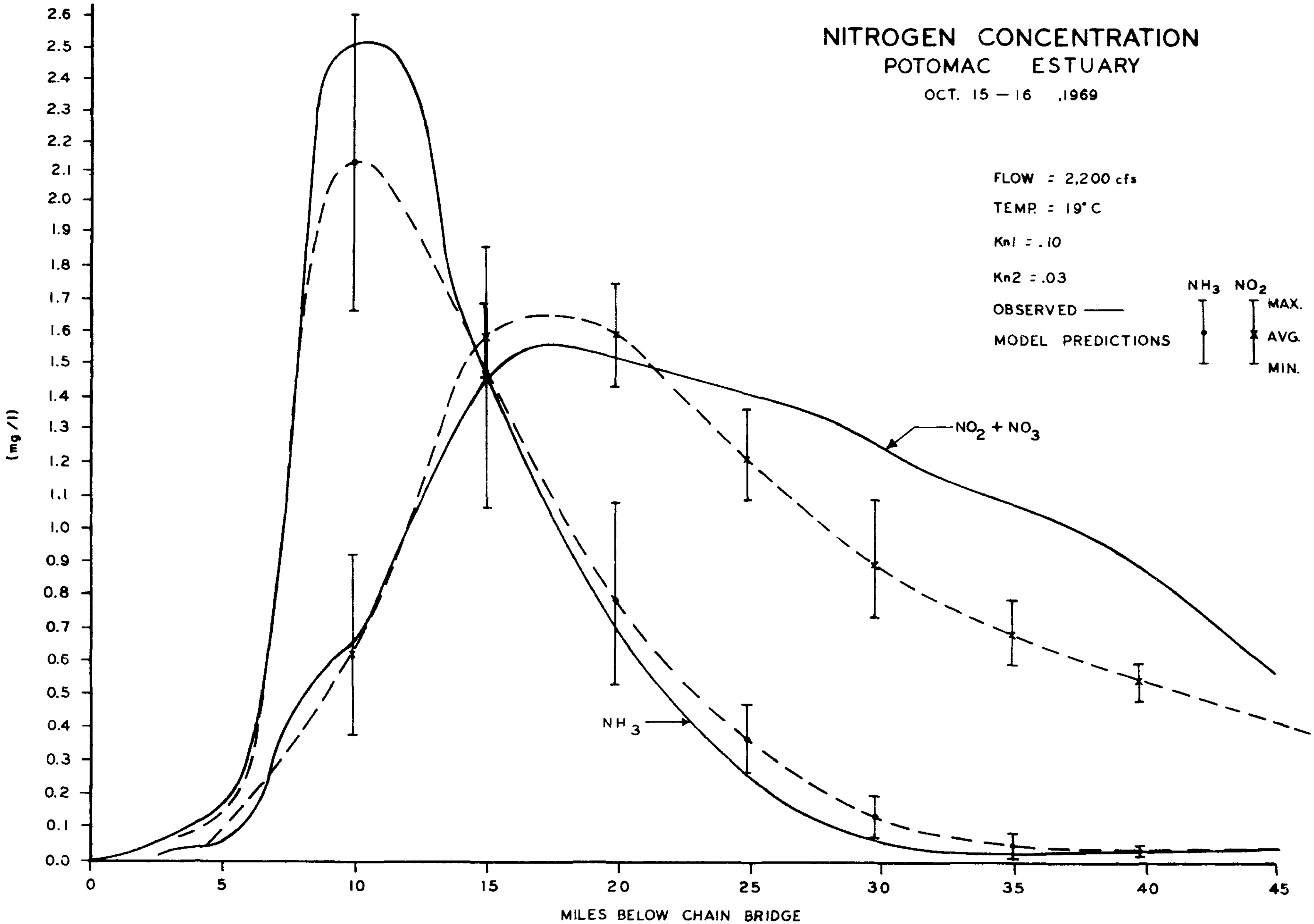

NITROGEN CONCENTRATION
POTOMAC ESTUARY
OCT. 15 – 16 ,1969
FLOW = 2,200 cfs
TEMP. = 19°C
Kn1 = .10
Kn2 = .03
OBSERVED ——
MODEL PREDICTIONS
NH3 NO2
MAX.
AVG.
MIN.
NO2 + NO3
NH3
(mg/l)
MILES BELOW CHAIN BRIDGE

FIGURE VI-11

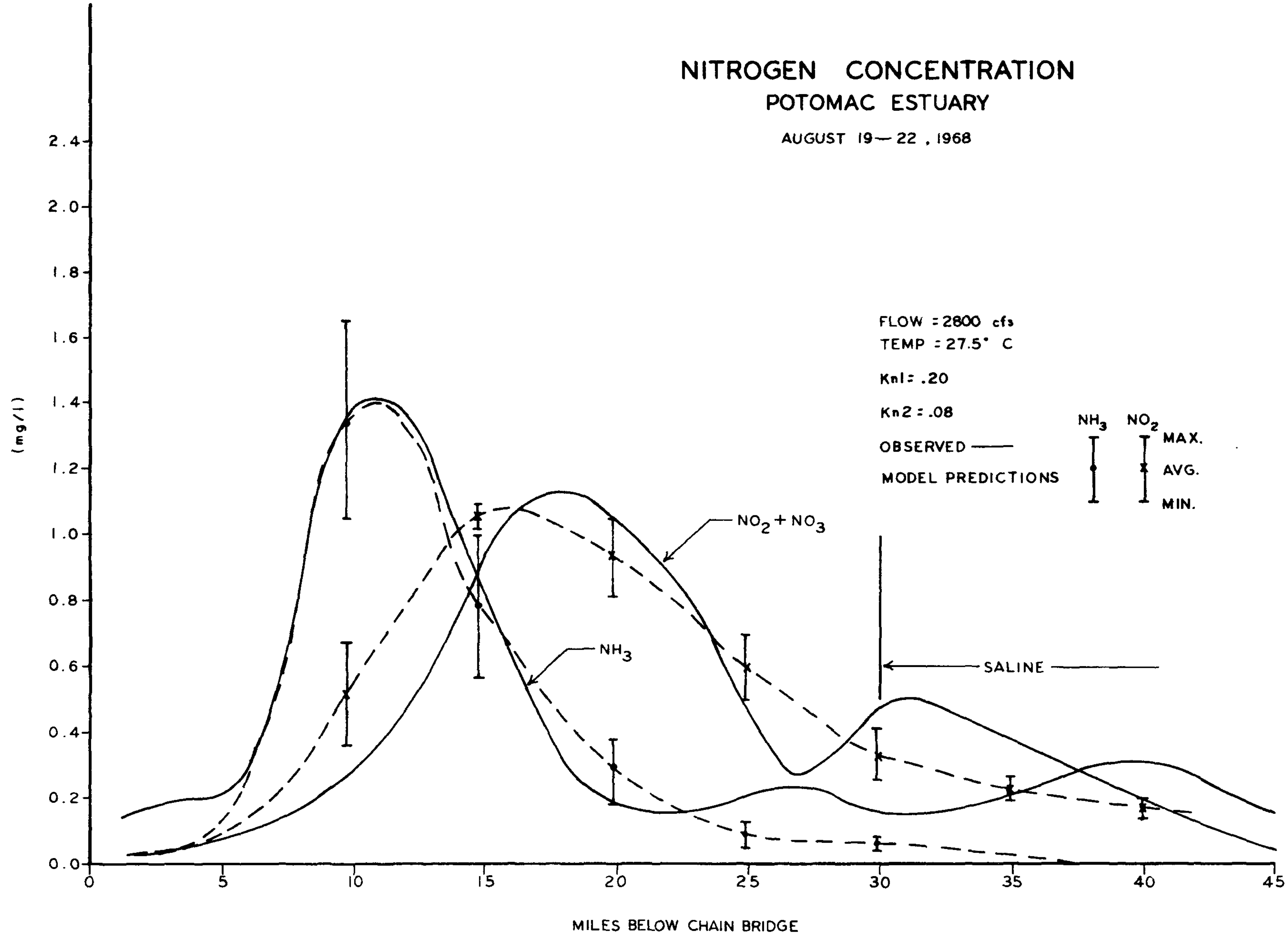

NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUGUST 19—22, 1968
FLOW = 2800 cfs
TEMP = 27.5° C
Kn1 = .20
Kn2 = .08
OBSERVED ——
MODEL PREDICTIONS - - -
NH3 NO2
MAX.
AVG.
MIN.
NO2 + NO3
NH3
SALINE
(mg/l)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.4
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-12

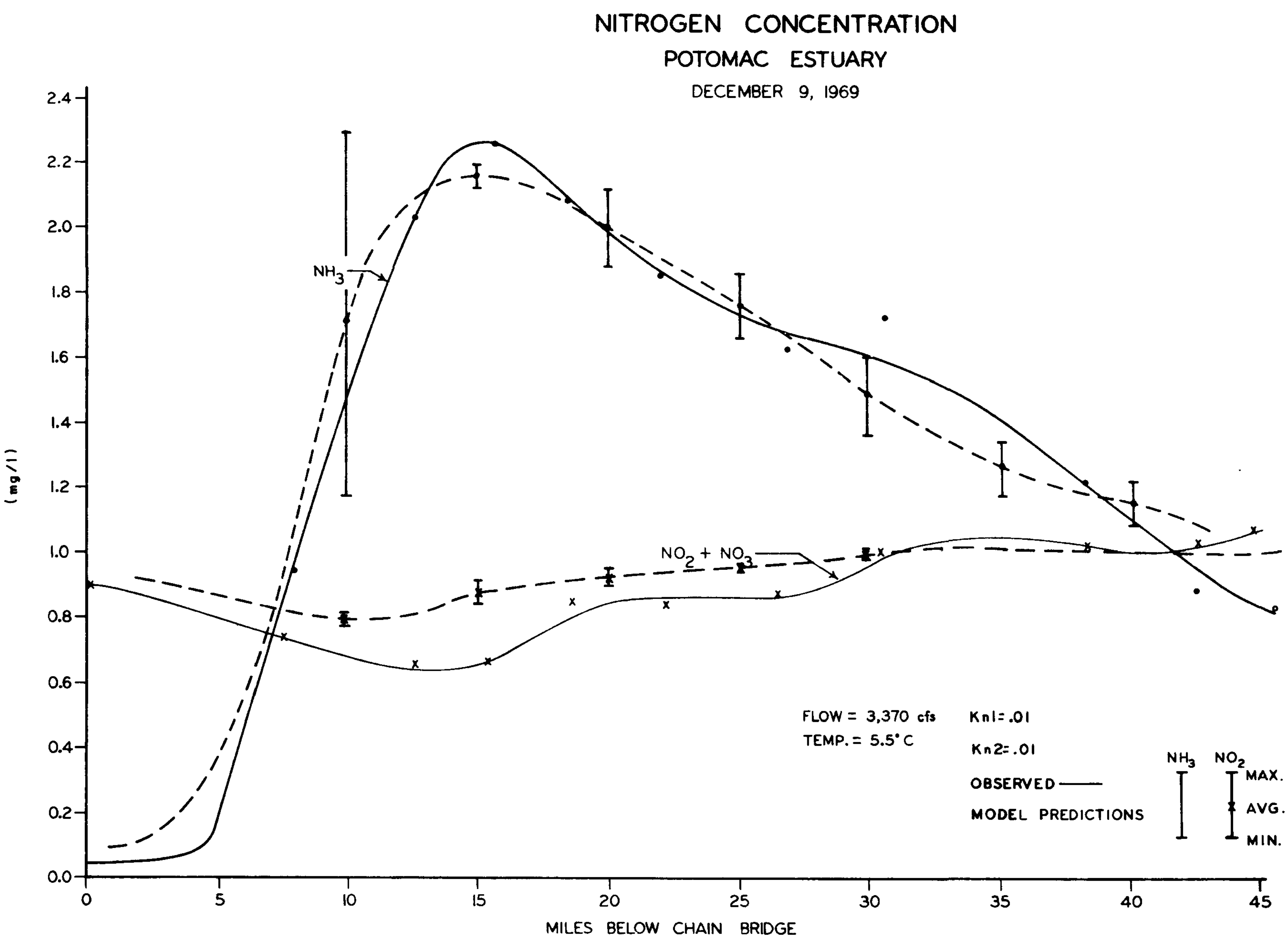

NITROGEN CONCENTRATION
POTOMAC ESTUARY
DECEMBER 9, 1969
(mg/l)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE
NH3
NO2 + NO3
FLOW = 3,370 cfs
TEMP. = 5.5°C
Kn1=.01
Kn2=.01
OBSERVED
MODEL PREDICTIONS
NH3
NO2
MAX.
AVG.
MIN.

FIGURE VI-13

NITROGEN CONCENTRATION
POTOMAC ESTUARY
NOVEMBER 24, 1969

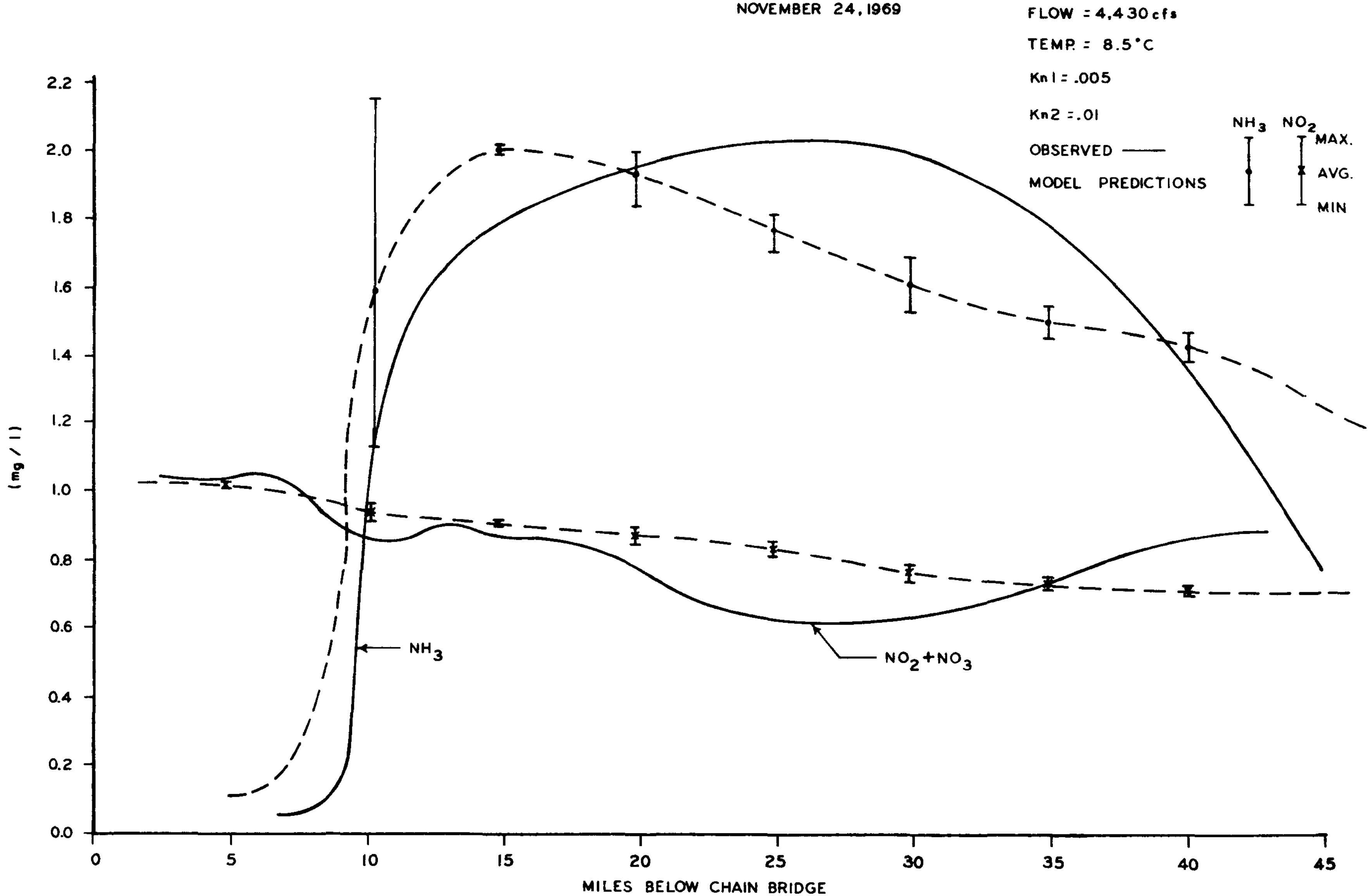


FIGURE VI-14

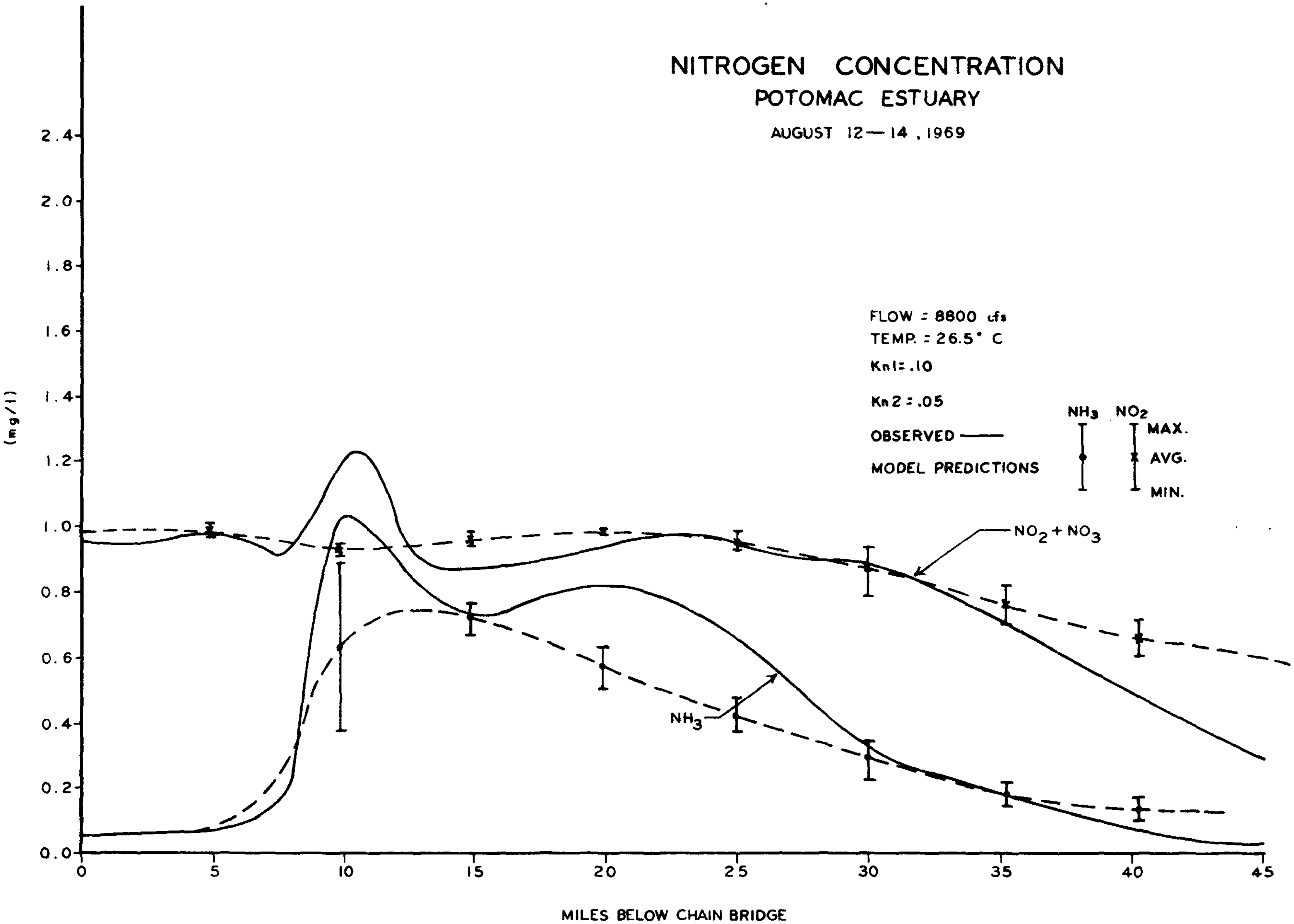

NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUGUST 12—14, 1969
FLOW = 8800 cfs
TEMP. = 26.5° C
Kn1 = .10
Kn2 = .05
OBSERVED
MODEL PREDICTIONS
NH_3
NO_2
MAX.
AVG.
MIN.
$NO_2 + NO_3$
NH_3
(mg/l)
2.4
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-15

NITROGEN CONCENTRATION
POTOMAC ESTUARY
APRIL 21, 1966

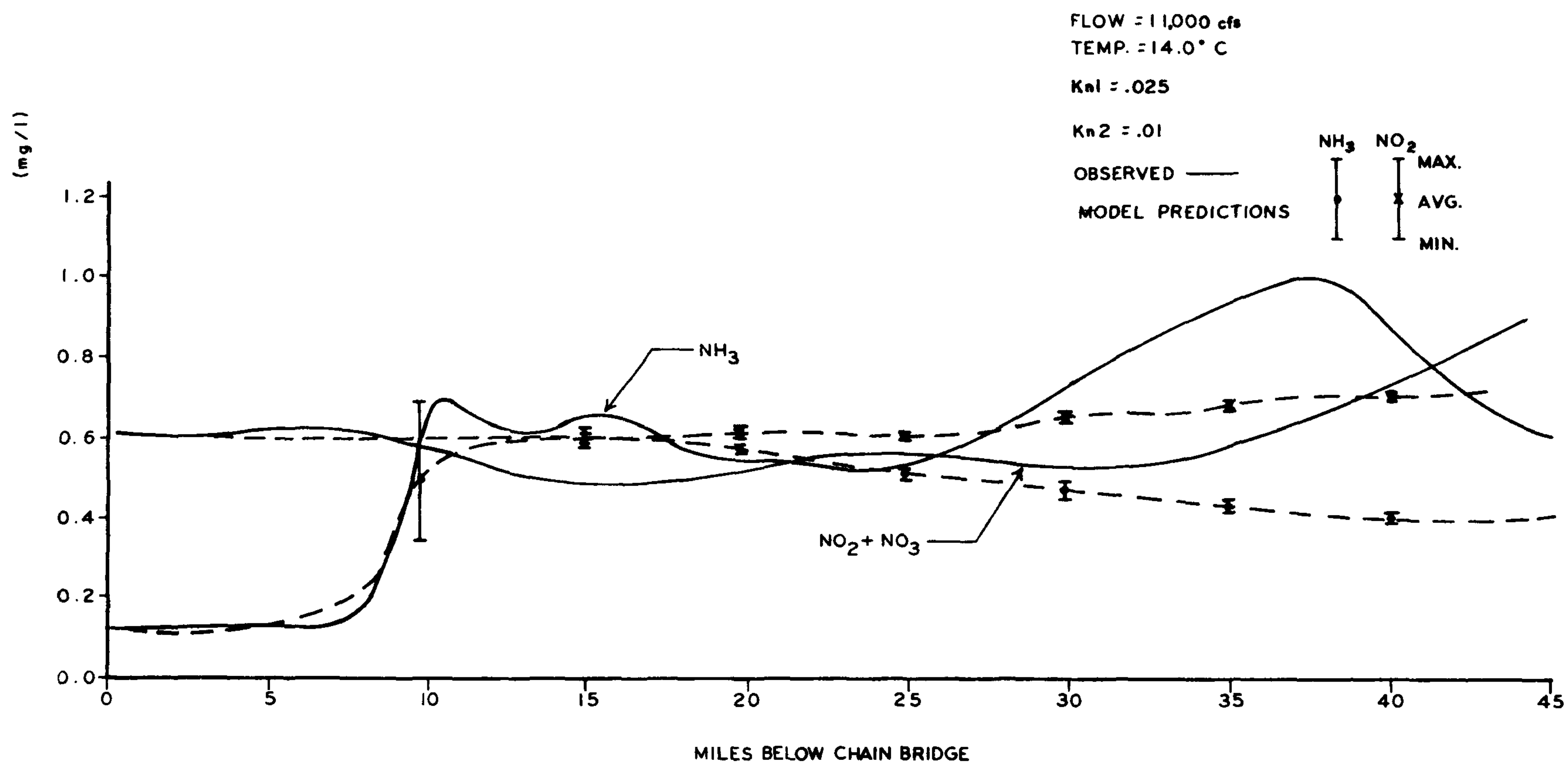


FIGURE VI-16

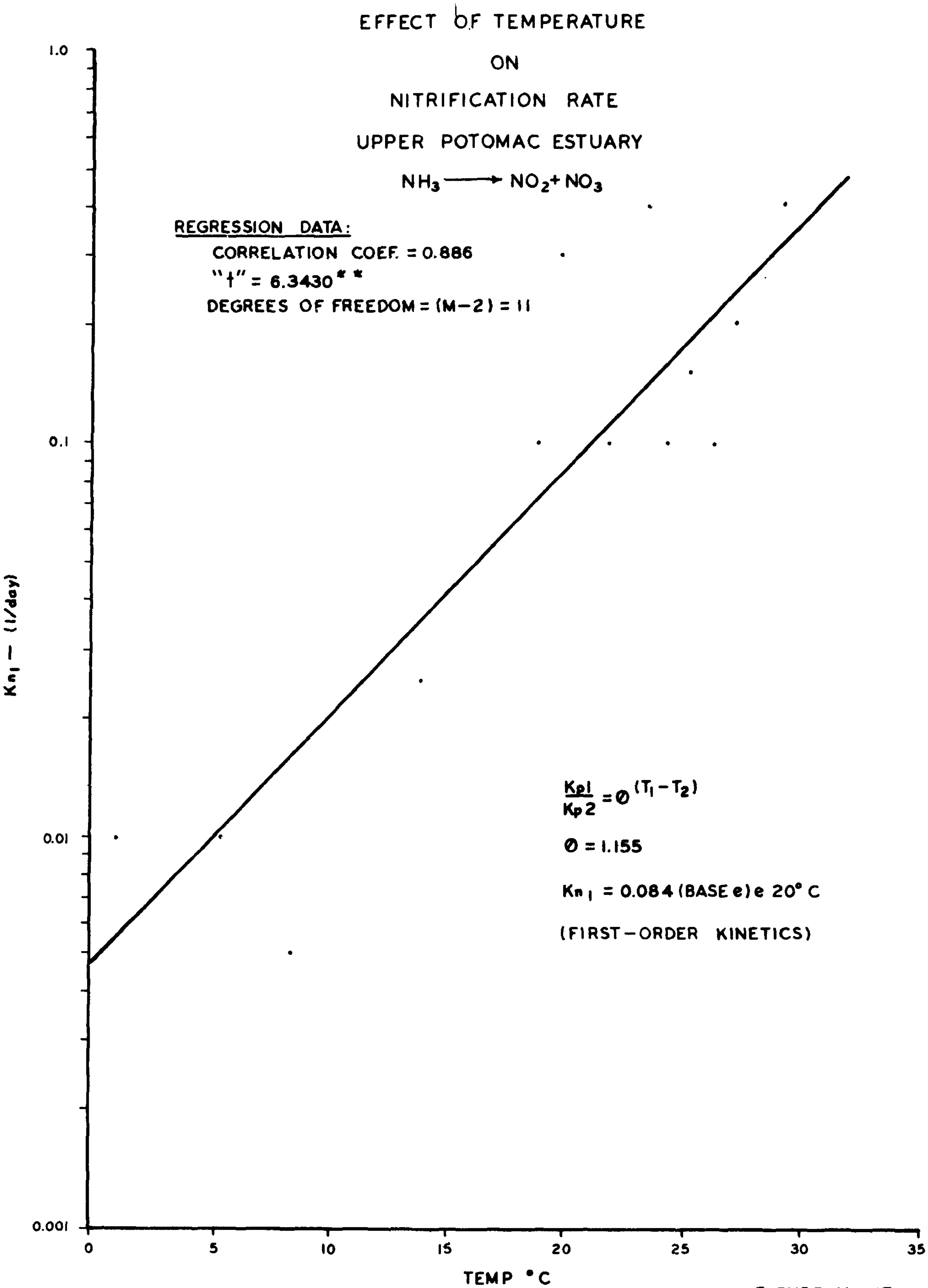

EFFECT OF TEMPERATURE
ON
NITRIFICATION RATE
UPPER POTOMAC ESTUARY
NH3 → NO2 + NO3
REGRESSION DATA:
CORRELATION COEF. = 0.886
"t" = 6.3430**
DEGREES OF FREEDOM = (M-2) = 11
Kp1/Kp2 = Ø^(T1-T2)
Ø = 1.155
Kn1 = 0.084 (BASE e) e 20° C
(FIRST-ORDER KINETICS)
Kn1 — (1/day)
1.0
0.1
0.01
0.001
0
5
10
15
20
25
30
35
TEMP °C

FIGURE VI-17

2. Algal Uptake

The predicted formation of nitrate nitrogen by the nitrification process was found to be quite high when compared with actual sampling data. It was, therefore, necessary to apply a decay mechanism to account for the nitrate uptake by phytoplankton and effect a better comparison. The appropriate reaction rates were determined utilizing the mathematical model and a trial and error approach similar to the one described for nitrification in the preceding section.

Figures VI-4 through VI-16 show observed and predicted nitrate profiles for the upper Potomac Estuary at different temperature and flow conditions. Also shown are the algal uptake rates used in the model. The figures indicate that reasonable agreement between prototype and model data was obtained.

The effect of temperature on the rates of algal nitrogen utilization is presented in Figure VI-18. A regression analysis was performed on the data and the results are statistically valid. At 20°C, the rate of nitrogen uptake by algae is 0.037/day (base e).

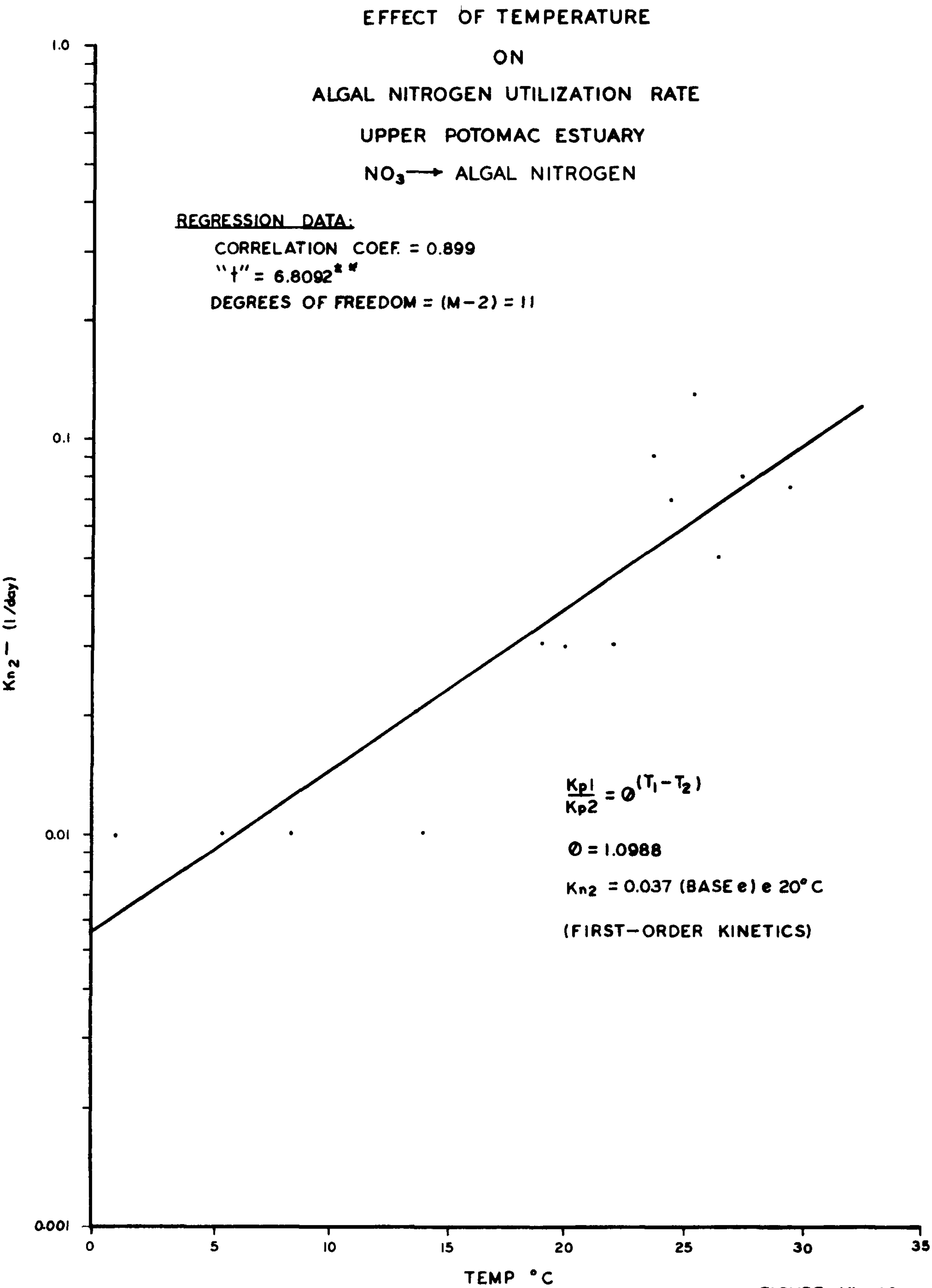

EFFECT OF TEMPERATURE
ON
ALGAL NITROGEN UTILIZATION RATE
UPPER POTOMAC ESTUARY
NO3 → ALGAL NITROGEN
REGRESSION DATA:
CORRELATION COEF. = 0.899
"t" = 6.8092**
DEGREES OF FREEDOM = (M-2) = 11
Kp1/Kp2 = Ø^(T1-T2)
Ø = 1.0988
Kn2 = 0.037 (BASE e) @ 20° C
(FIRST-ORDER KINETICS)
Kn2 - (1/day)
1.0
0.1
0.01
0.001
0
5
10
15
20
25
30
35
TEMP °C

FIGURE VI - 18

C. SIMULATION OF NITROGEN TRANSPORT THROUGH AN ANNUAL CYCLE

The two primary reactions involving nitrogen, i.e. nitrification and algal uptake of inorganic nitrogen, were incorporated in the DECS III version of the Thomann Model to simulate nitrogen transport in the Potomac Estuary throughout an annual cycle. Observed data collected weekly from February 1969 to July 1970 was used for comparison purposes and model verification.

The reaction rates and temperature effects developed from the preceding nitrogen verification runs were used in the model with certain modifications. These modifications generally consisted of reducing the nitrification rates to reflect (1) low DO concentrations and (2) high freshwater inflows. The former would inhibit biological oxidation by the aerobic nitrifying bacteria and the latter would cause a flushing action resulting in a lag time for repopulation of the nitrifiers which must be anticipated. In the case of biological uptake rates, a downward attenuation was performed when and where algal standing crop levels were believed to be abnormally low.

Observed and predicted nitrogen profiles (both ammonia and nitrate nitrogen) are presented in Figures VI-19 to VI-23 for five different sampling stations in the Potomac Estuary. An examination of the data indicates that the basic seasonal and spatial distributions were simulated surprisingly well. In view of limitations in observed data and simplification in the model itself, a closer agreement, especially in short-term fluctuations, was not really expected.

ANNUAL NITROGEN PROFILES
POTOMAC ESTUARY AT HAINS POINT
1969 – 1970

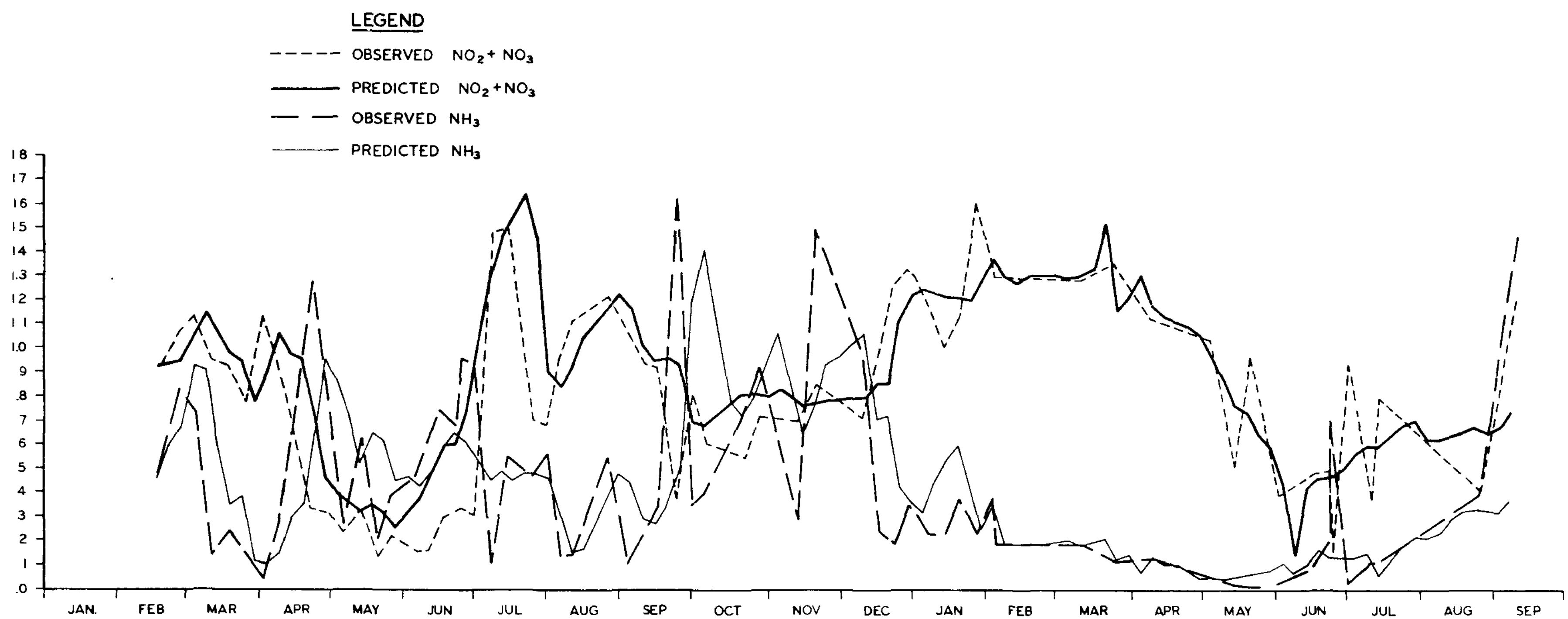


FIGURE VI – 19

ANNUAL NITROGEN PROFILES
POTOMAC ESTUARY AT PISCATAWAY CREEK
1969 – 1970

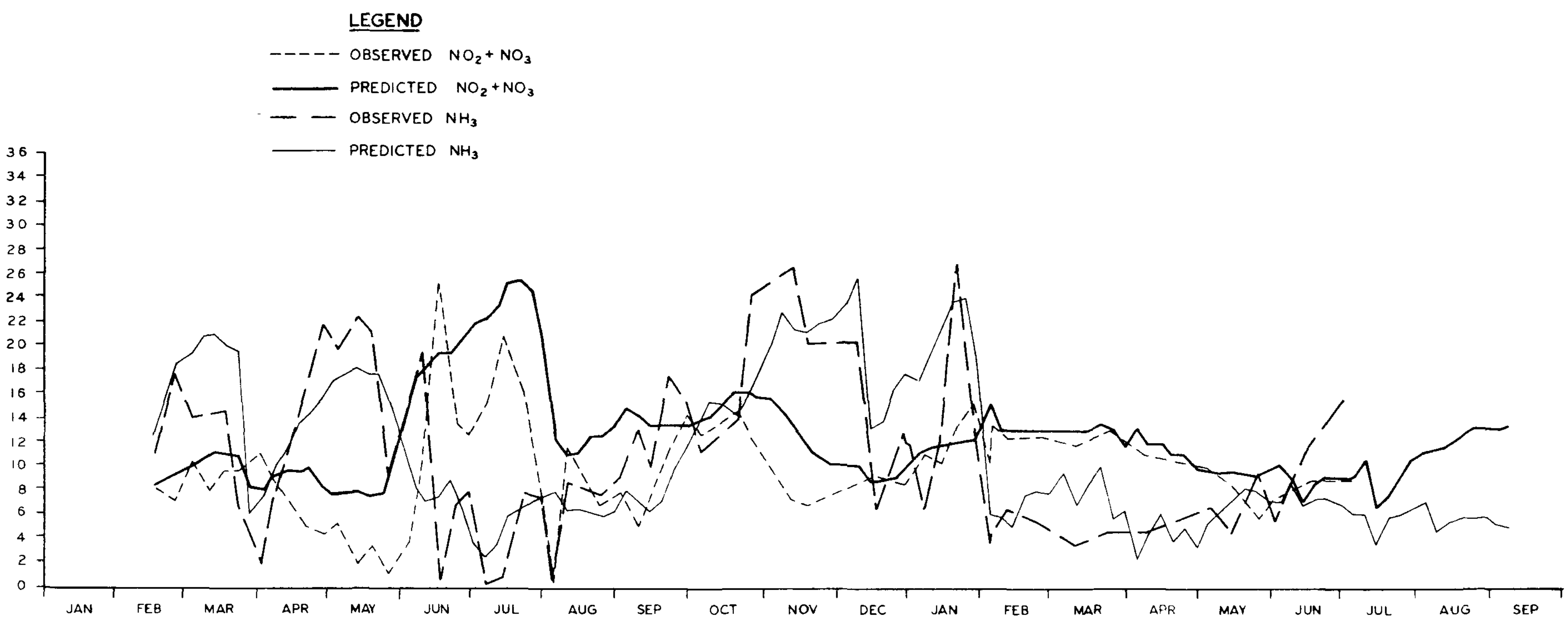


FIGURE VI – 20

ANNUAL NITROGEN PROFILES
POTOMAC ESTUARY AT INDIAN HEAD
1969 – 1970

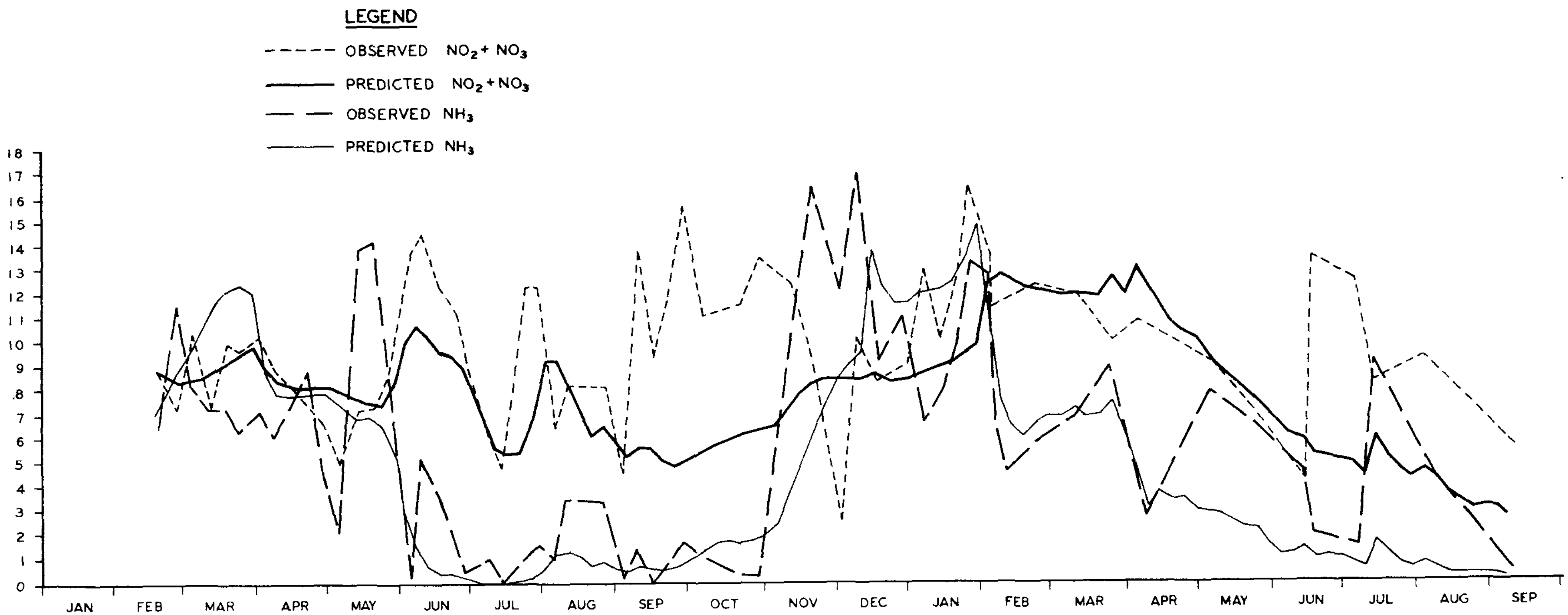


FIGURE VI-21

ANNUAL NITROGEN PROFILES
POTOMAC ESTUARY AT MARYLAND POINT
1969 – 1970

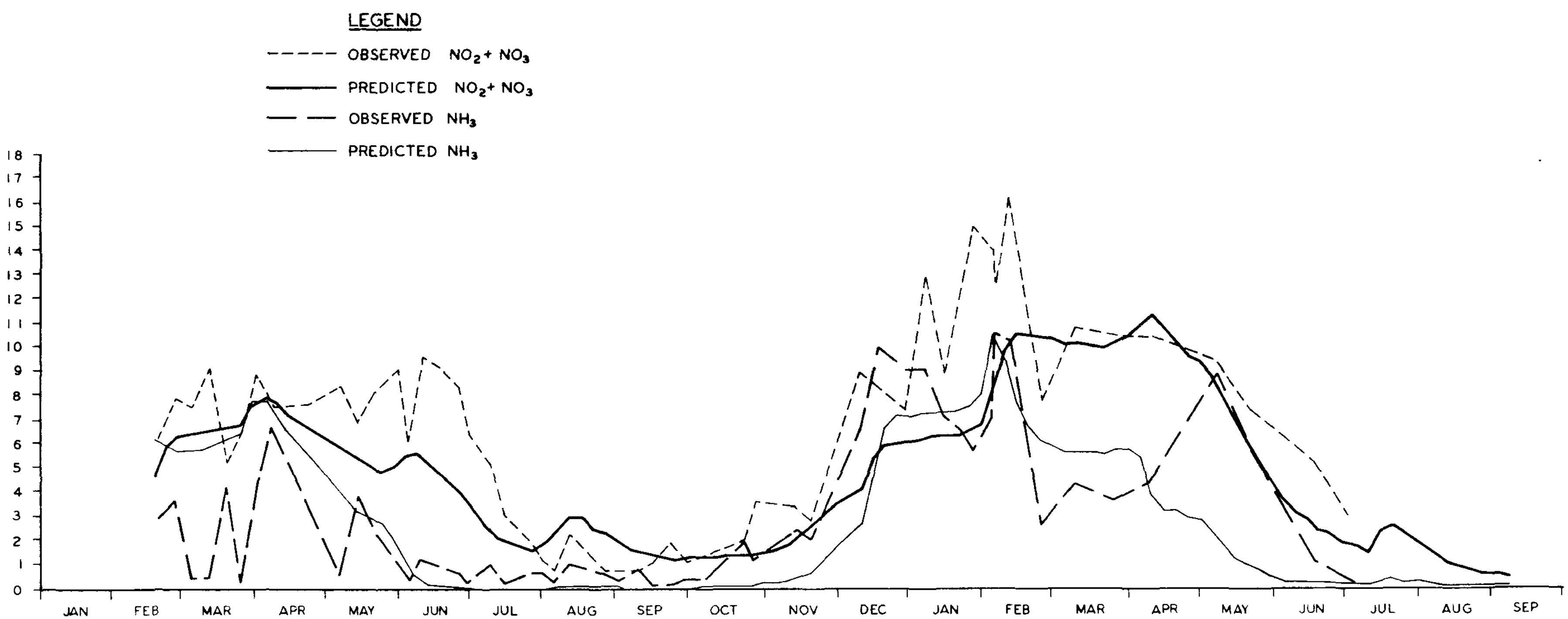


FIGURE VI – 22

ANNUAL NITROGEN PROFILES
POTOMAC ESTUARY AT PINEY POINT
1969 – 1970

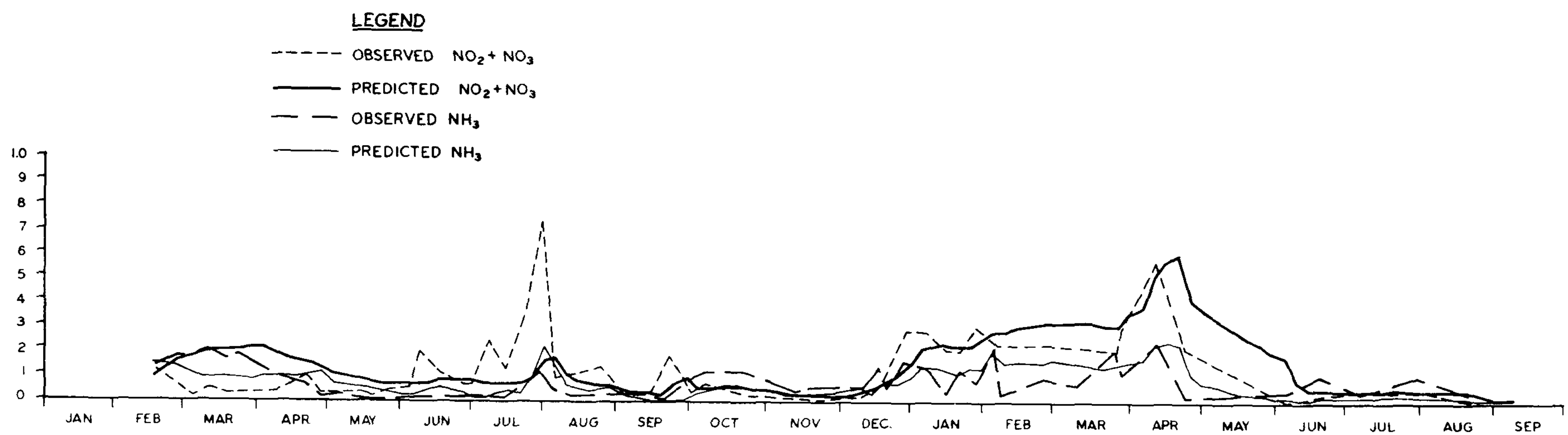


FIGURE VI – 23

D. CHLOROPHYLL PREDICTIONS BASED ON NITROGEN ASSIMILATION BY THE BIOMASS

Subsequent to application of the Dynamic Estuary Model for determining reaction rates involving nitrogen in the Potomac Estuary, the next logical step pursued was to mathematically "link" the nitrogen cycle with algal production. The purpose of extending the DEM in this manner was essentially twofold: (1) to determine whether nitrogen was indeed the growth-rate-limiting nutrient in the middle estuary as indicated by other methods of analysis and (2) to establish permissible nitrogen concentrations and loadings for the maintenance of a balanced ecological system.

In order to simulate the standing crop of algae as measured by chlorophyll a, the DEM was modified to convert losses of nitrate nitrogen to algal biomass. As indicated previously, it appeared that biological assimilation of ammonia nitrogen was minimal since nitrification occurring upstream from bloom areas reduced its availability during high temperature periods. The mass conversion factor was estimated, from 1970 algal composition analysis data, to be 90.0. This inferred that a 1.0 mg loss of nitrate would create a chlorophyll a mass of 90 μg. Practically complete utilization of nitrogen by the algal cells was assumed.

Figures VI-24 through VI-31 present observed and predicted chlorophyll a profiles for the upper 40 miles of the Potomac Estuary based on the "surrogate" version of the DEM. Also shown are the flows, temperatures, and decay rates for which these data apply. From these mathematical model runs, it appears that the standing crop of algae, as measured by chlorophyll a, can be predicted using the nitrogen cycle, and that the availability of nitrogen may be the factor controlling algal growth in the critical area of the Potomac Estuary.

To achieve a satisfactory comparison between the observed and predicted chlorophyll data shown in Figures VI-24 to VI-31, it was necessary to incorporate a decay rate in the model ranging from about 0.01 to 0.07/day. This decay probably represents death and/or deposition of the algal cells. The decay rates needed for the various model runs did not appear to be closely related to temperature or the quantity of algae in the system.

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
SEPT. 6 – 9, 1966

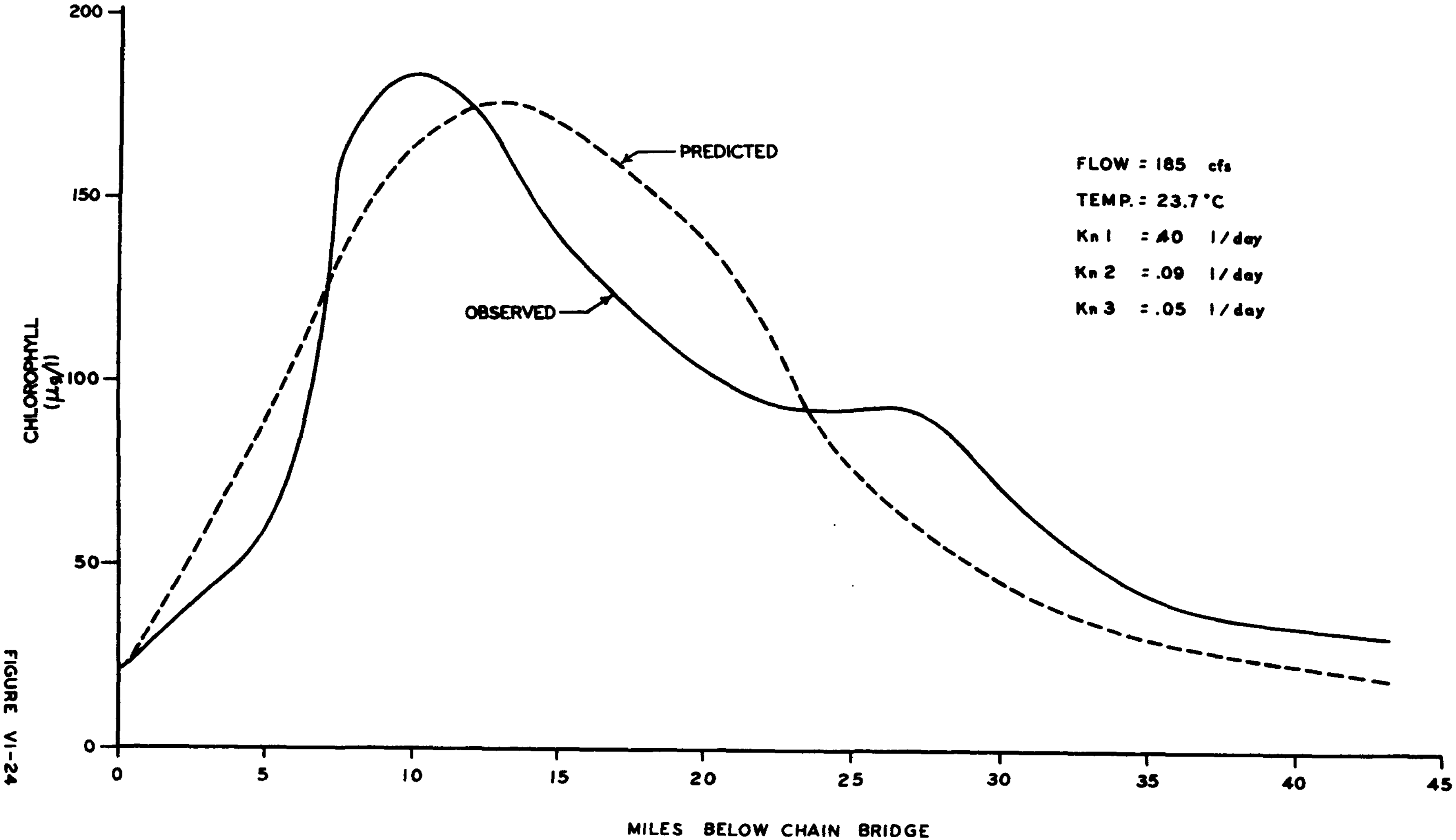


FIGURE VI-24

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
OCT 7, 1968

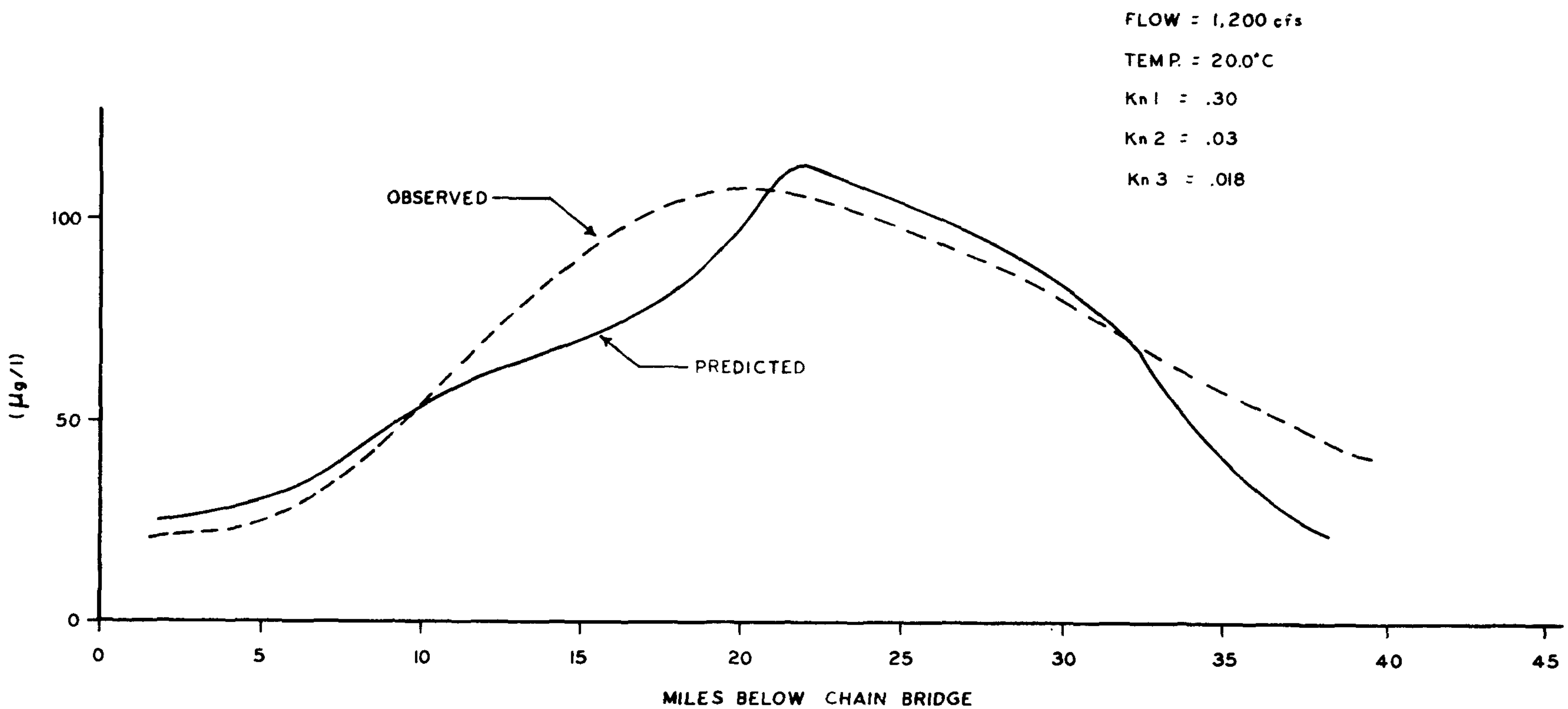


FIGURE VI-25

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
SEPT 28 — 30, 1970

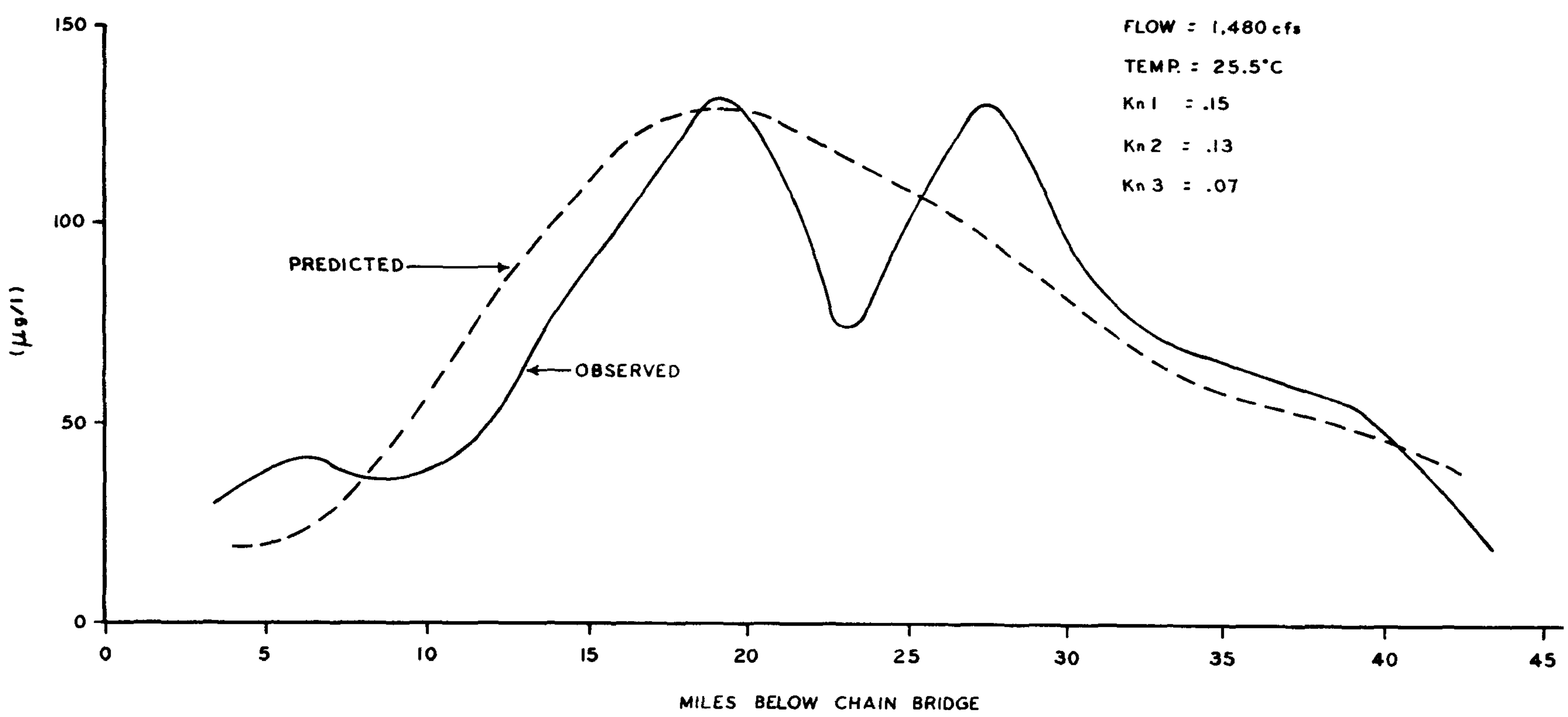


FIGURE VI-26

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
SEPT. 20 – 21, 1967

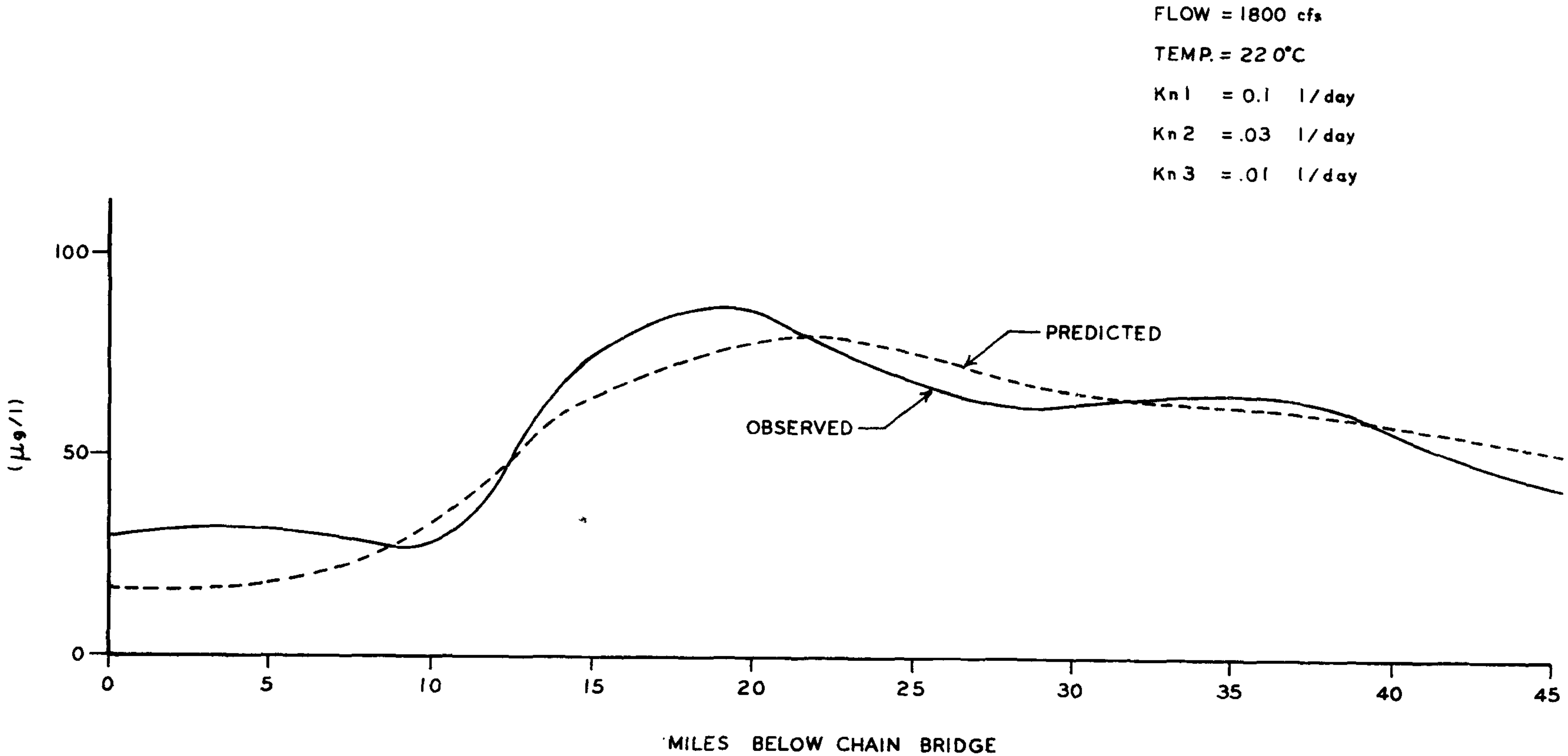


FIGURE VI – 27

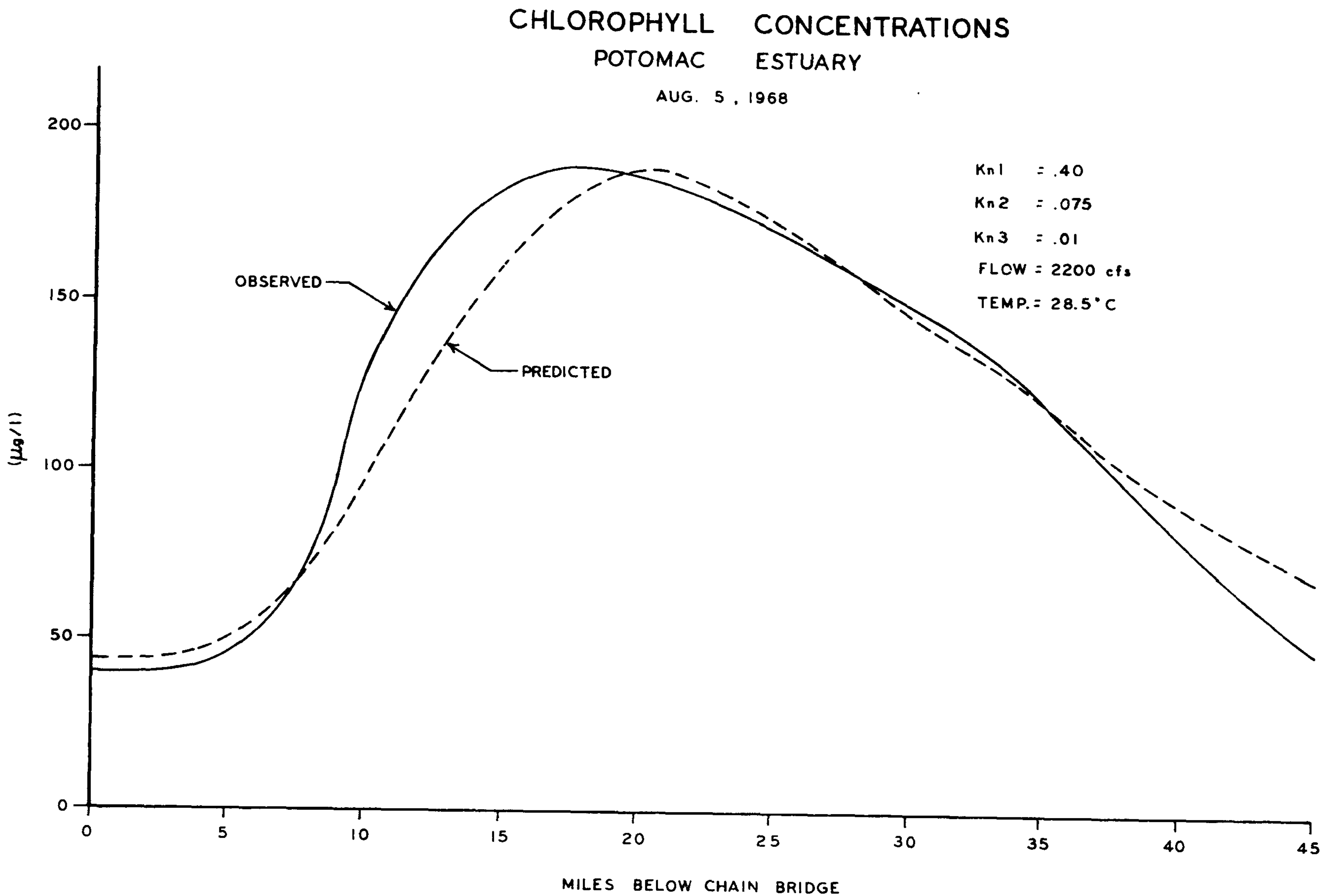

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
AUG. 5, 1968
Kn1 = .40
Kn2 = .075
Kn3 = .01
FLOW = 2200 cfs
TEMP. = 28.5°C
OBSERVED
PREDICTED
(μg/l)
0
50
100
150
200
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-28

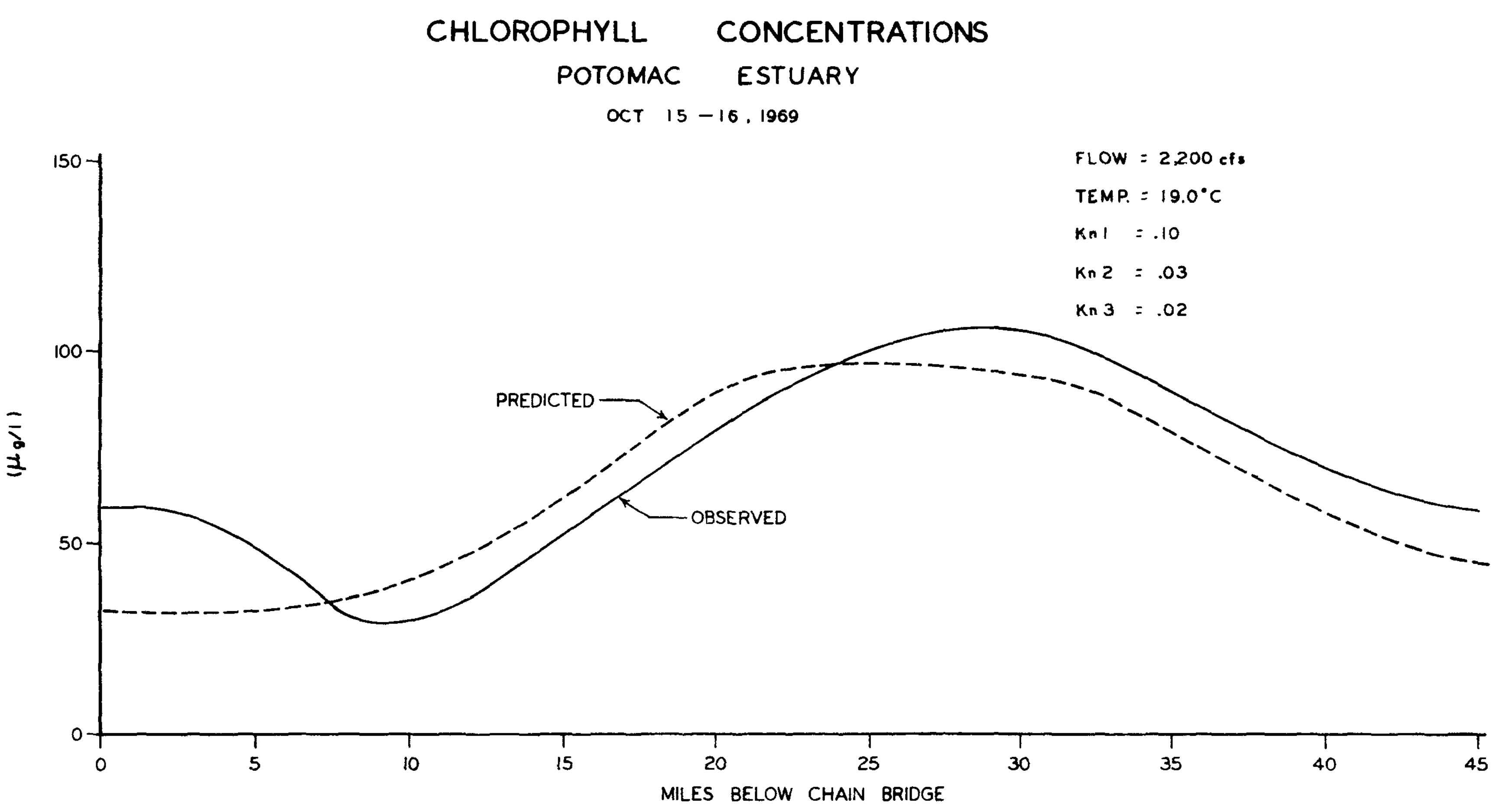
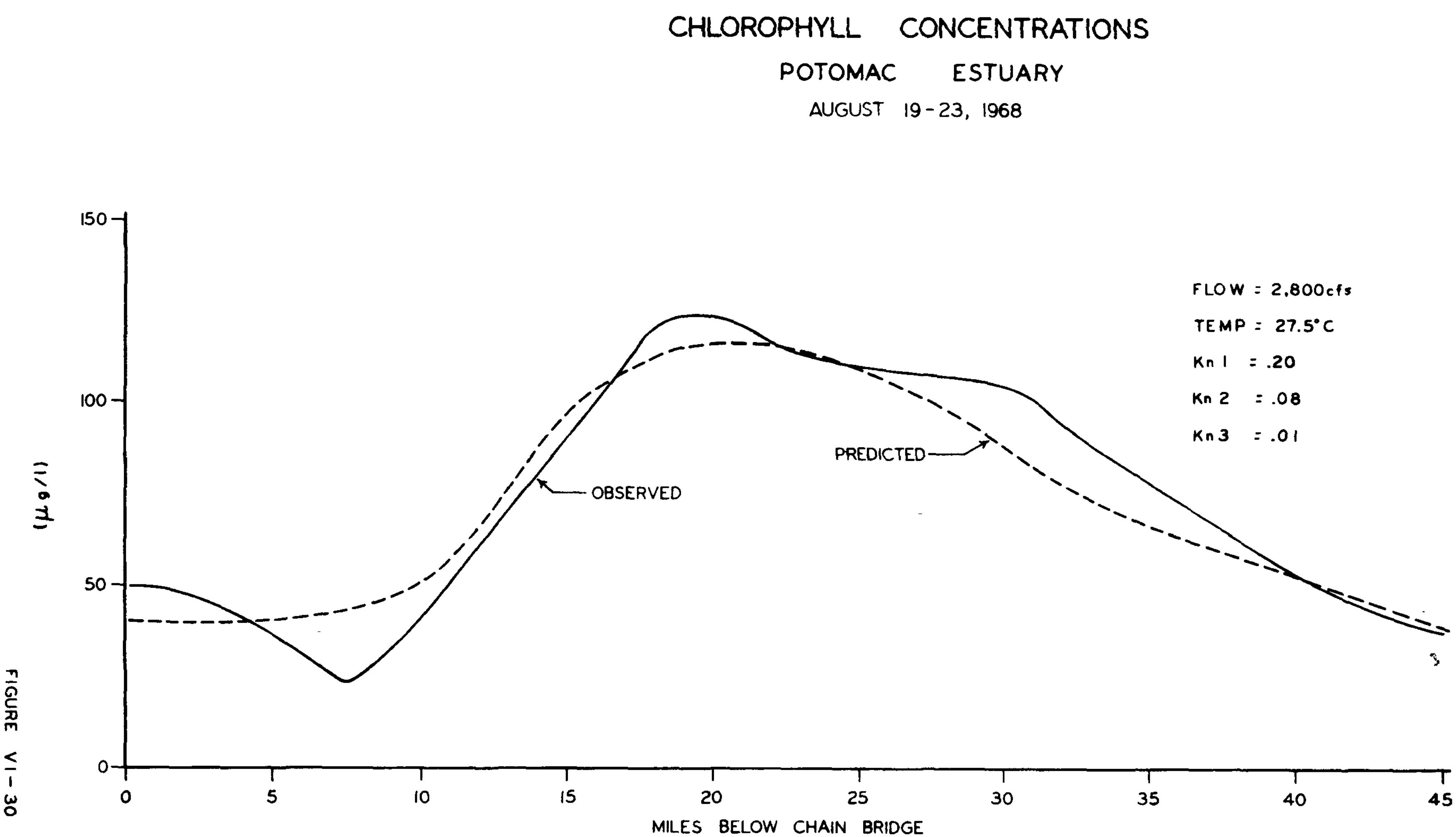

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
OCT 15 – 16, 1969
FLOW = 2,200 cfs
TEMP. = 19.0°C
Kn 1 = .10
Kn 2 = .03
Kn 3 = .02
PREDICTED
OBSERVED
(μg/l)
150
100
50
0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-29



CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
AUGUST 19-23, 1968
FLOW = 2,800cfs
TEMP = 27.5°C
Kn 1 = .20
Kn 2 = .08
Kn 3 = .01
OBSERVED
PREDICTED
(μg/l)
0
50
100
150
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-30

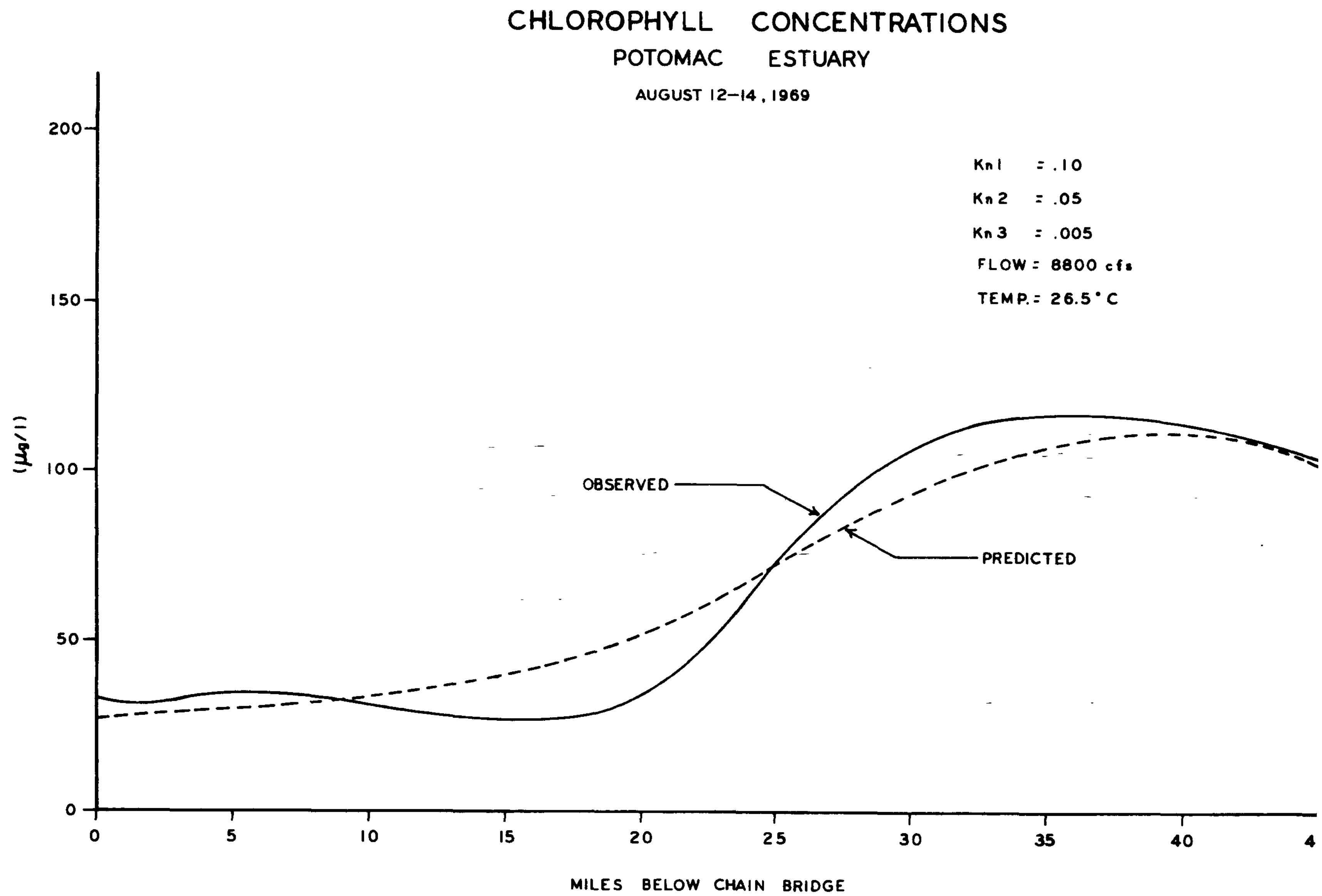

CHLOROPHYLL CONCENTRATIONS
POTOMAC ESTUARY
AUGUST 12-14, 1969
Kn1 = .10
Kn2 = .05
Kn3 = .005
FLOW = 8800 cfs
TEMP. = 26.5° C
(μg/l)
200
150
100
50
0
OBSERVED
PREDICTED
0
5
10
15
20
25
30
35
40
4
MILES BELOW CHAIN BRIDGE

FIGURE VI-31

CHAPTER VII

PHOSPHORUS ASSIMILATION AND TRANSPORT

A. TEMPORAL AND SPATIAL DISTRIBUTION

Like nitrogen, the distribution of phosphorus in the Potomac Estuary is strongly dependent upon such factors as temperature, biological activity, and freshwater flow rates. Figure VII-1 shows, by means of an isopleth, the spatial distribution of inorganic phosphorus during 1969 and 1970. Of special importance are the maximum concentrations of 2.0 to 2.5 mg/l (as PO_4) which were observed between Bellevue (River Mile 10) and Piscataway Creek (River Mile 18) during the low-flow periods of June, July, October, and early November 1969. The month of August (1969) was characterized by abnormally high flows and low phosphorus levels, the result of phosphorus deposition by adsorption onto silt particles during high flow periods.

A similar occurrence had been observed previously (March 1967) and it was concluded that, while periods of high freshwater inflows contribute an excessive phosphorus load, the overall effects of adsorption and deposition produce a net decrease in phosphorus during these periods in the upper Potomac Estuary.

Inorganic phosphorus concentrations upstream from Hains Point (River Mile 7.6) were usually less than 0.5 mg/l. Downstream from Piscataway Creek, inorganic phosphorus levels decreased appreciably during high temperature periods due to continued deposition and biological uptake by phytoplankton. During low temperature periods, when biological activity was at a minimum, the decrease in inorganic phosphorus levels in the middle estuary was considerably less pronounced. The entire lower half of the estuary normally contained less than 0.5 mg/l of inorganic phosphorus.

The total phosphorus (inorganic plus organic) data collected during the 1969-70 survey are shown in Figure VII-2. A comparison of Figures VII-1 and VII-2 will reveal similar patterns in the spatial and temporal distribution of total and inorganic phosphorus. For example, maximum concentrations of total phosphorus (3.5 - 4.0 mg/l as PO_4), as well as inorganic phosphorus, were observed between Bellevue and Piscataway Creek during low-flow periods. During high flows, total phosphorus concentrations were much lower because of the aforementioned deposition process.

Although variations in total phosphorus concentrations generally corresponded to those of inorganic phosphorus, there were slight differences in the ratios. In the upper reach of the Potomac Estuary, the ratio of total phosphorus to inorganic phosphorus ranged from 1.1 to 1.5, while the ratio in the middle reach normally varied from 1.5 to 2.0. This difference in a high productivity area may be due to the biological conversion of soluble inorganic phosphorus to cellular organic forms.

INORGANIC PHOSPHORUS ISOPLETH
POTOMAC ESTUARY
1969-1970 DATA

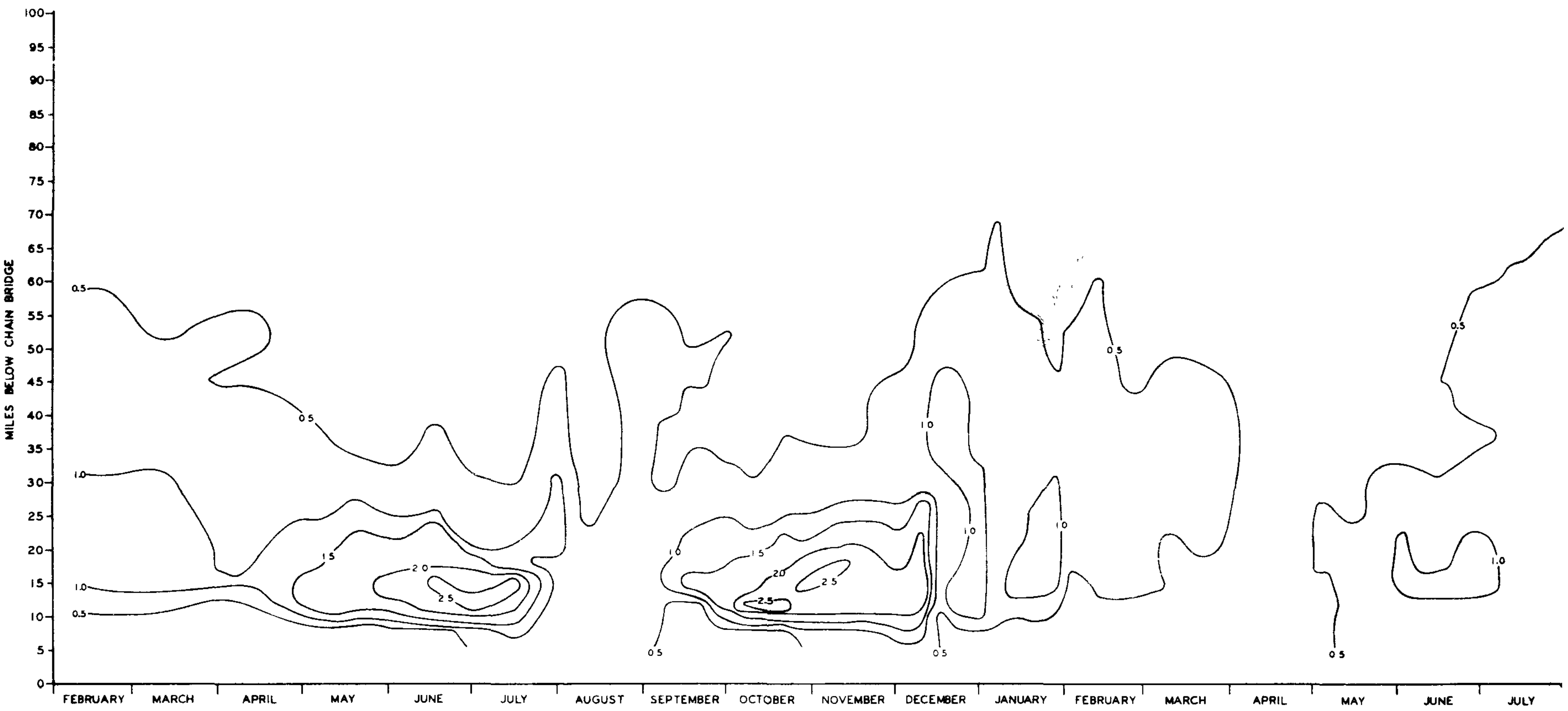


FIGURE VII-1

TOTAL PHOSPHORUS ISOPLETH
POTOMAC ESTUARY
1969-1970 DATA

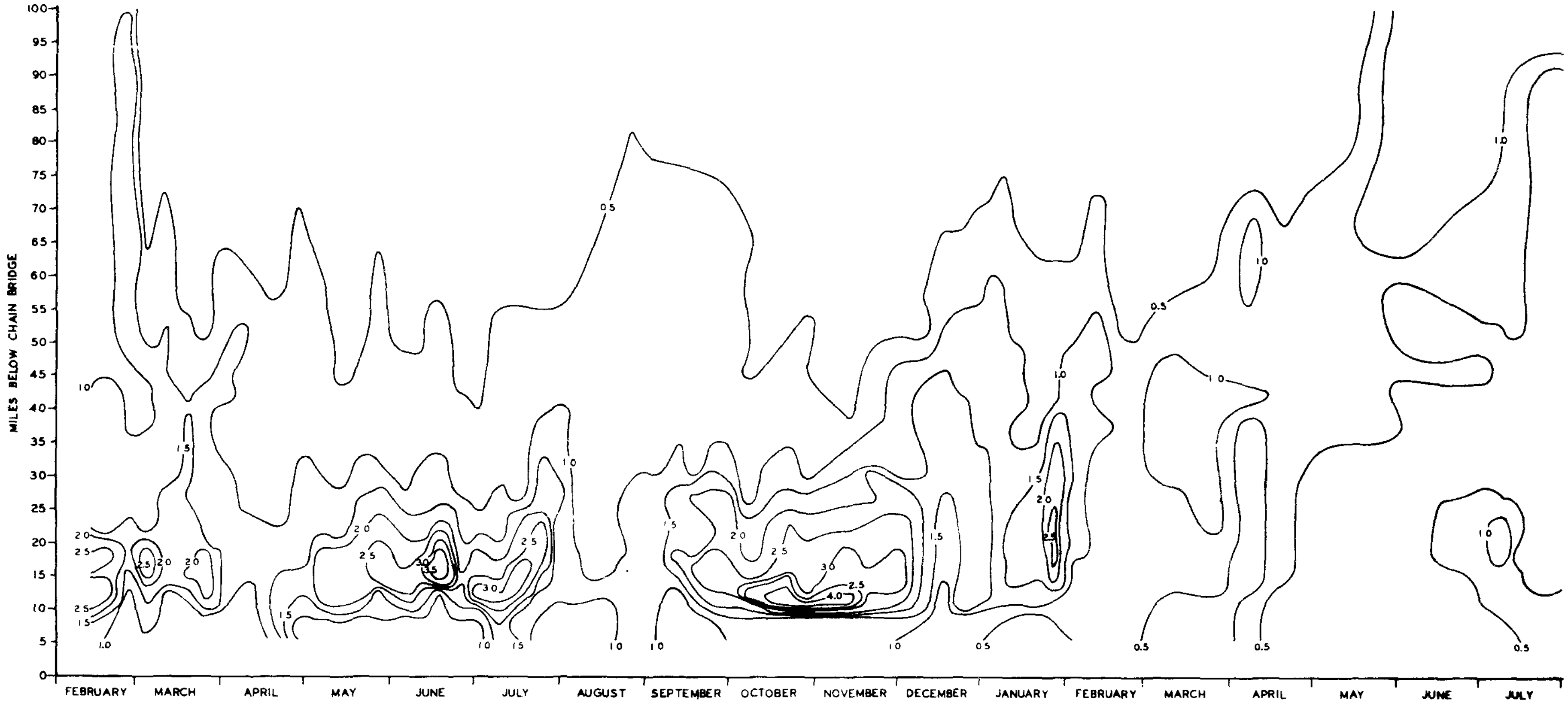


FIGURE VII-2

B. DETERMINATION OF LOSS RATE AND TEMPERATURE EFFECTS

Water quality sampling data collected in the upper Potomac Estuary from fourteen separate surveys were used for purposes of Dynamic Estuary Model verification, and more specifically, to determine the magnitude of the overall phosphorus loss rate. During these model studies, no distinction was made as to the relative importance of (1) deposition to bottom muds and (2) biological uptake by algal cells. All of the sampling data were collected under relatively steady-state flow conditions, ranging from 185 cfs to 11,000 cfs. A range in water temperatures, from 1.0°C to 28.5°C, was also represented.

Figures VII-3 through VII-16 depict the observed total phosphorus and inorganic phosphorus profiles in the upper 45 miles of estuary, as well as the model predictions for total phosphorus. The close relationship between observed TP and Pi data eliminated the necessity for separate simulations. An examination of these figures will indicate that the magnitude of peak concentrations and the rate of decrease in phosphorus downstream from those peaks were accurately simulated. In order to obtain this agreement with the model, it was necessary to utilize second-order kinetics having the following form:

$$\frac{dc}{dt} = -kc^2 .$$

where c = concentration

t = time

and k = reaction rate (gr/day)

The reaction rates required for model verification were greatly affected by temperature, as can be seen in Figure VII-17.

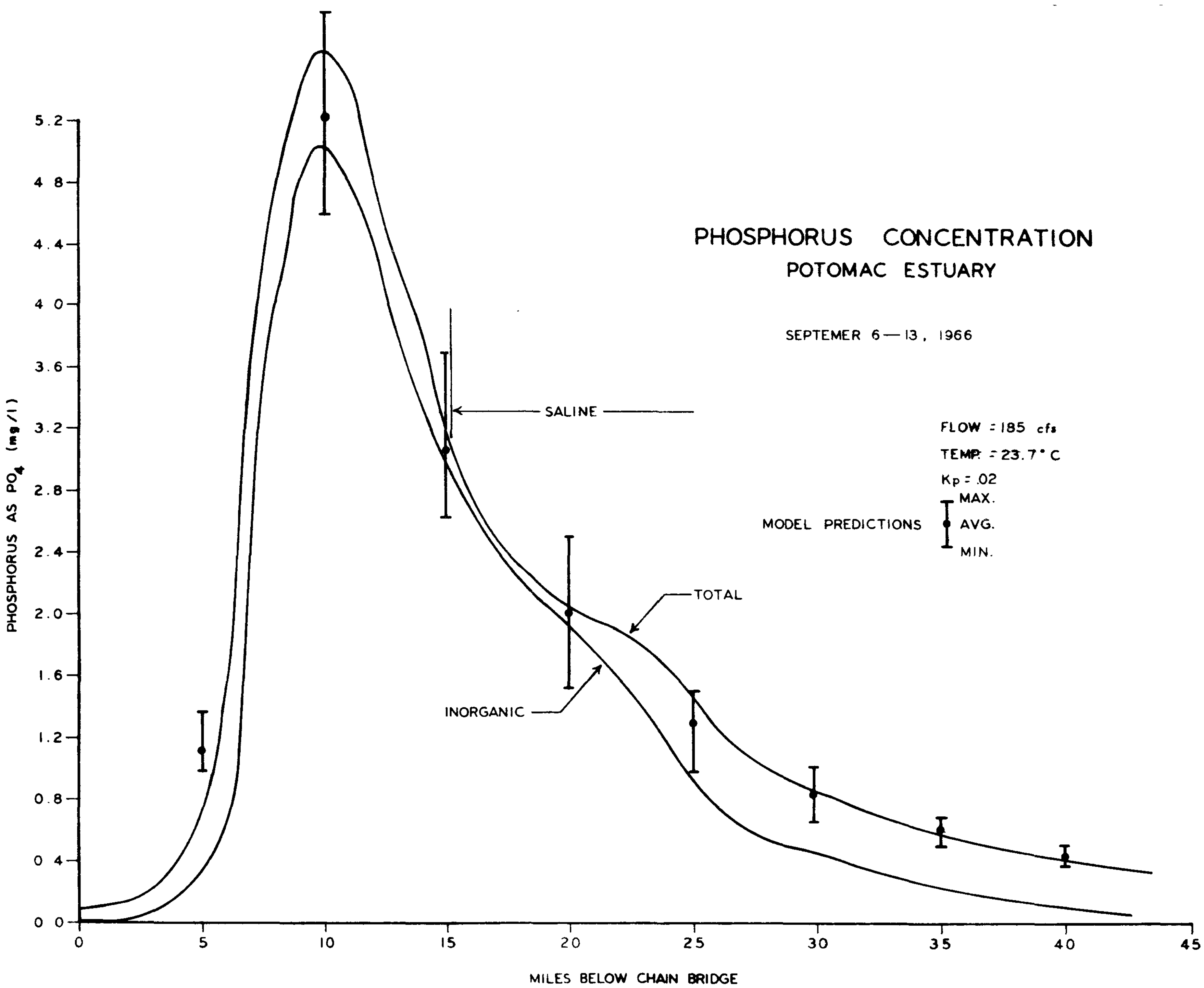

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPTEMER 6 — 13, 1966
FLOW = 185 cfs
TEMP. = 23.7° C
Kp = .02
MODEL PREDICTIONS
MAX.
AVG.
MIN.
SALINE
TOTAL
INORGANIC
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
5.2
4.8
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0
5
10
15
20
25
30
35
40
45

FIGURE VII-3

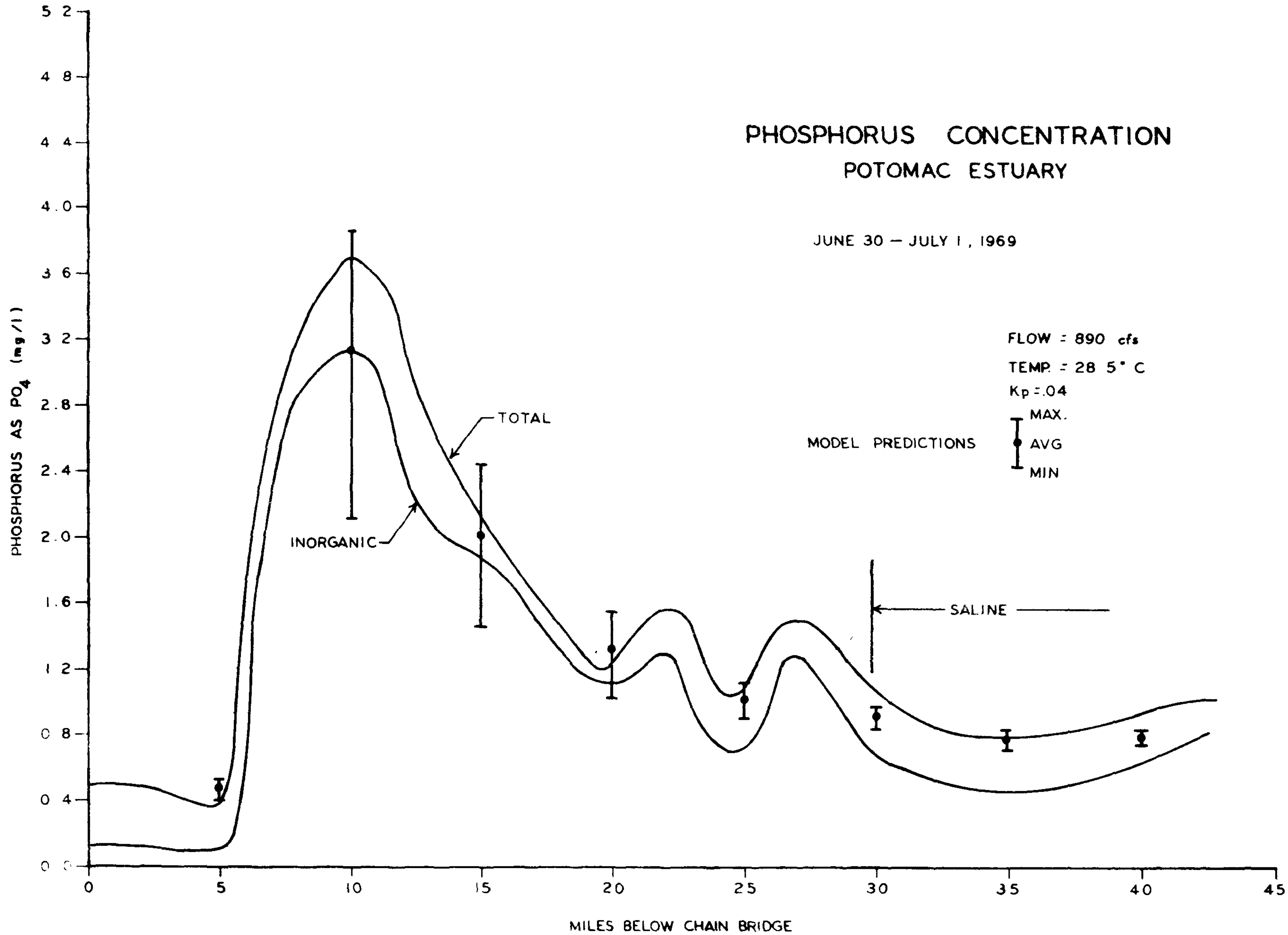

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
JUNE 30 – JULY 1, 1969
FLOW = 890 cfs
TEMP. = 28 5° C
Kp =.04
MODEL PREDICTIONS
MAX.
AVG
MIN
TOTAL
INORGANIC
SALINE
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
5 2
4 8
4 4
4.0
3 6
3 2
2.8
2.4
2.0
1.6
1 2
0 8
0 4
0
5
10
15
20
25
30
35
40
45

FIGURE VII-4

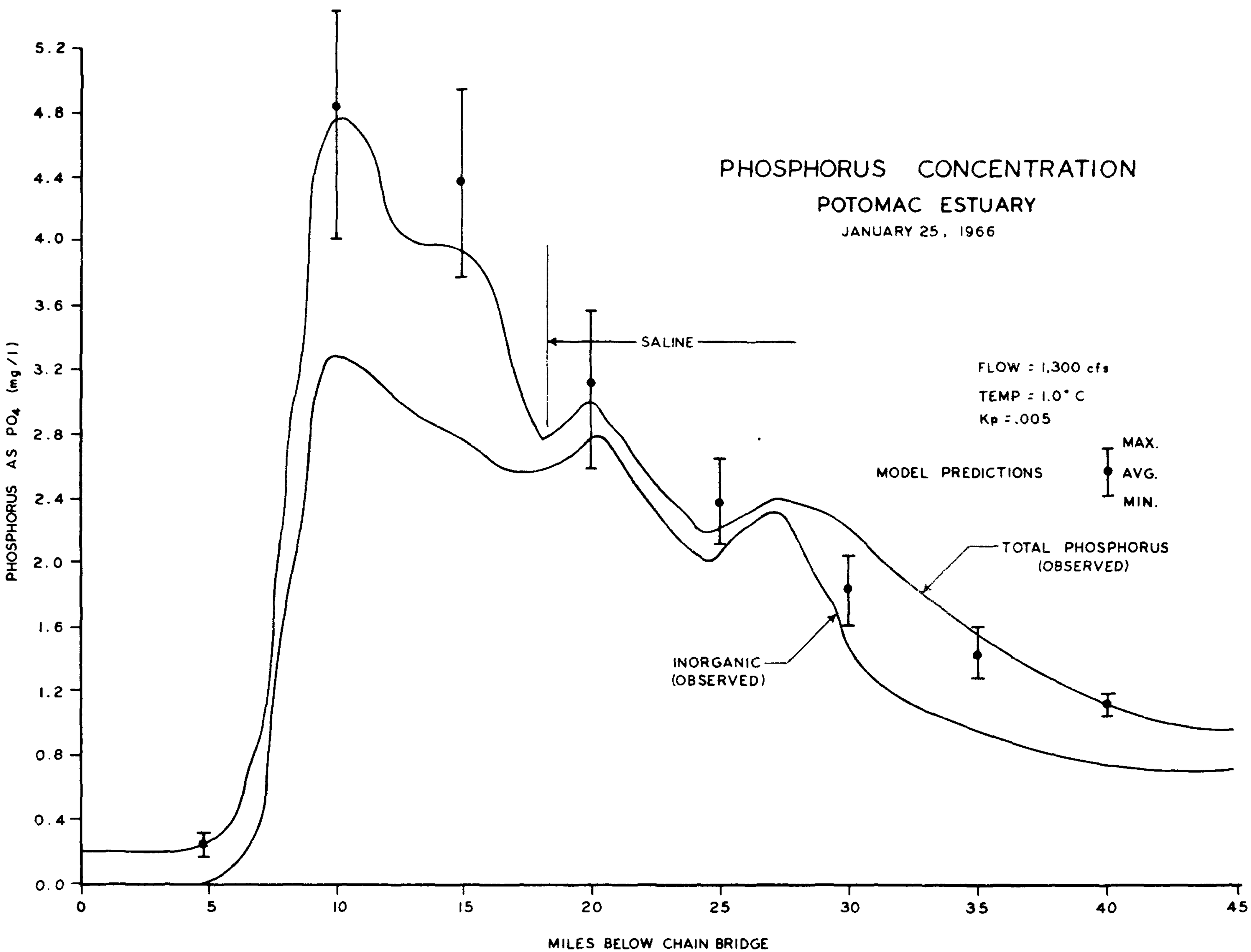
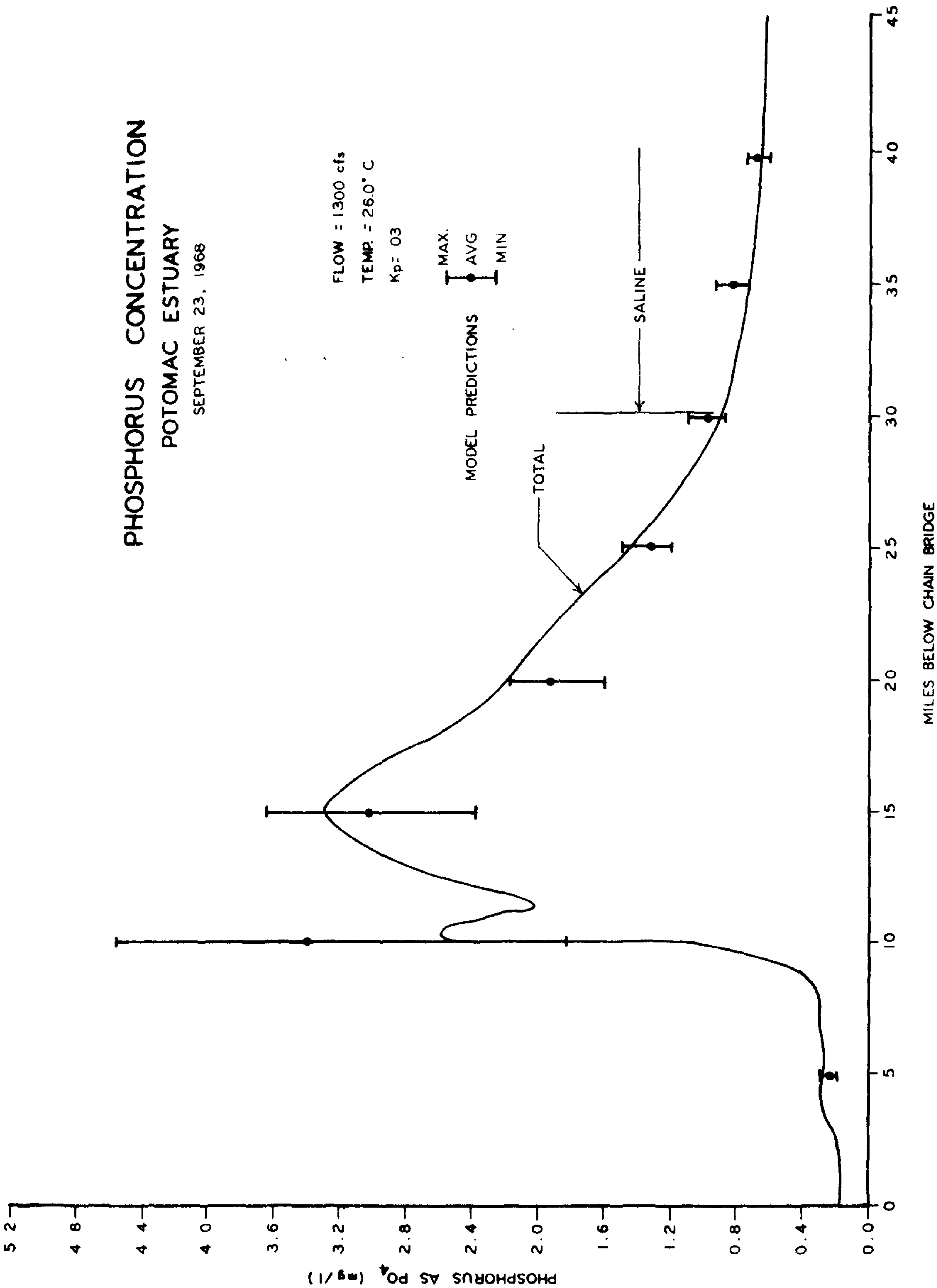

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
JANUARY 25, 1966
FLOW = 1,300 cfs
TEMP = 1.0° C
Kp = .005
MODEL PREDICTIONS
MAX.
AVG.
MIN.
SALINE
TOTAL PHOSPHORUS (OBSERVED)
INORGANIC (OBSERVED)
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40
45

FIGURE VII-5



PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPTEMBER 23, 1968
FLOW = 1300 cfs
TEMP. = 26.0° C
Kp = 03
MAX.
AVG
MIN
MODEL PREDICTIONS
TOTAL
SALINE
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40
45

FIGURE VII-6

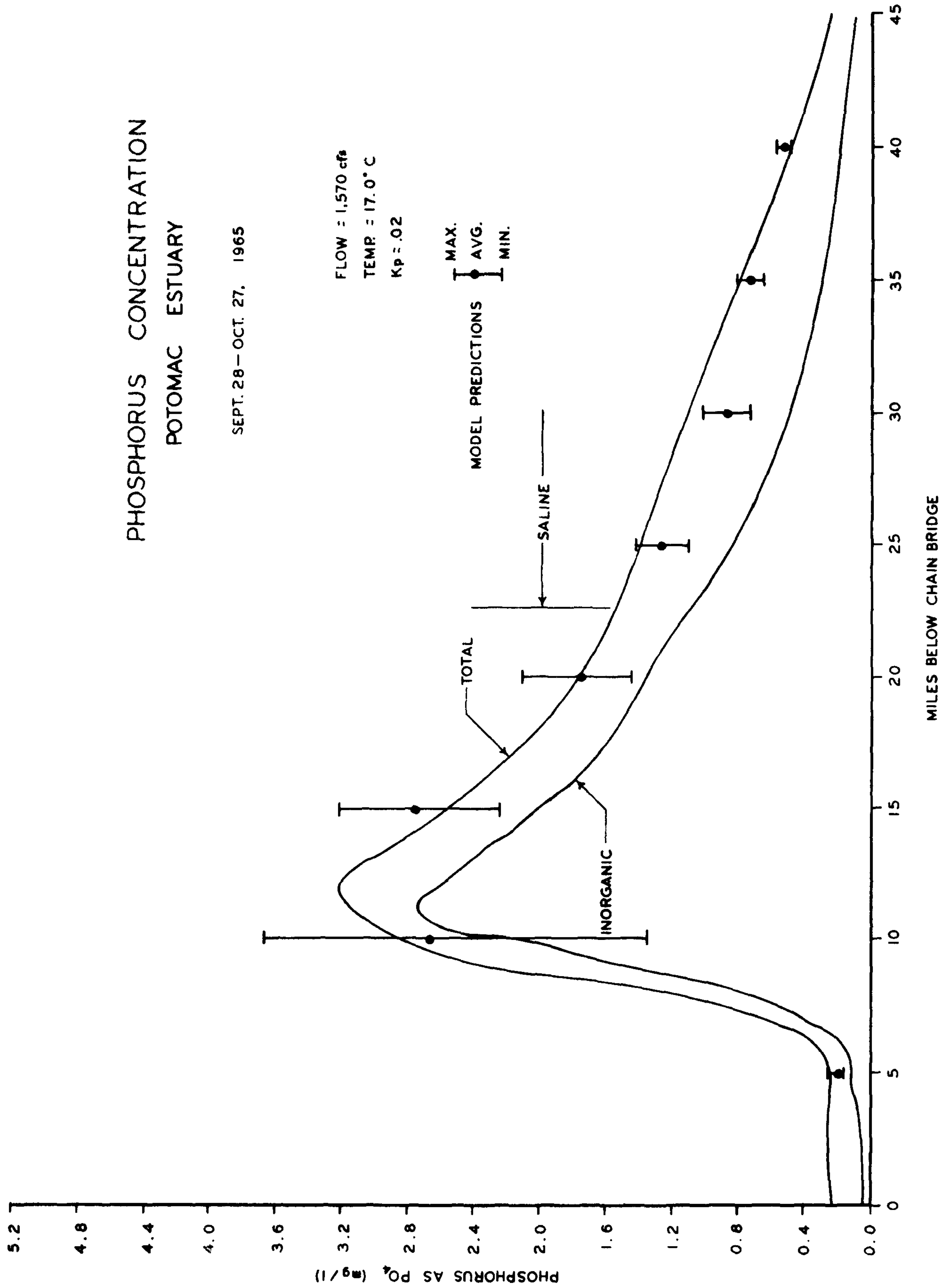
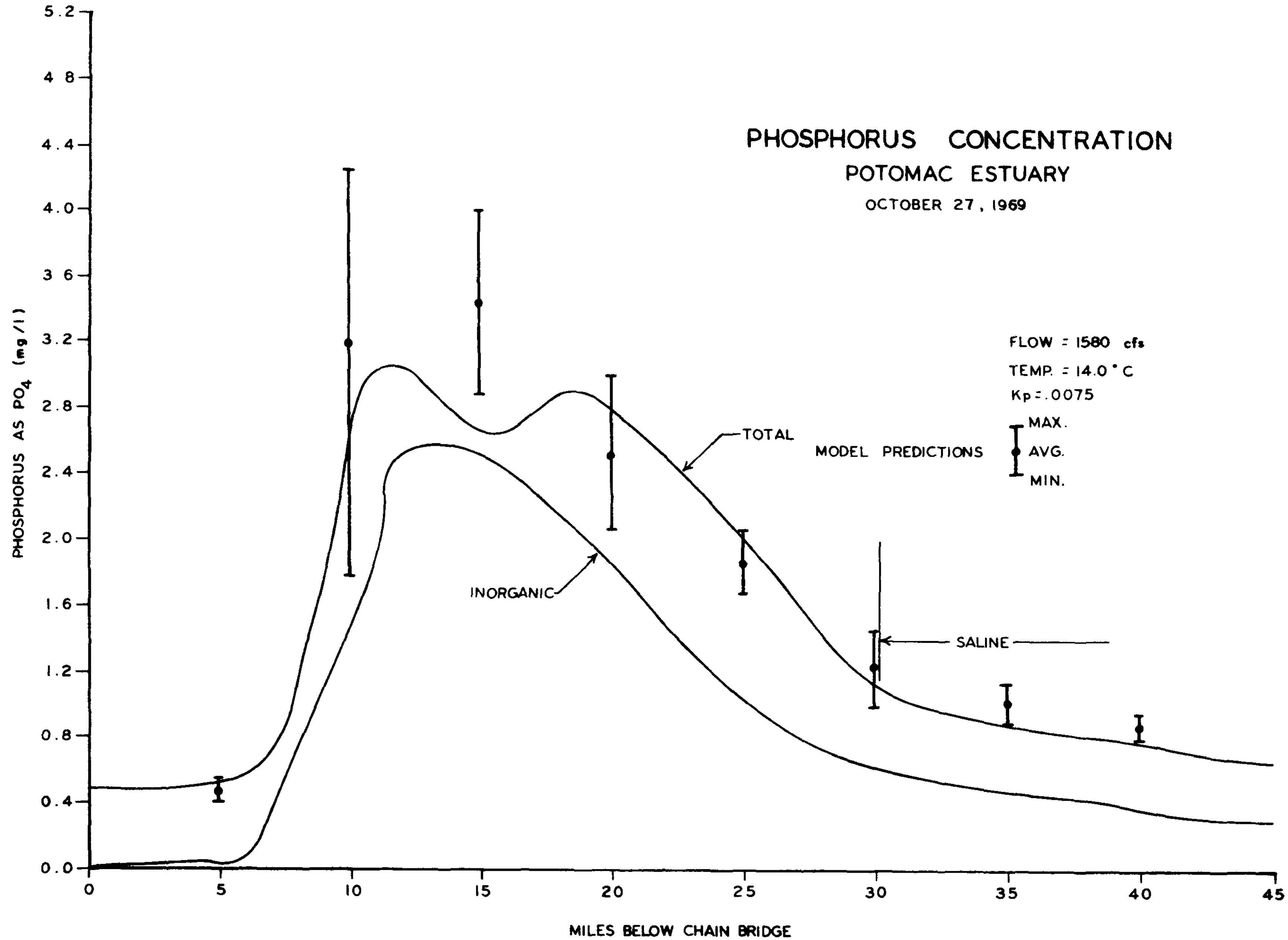

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPT. 28 — OCT. 27, 1965
FLOW = 1,570 cfs
TEMP. = 17.0° C
Kp = .02
MODEL PREDICTIONS
MAX.
AVG.
MIN.
SALINE
TOTAL
INORGANIC
PHOSPHORUS AS PO_4 (mg/l)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
MILES BELOW CHAIN BRIDGE
0
5
10
15
20
25
30
35
40
45

FIGURE VII-7



PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
OCTOBER 27, 1969
FLOW = 1580 cfs
TEMP. = 14.0 °C
Kp = .0075
MODEL PREDICTIONS
MAX.
AVG.
MIN.
TOTAL
INORGANIC
SALINE
PHOSPHORUS AS PO_4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3 6
4.0
4.4
4 8
5.2
0
5
10
15
20
25
30
35
40
45

FIGURE VII-8

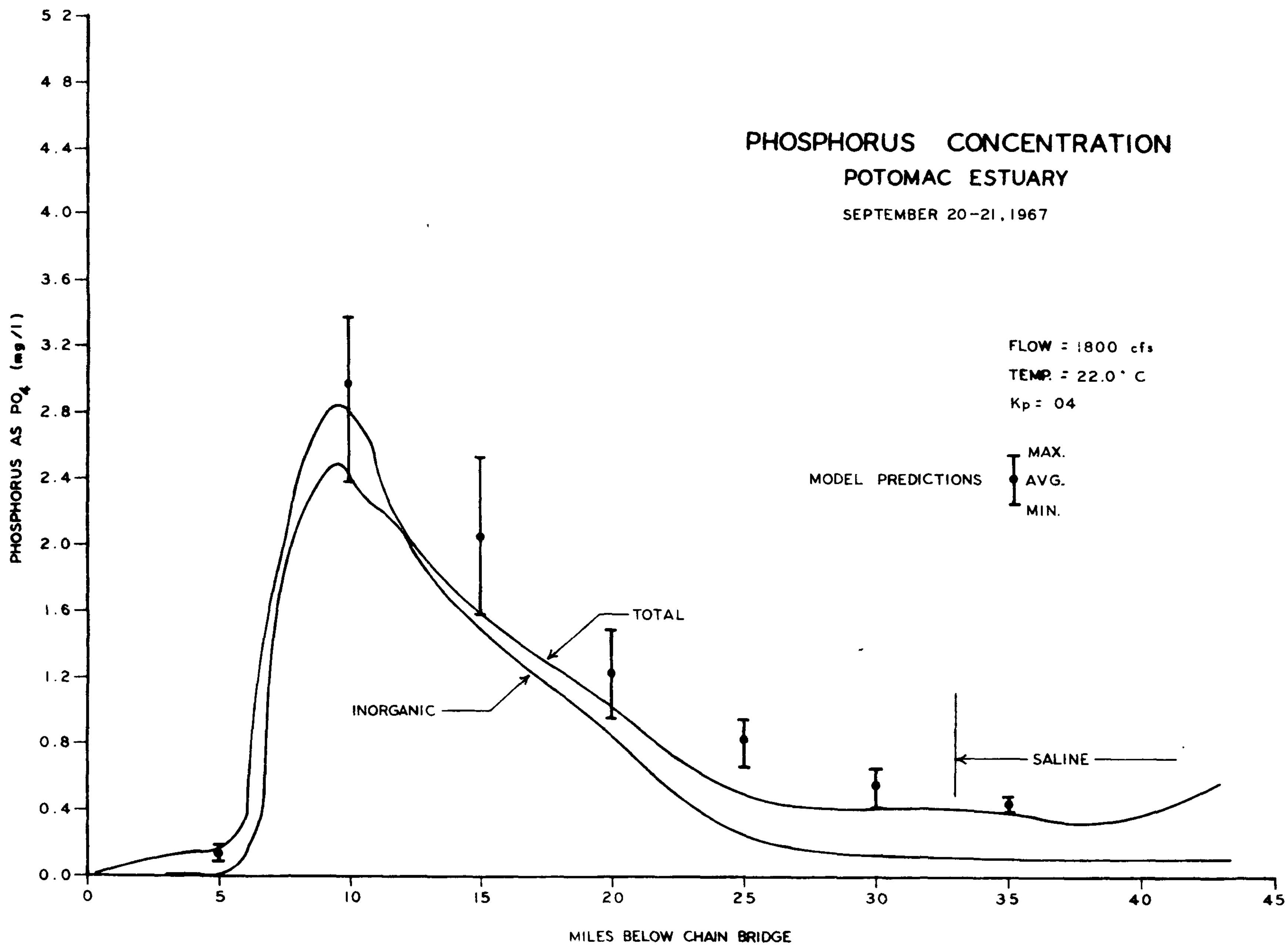

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPTEMBER 20-21, 1967
FLOW = 1800 cfs
TEMP. = 22.0° C
Kp = 04
MODEL PREDICTIONS
MAX.
AVG.
MIN.
TOTAL
INORGANIC
SALINE
PHOSPHORUS AS PO_4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4 8
5 2
0
5
10
15
20
25
30
35
40
45

FIGURE VII-9

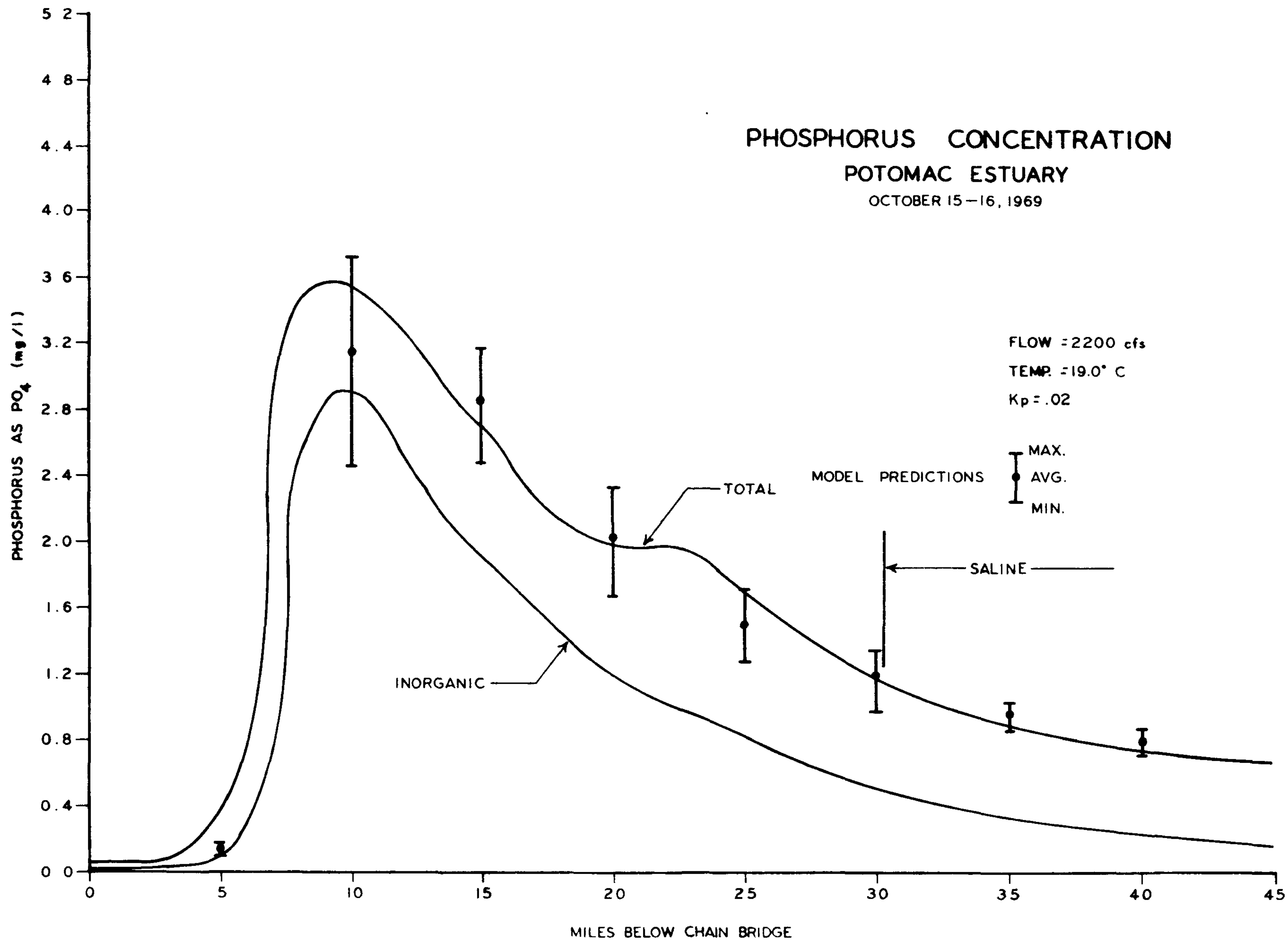


FIGURE VII-10

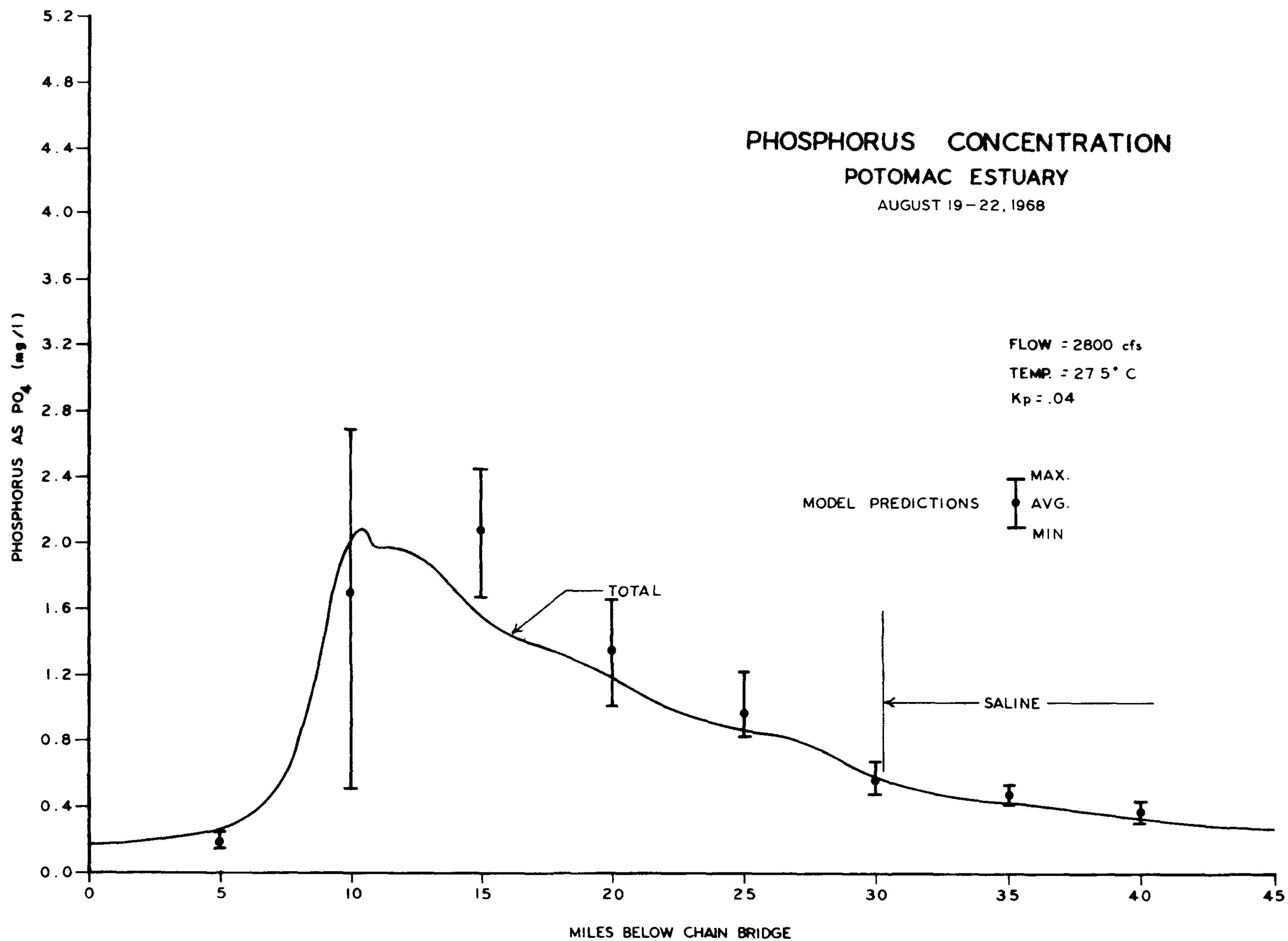


FIGURE VII-11

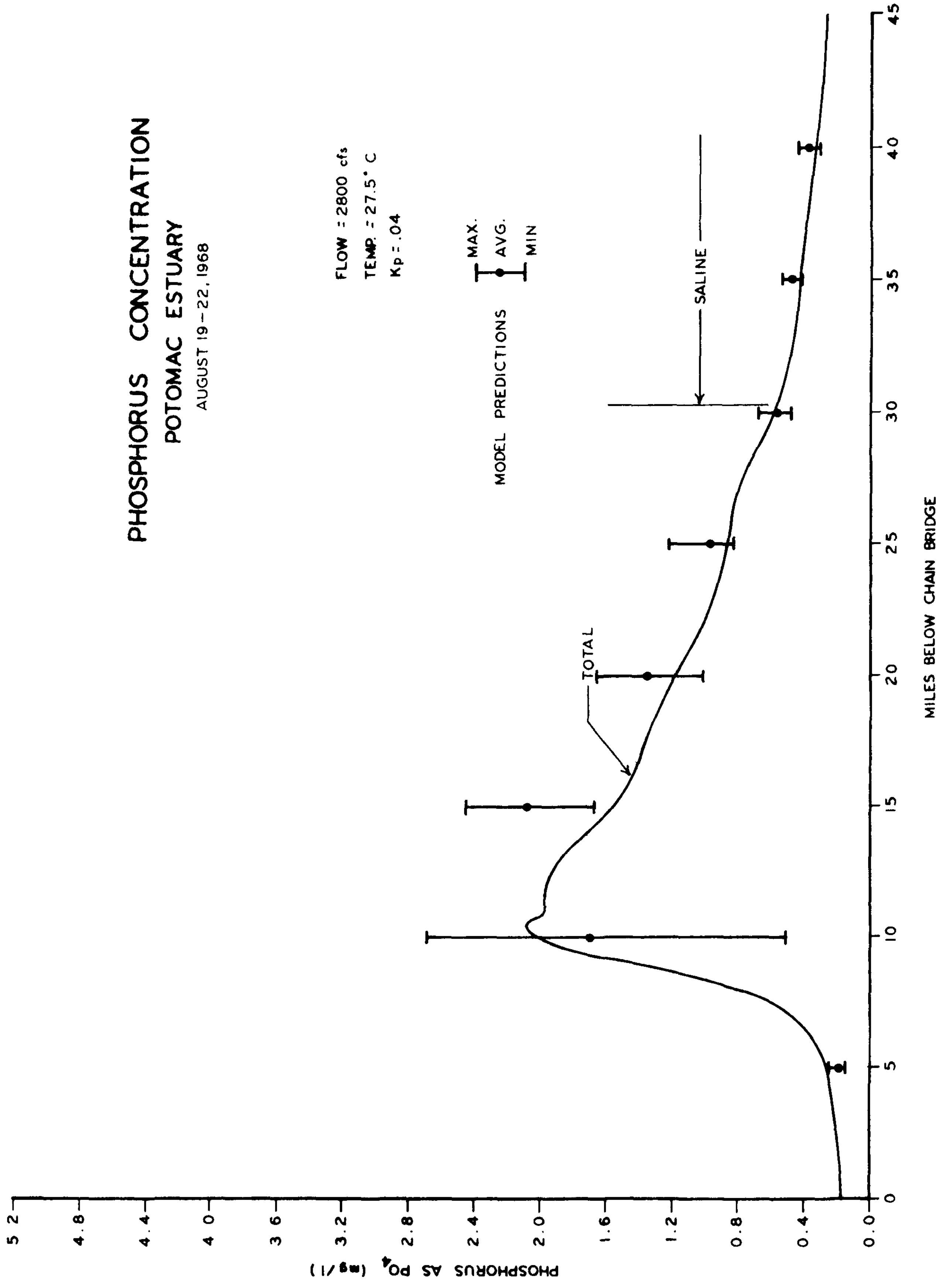


FIGURE VII-11

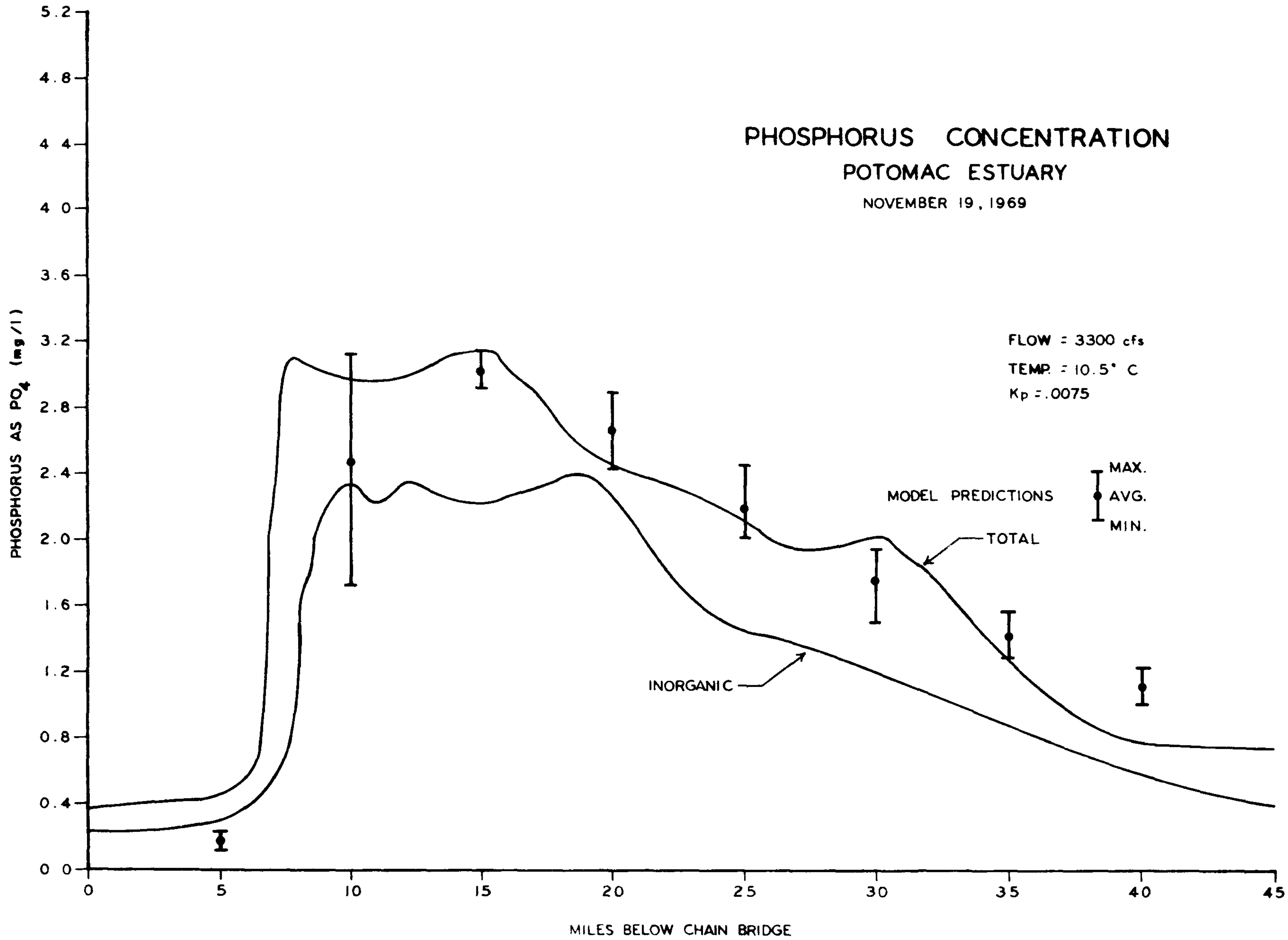


FIGURE VII-12

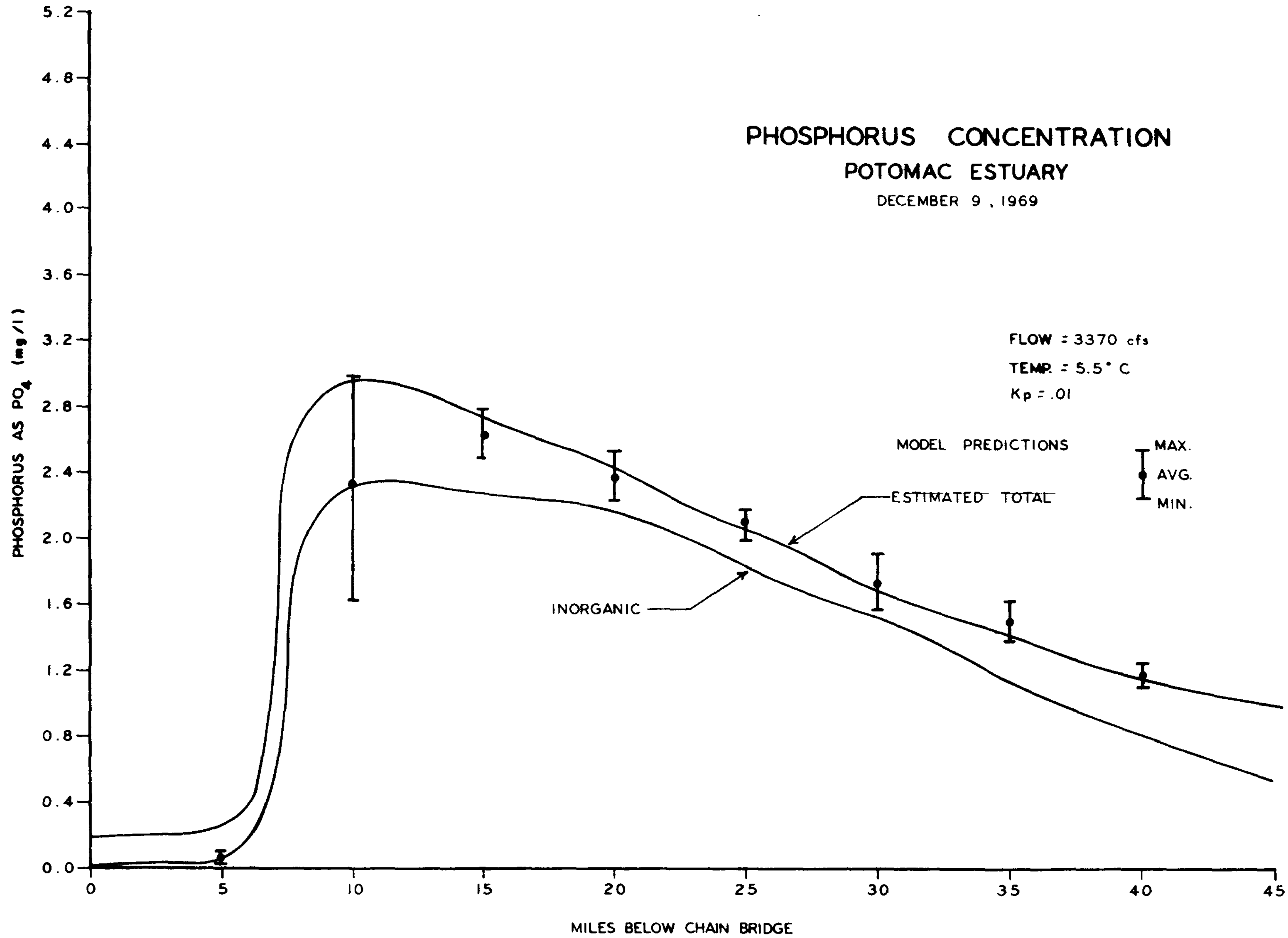


FIGURE VII-13

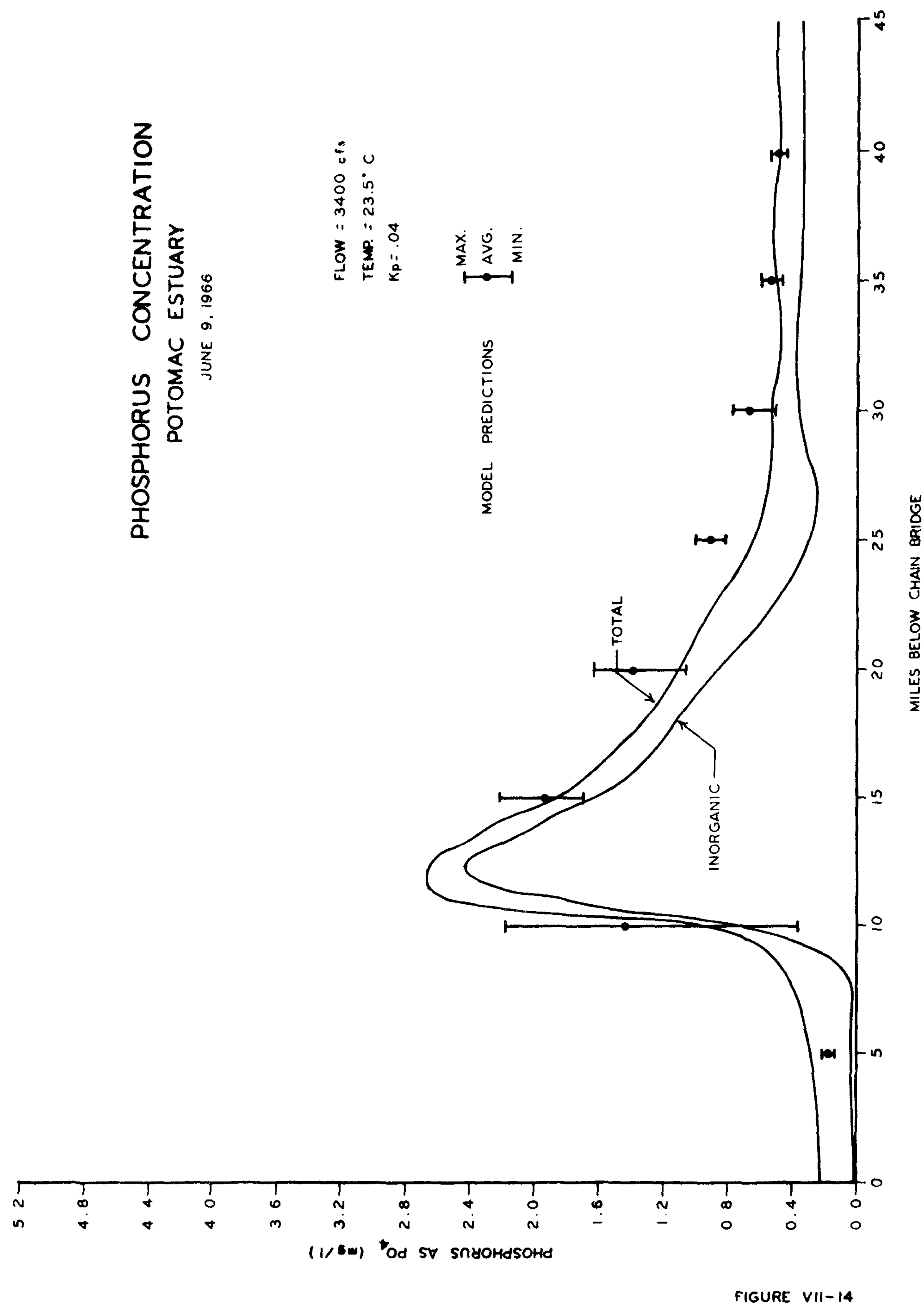


FIGURE VII-14

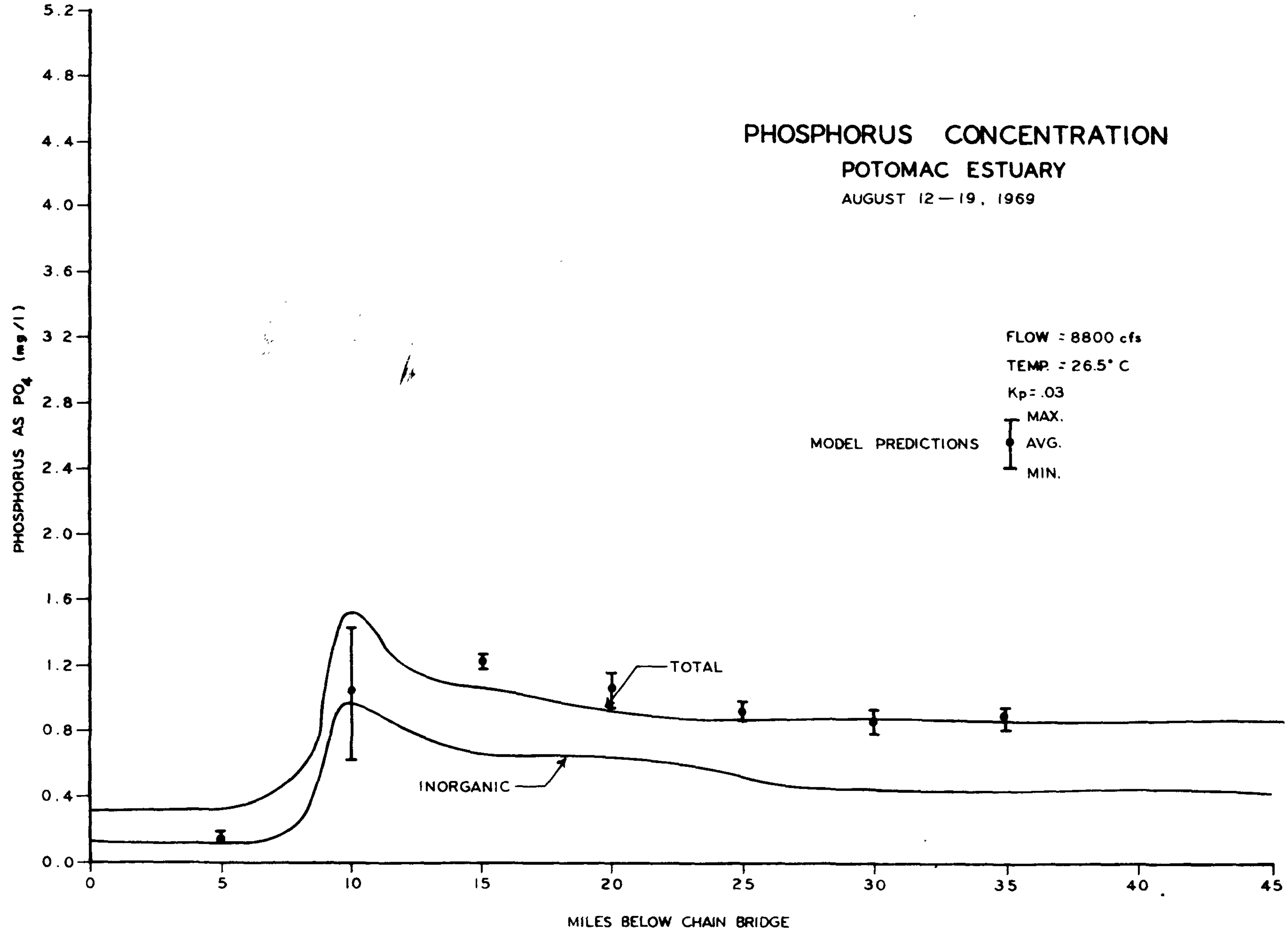


FIGURE VII-15

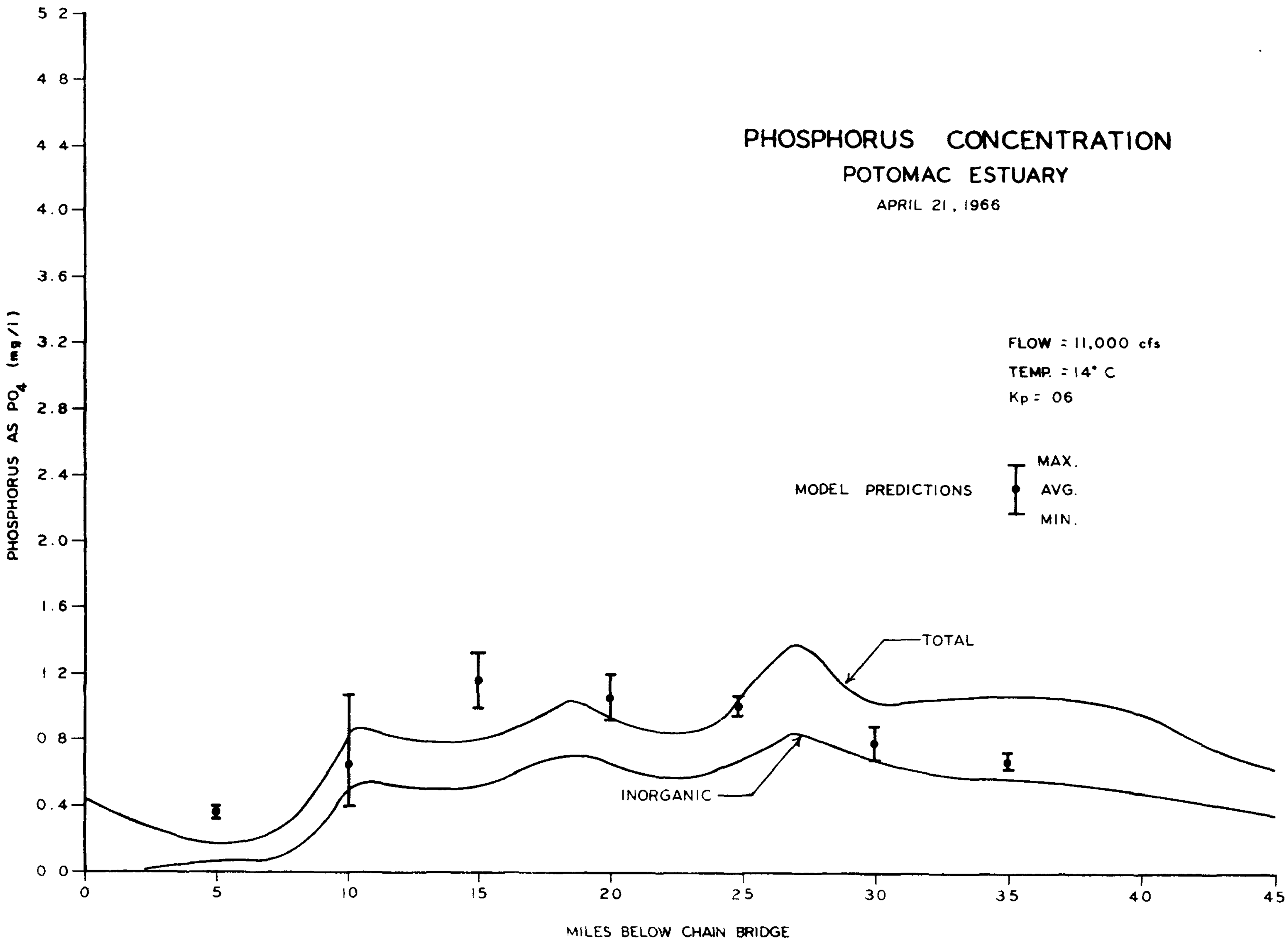


FIGURE VII-16

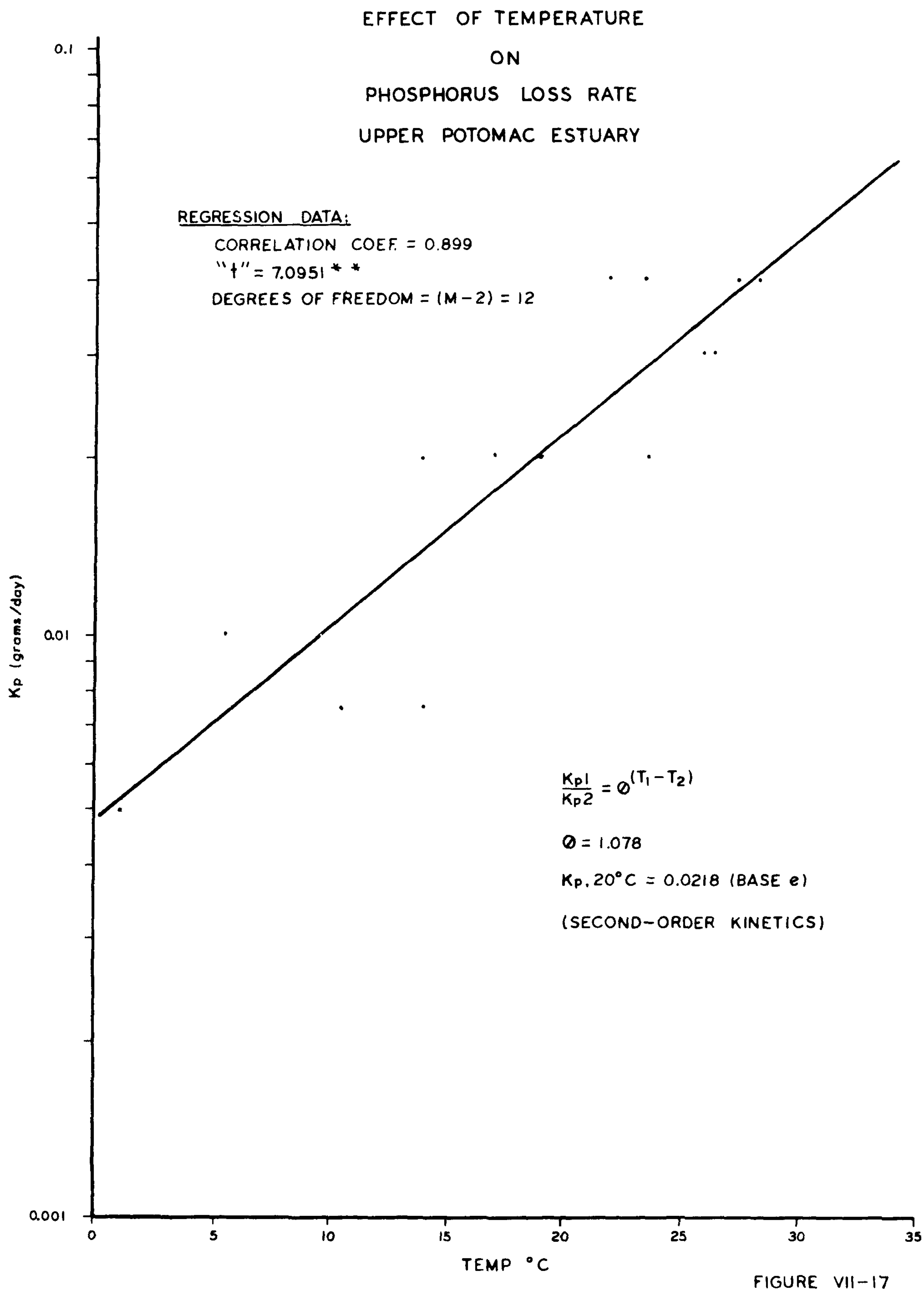


FIGURE VII-17

C. SIMULATION OF PHOSPHORUS TRANSPORT THROUGH AN ANNUAL CYCLE

The mass transport and spatial distribution of total phosphorus over an annual cycle must be known and predictable if the role of phosphorus in the eutrophication process and a management program for wastewater treatment are to be determined. Because of its importance, AFO endeavored to mathematically model phosphorus transport in the Potomac Estuary during a 15-month period in 1969 and 1970. This period was characterized by both high and low summer flows and offered an ideal situation for simulation. A modified version of the Thomann Model (DECS III) which incorporated second-order kinetics and the phosphorus loss rated developed in the preceding section was used for this simulation.

Observed and predicted phosphorus (TPO_4) data are shown for five selected stations in Figures VII-18 through VII-22. A comparison of the two profiles in each figure will indicate that the basic temporal distribution, including seasonal trends, was simulated reasonably well.

Some difficulty was experienced in simulating phosphorus under excessive algal productivity conditions. This problem can be evidenced in Figures VII-19 (Piscataway Creek), VII-20 (Indian Head) and VII-21 (Maryland Point). In order to improve the predictive capability of the model during these periods, such factors as the extent of phosphorus regeneration following the death of algal cells and the quantity of phosphorus exchange with the bottom sediments during different flow conditions would have to be quantitatively defined.

ANNUAL PHOSPHORUS PROFILES
POTOMAC ESTUARY AT HAINS POINT
1969–1970

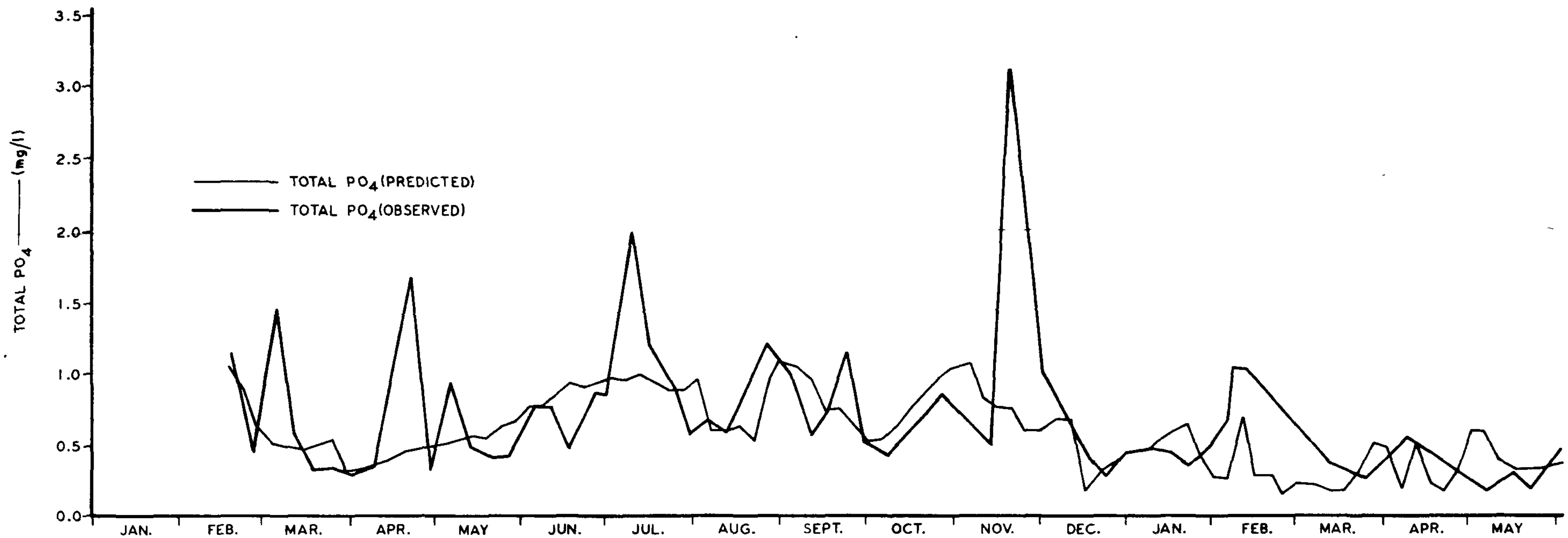


FIGURE VII - 18

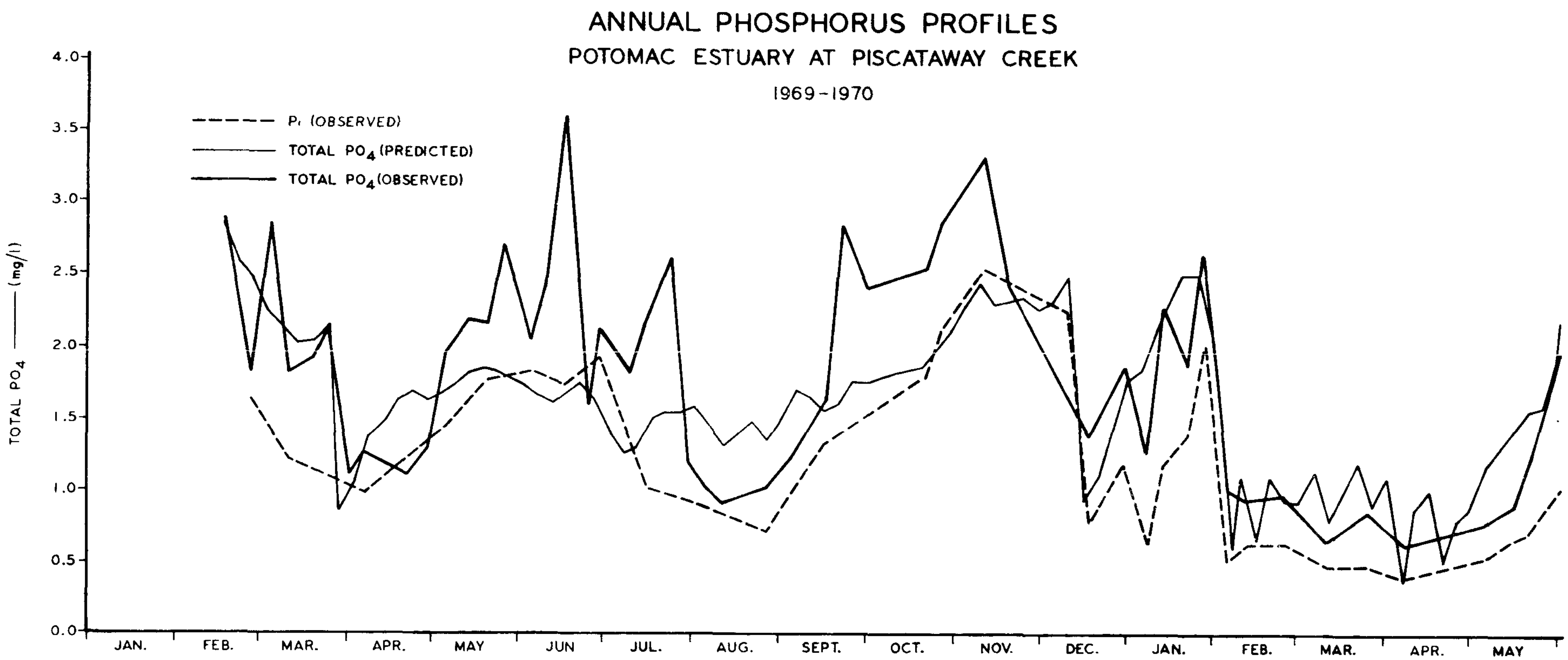


FIGURE VII-19

ANNUAL PHOSPHORUS PROFILES
POTOMAC ESTUARY AT INDIAN HEAD

1969–1970

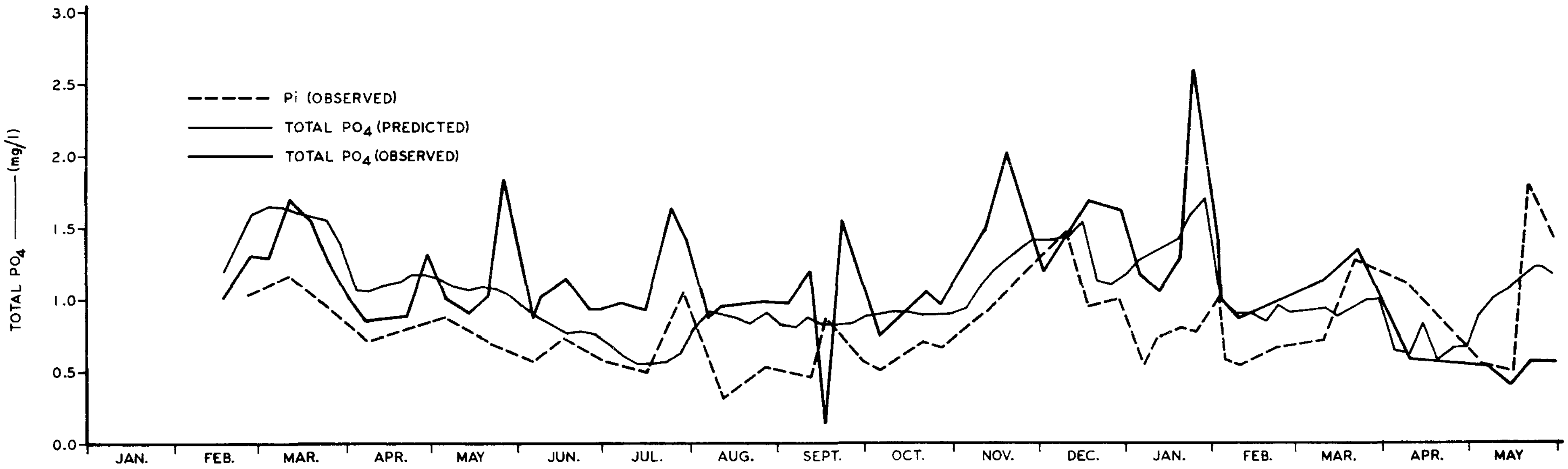


FIGURE VII-20

ANNUAL PHOSPHORUS PROFILES
POTOMAC ESTUARY AT MARYLAND POINT
1969–1970

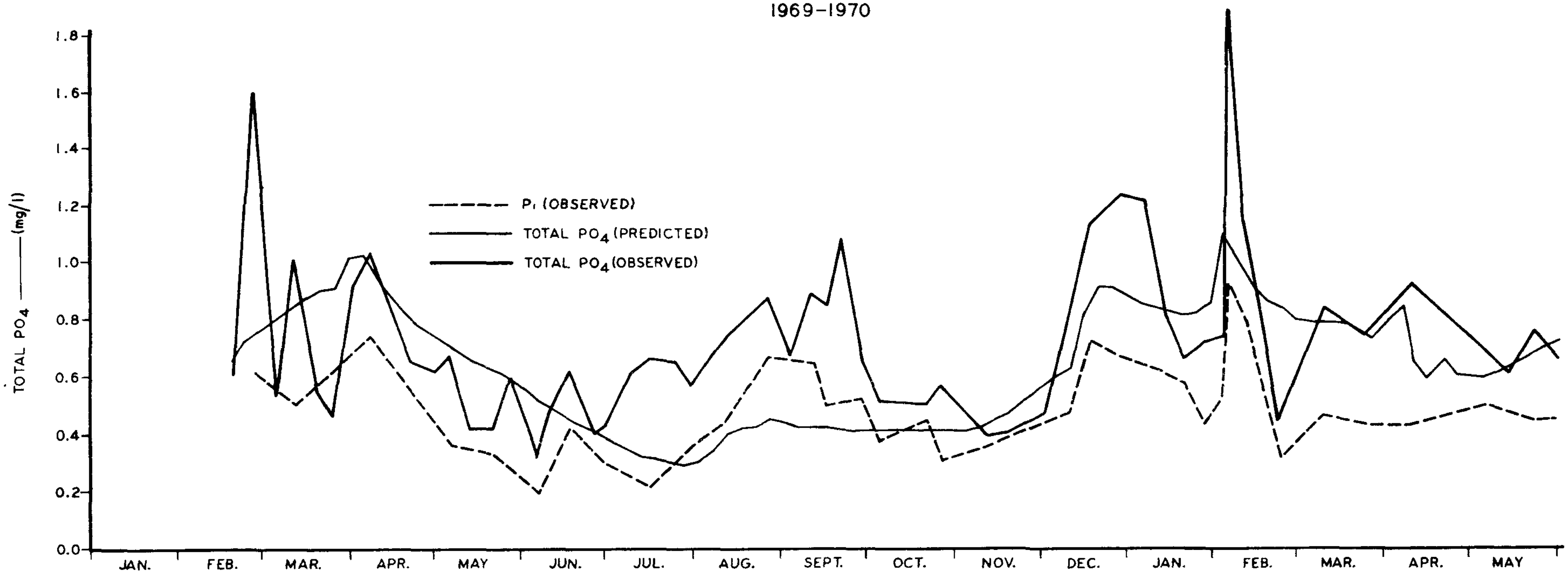


FIGURE VII-21

ANNUAL PHOSPHORUS PROFILES
POTOMAC ESTUARY AT PINEY POINT
1969–1970

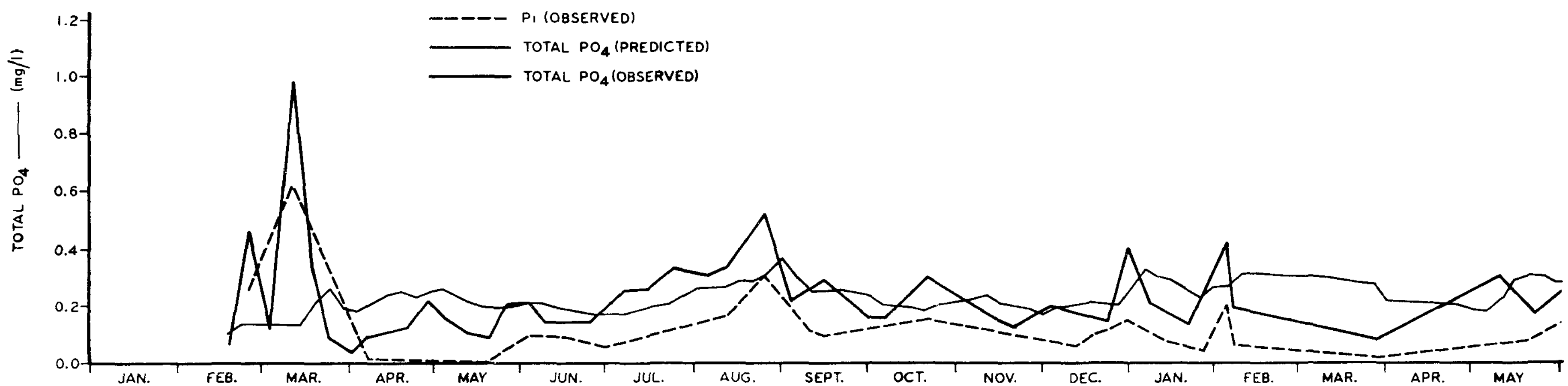


FIGURE VII-22

D. CHLOROPHYLL PREDICTIONS BASED ON PHOSPHORUS ASSIMILATION BY THE BIOMASS

To delineate that portion of the previously computed loss rate representing biological uptake of phosphorus by algal cells from other processes and to better understand the phosphorus contribution to eutrophic conditions in the Potomac Estuary, an attempt was made to predict chlorophyll levels based upon various phosphorus conversion or assimilation factors. A special version of the DEM that correlated algal production, as measured by chlorophyll a, with inorganic phosphorus uptake was used for simulation under four historical conditions. Mass relationships between the two were determined from algal chemical composition analysis.

Figures VII-23 to VII-26 show observed chlorophyll profiles and those obtained from the model assuming phosphorus conversion factors of (1) 10 percent, (2) 25 percent, (3) 50 percent, and (4) 75 percent. The data pertain to late summer and early fall periods during which freshwater flows varied from 185 to 2,200 cfs. As can be seen, the model predictions indicate that only about 10 to 20 percent of the phosphorus losses from the aqueous system can be accounted for by uptake of algal cells. Therefore, the remaining 80-90 percent must be associated with the deposition of phosphorus or some other physical process. Analyses of the bottom muds in the upper estuary further substantiate the fact that large quantities of phosphorus are indeed being lost to sediments.

Insofar as eutrophication is concerned, it appears that there is an abundance of phosphorus in the critical algal growing areas of the Potomac Estuary. Since the standing crop of blue-green algae was predicted from the nitrogen cycle, and only a 50 percent utilization of the available phosphorus produced excessive chlorophyll when compared to observed data, and for other reasons enumerated by Jaworski et al. [5], nitrogen is probably the growth-rate-limiting nutrient in the middle portion of the estuary at the present time. However, this presumption does not lessen the need to control phosphorus to the maximum extent possible, including loadings from wastewater treatment facilities, in the Potomac Estuary for several reasons: (1) the potential for controlling phosphorus is extremely great, especially during high flow periods (2) rapid phosphorus transport and mobility and uncertainty of its recycling ability and (3) phosphorus criteria for eutrophication control are considerably more stringent than nitrogen criteria for comparable reaches of the estuary.

PREDICTED CHLOROPHYLL PROFILES BASED ON VARIOUS PHOSPHORUS ASSIMILATION RATES

UPPER POTOMAC ESTUARY

SEPTEMBER 1966

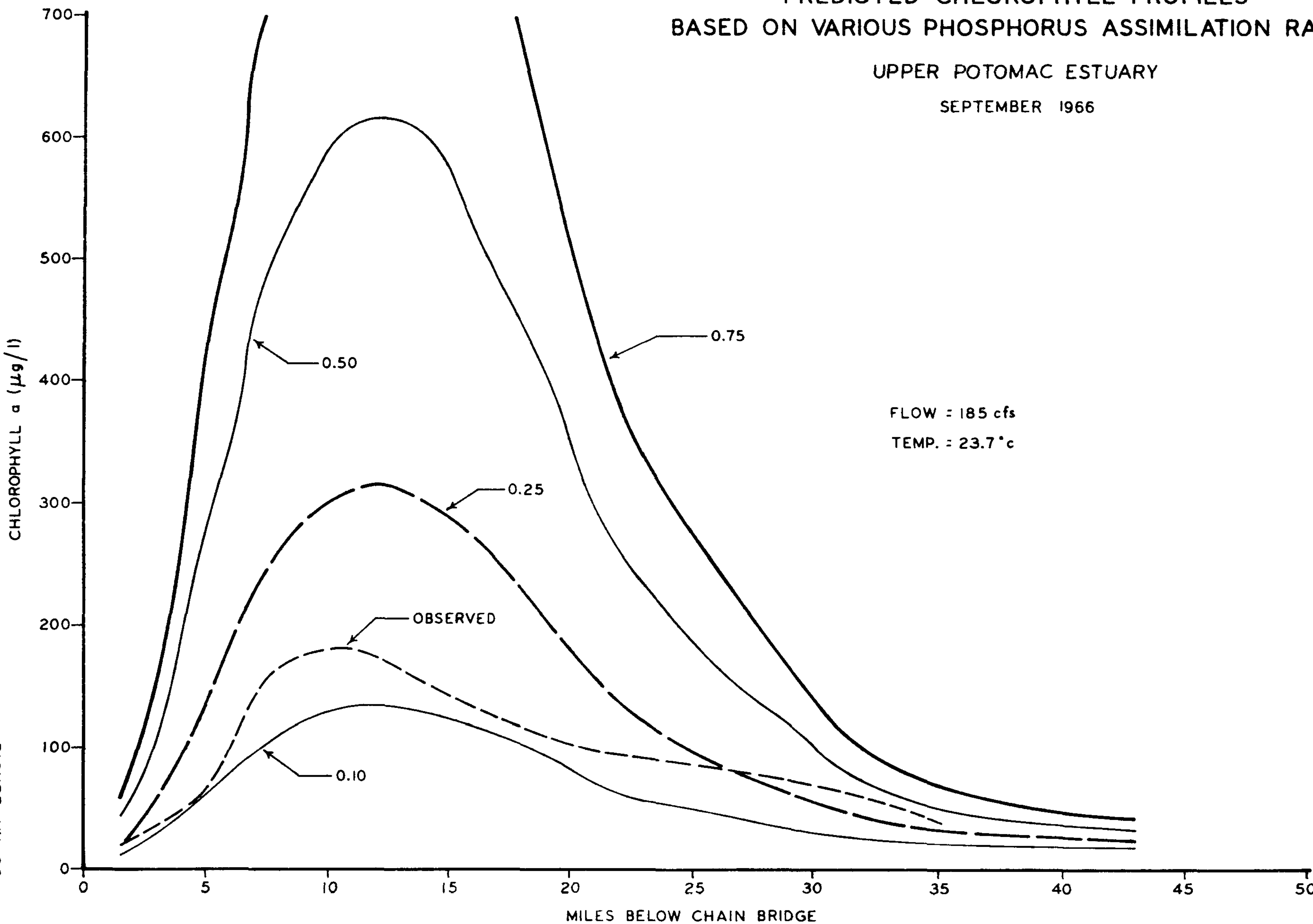


FIGURE VII-23

PREDICTED CHLOROPHYLL PROFILES BASED ON VARIOUS PHOSPHORUS ASSIMILATION RATES

UPPER POTOMAC ESTUARY

OCTOBER 1968

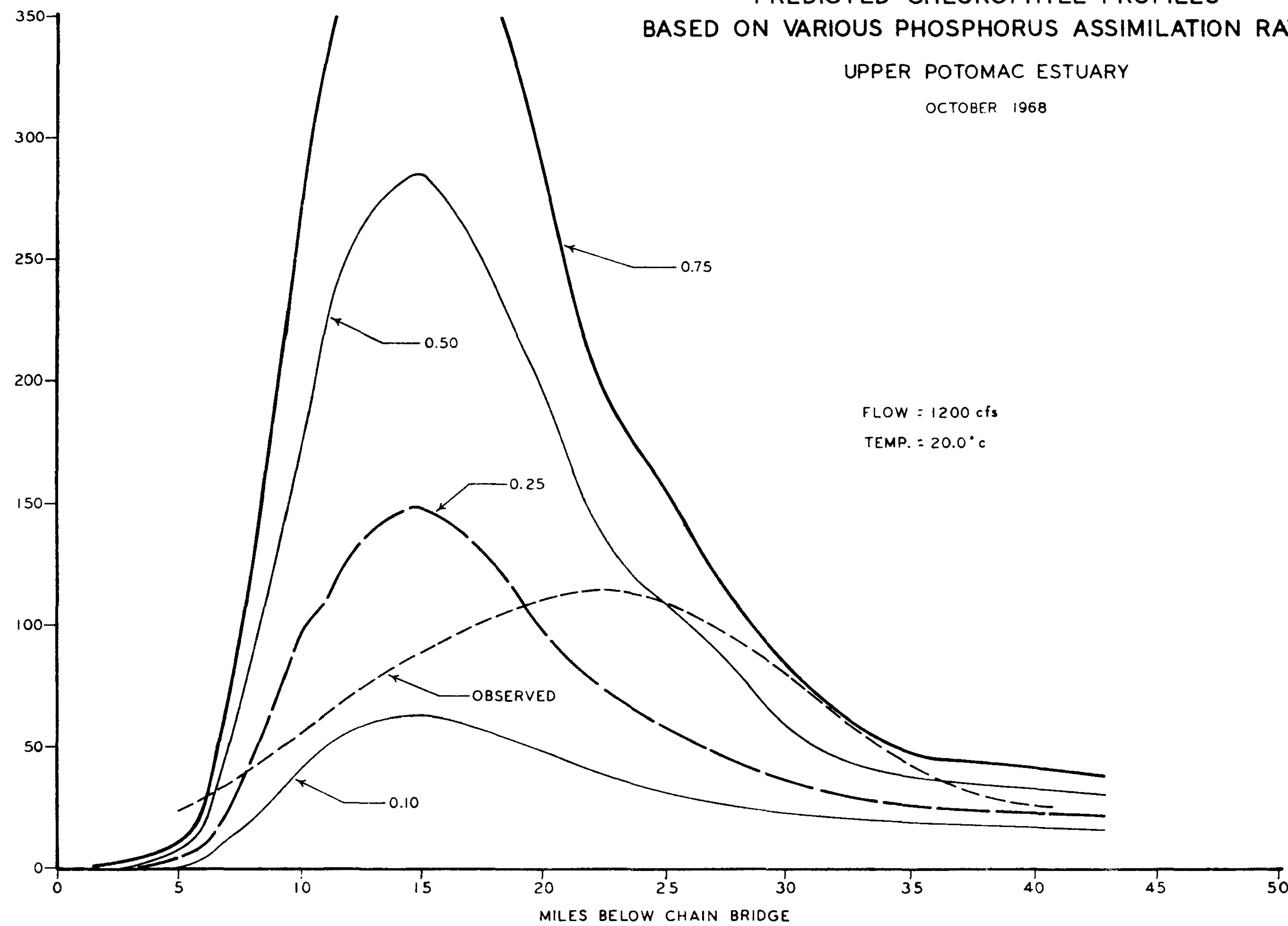


FIGURE VII-24

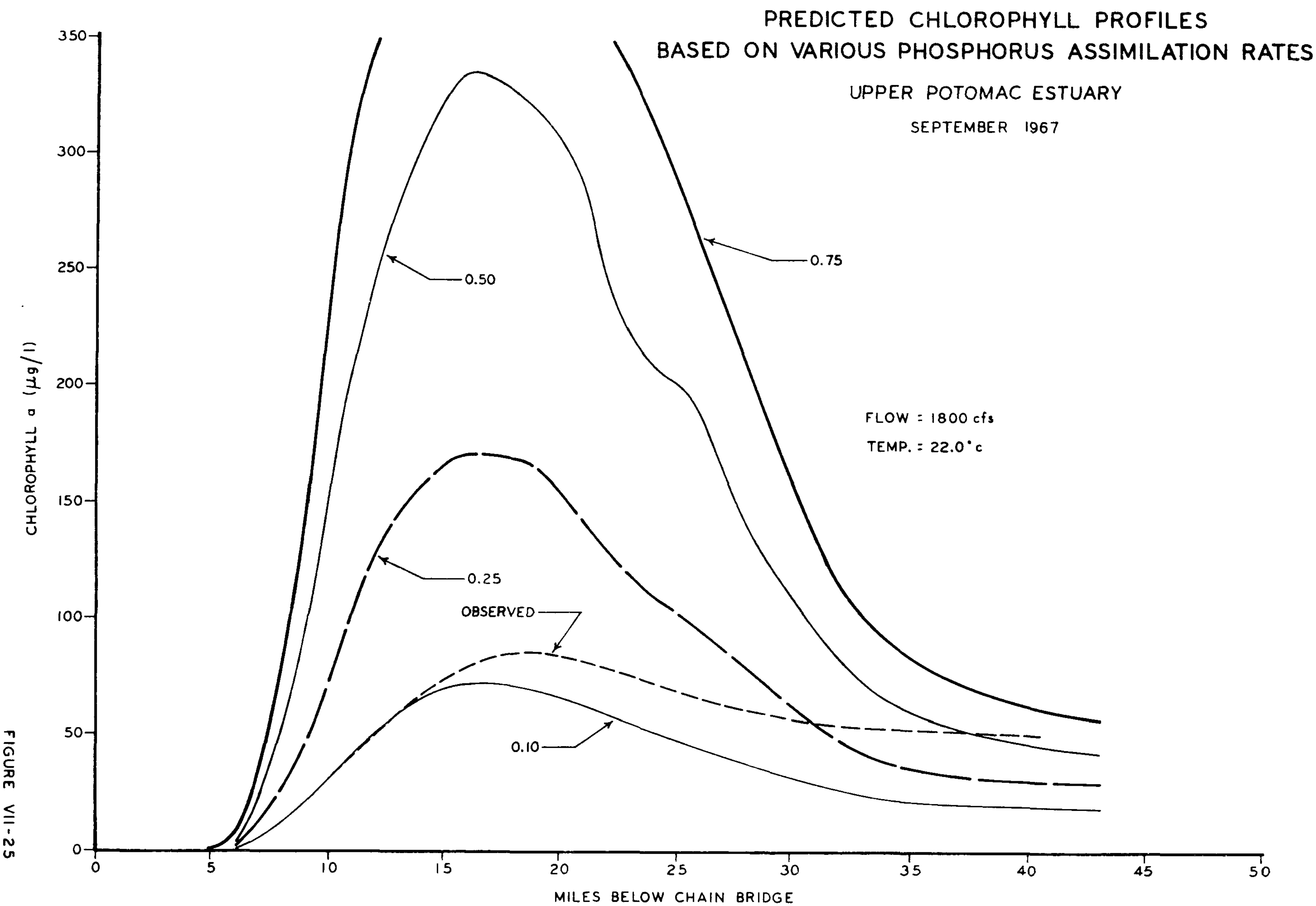


FIGURE VII-25

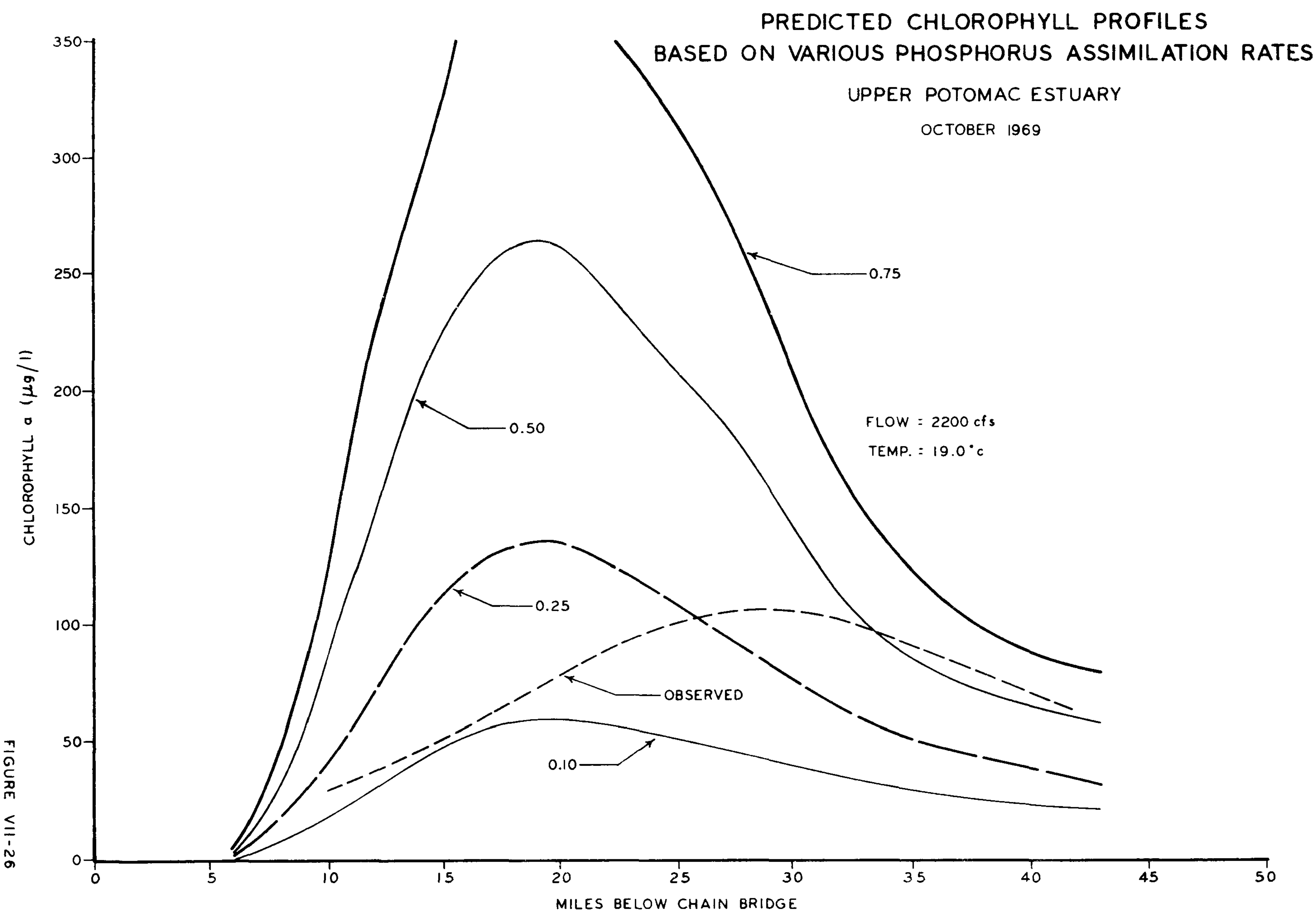


FIGURE VII-26

CHAPTER VIII

DISSOLVED OXYGEN BUDGET

A. FORMULATION OF SOURCES AND SINKS

A schematic diagram of the dissolved oxygen budget incorporated in the AFO mathematical model of the Potomac Estuary is shown in Figure V-3. As can be seen, the model consisted of the following five linkages:

1. Oxidation of carbonaceous matter,
2. Oxidation of nitrogenous matter (ammonia and organic nitrogen),
3. Oxygen production and respiration of simulated algal standing crops based upon the nitrogen cycle,
4. Benthic demand, and
5. Atmospheric reaeration.

One important limitation of the DO model presented above is that it neglected the oxygen demand of dying and decomposing algae. An effect such as this may be included relatively easily by regenerating the oxidizable carbon and nitrogen "tied-up" in plant cells and was considered in a subsequent version of the model discussed later in this report. Although this DO sink may be significant in the fall months when algal death is prevalent, the extremely low chlorophyll decay rates required for most model verification runs (Chapter VI) and the apparent success of the existing model in simulating various DO conditions suggests that it is negligible during the natural growth phase of the algae's life cycle when compared to other major sinks of oxygen.

The basic coefficients and assumptions employed in the DO budget model were:

Process	Rate (base e) at 20°C	Temperature Coefficient $\theta\ (T_1 - T_{20})$
Carbonaceous oxidation	0.170	1.047
Nitrogenous oxidation	0.084	1.16
Reaeration from the Atmosphere	*	1.021

Algal oxygen production rate = 0.012 mg O_2/hr/μg chlorophyll a

Algal respiration rate = 0.0008 mg O_2/hr/μg chlorophyll a

Euphotic zone = 2 feet

Respiration depth = full depth of water column

Algal oxygen production period = 12 hours

Algal respiration period = 24 hours

Benthic demand rate = 1.0 grams O_2/sq. meter/day

All of the above rates were established through field and laboratory studies, with the exception of the nitrogenous oxidation rate which was determined from modeling of the nitrogen cycle as presented in Chapter VI.

Light and dark bottle studies were conducted at various locations in the upper and middle Potomac Estuary during June-July, 1970, to

* Based on O'Connor-Dobbins velocity and depth formulation

estimate the oxygen production and respiration rates for a known standing crop of algae. The data collected during this survey are shown in Table VIII-1. A considerable amount of data relating to light penetration (Secchi Disk) was available for the entire Potomac Estuary. The assumed depth of the euphotic zone was based upon an analysis of this data. Finally, a benthic respirometer was used by AFO in the upper estuary to obtain benthic oxygen demand rates. These data, which are shown in Figure VIII-1, indicate that benthic uptake rates vary spatially, with the maximum rate occurring near the District of Columbia's Blue Plains Sewage Treatment Plant (River Mile 10.4).

Table VIII-1

OXYGEN PRODUCTION AND RESPIRATION RATE SURVEY
Upper and Middle Potomac Estuary
1970

Date	Water Temp. (°C)	Chlorophyll *a* Range (μg/l)	Light Intensity Range (foot candles)	Oxygen Production mg/hr/μg of Chlorophyll a	Respiration mg/hr/μg of Chlorophyll a
6-22	26	40-110	250-300	.0073	.0023
6-23	27	70-120	200-300	.0084	.0011
6-24	27	54-110	200-300	.0087	.0024
6-25	27	50-60	200-300	.0121	.0033
7-20	28	30-100	250-400	.0130	.0022
7-21	27	30-143	200-300	.0130	.0016
7-22	26	30-140	100-200	.0146	.0017
7-27	28	-	-	.0060	.0010

BENTHIC UPTAKE

POTOMAC ESTUARY

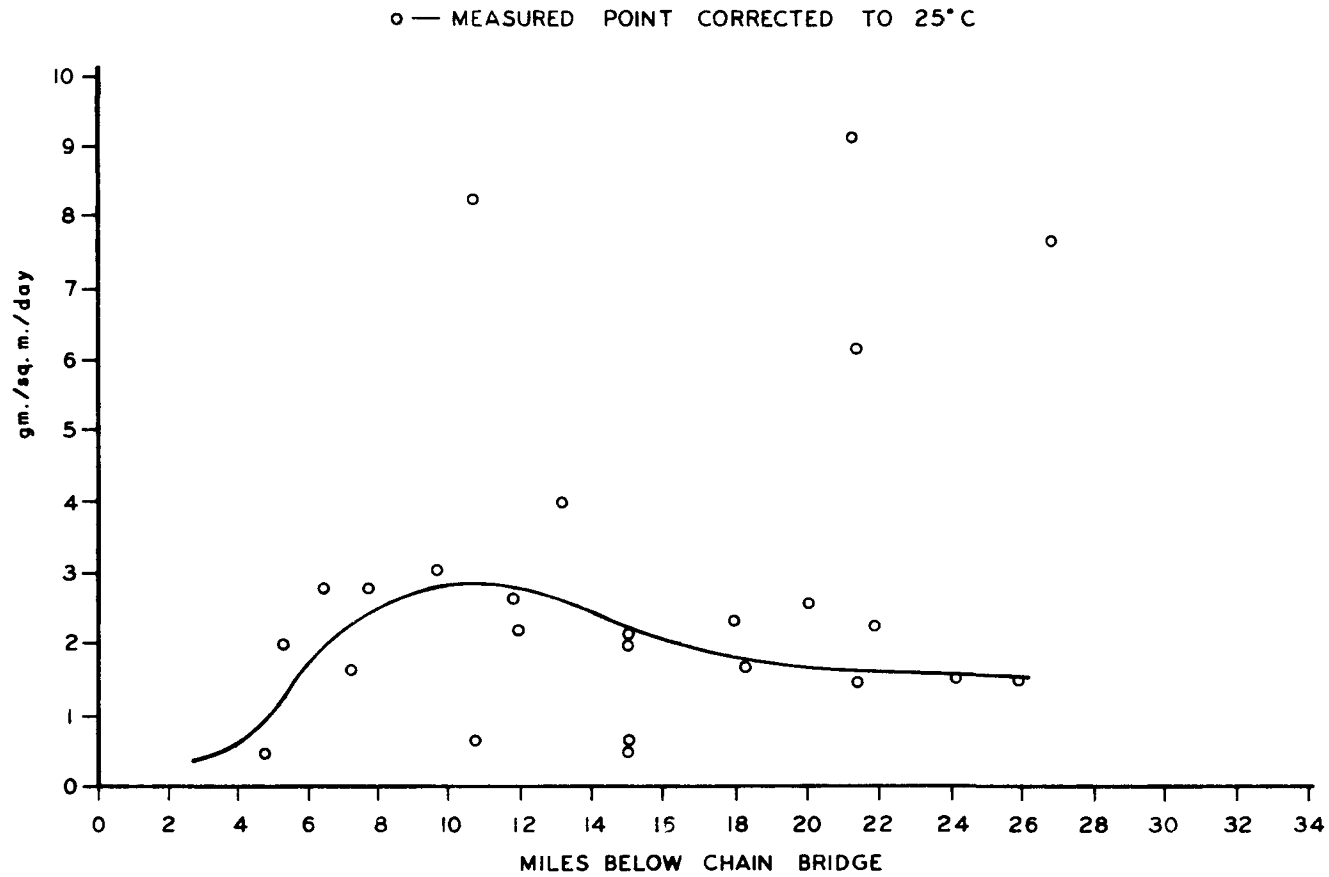


FIGURE VIII-1

B. SIMULATION AND MODEL VERIFICATION STUDIES

Eight separate intensive sampling runs conducted in the upper Potomac Estuary between 1965 and 1969 were used, initially, to verify the DO budget model, including the various reaction rates and assumptions presented in the previous section. Each run represented approximately a 20- to 30-day period under relatively steady-state conditions. The flows for the eight sets of sampling data ranged from 185 cfs to 8,800 cfs.

Figures VIII-2 through VIII-9 show the observed DO profiles and those predicted by the mathematical model. As can be seen, favorable agreement was obtained in every case. Although the two sets of profiles did not coincide exactly, the magnitude and location of the critical DO deficit and the general rate of depression and recovery appeared to be simulated reasonably well using the aforementioned coefficients. The critical deficit was primarily the result of the oxidation of carbonaceous and nitrogenous material in the wastewater effluents; the rate and extent of DO recovery was influenced greatly by the net effect of algal photosynthesis and respiration.

The pronounced decrease in DO predicted by the model in the extreme upper portion of the estuary during lower flow periods could have been due to the very deep holes in this area, which lowered the reaeration capacity and magnified the effects of algal respiration.

As a further test of the model's capability to predict dissolved oxygen distribution in the Potomac Estuary, a completely independent and more recent (September 1970) condition was simulated. The sampling data collected by AFO on September 9, served to define the initial conditions. Data collected 20 days later and compared to model predictions after a comparable time period were used as a basis for verification.

The freshwater flow during this period ranged from 1,200 cfs to 1,900 cfs (1,500 cfs average), and the reaction rates and assumptions incorporated in the other eight runs were applied without change. The results of this simulation are shown in Figure VIII-10. Generally, good agreement was obtained between observed and predicted data describing the rate of oxygen depletion, the magnitude and location of the critical deficit, and the initial stage of recovery. The considerable divergence in the later stages of recovery may be ascribed to the extensive algal death and decomposition which normally occurs in that area of the estuary during late September. As stated previously the additional oxygen demanding load resulting from the biological decay of algal cells and nutrient regeneration had not been incorporated into this version of the model, and consequently, the secondary DO depressions that at times exist in the Potomac Estuary were not accurately simulated.

DISSOLVED OXYGEN PROFILES

UPPER POTOMAC ESTUARY

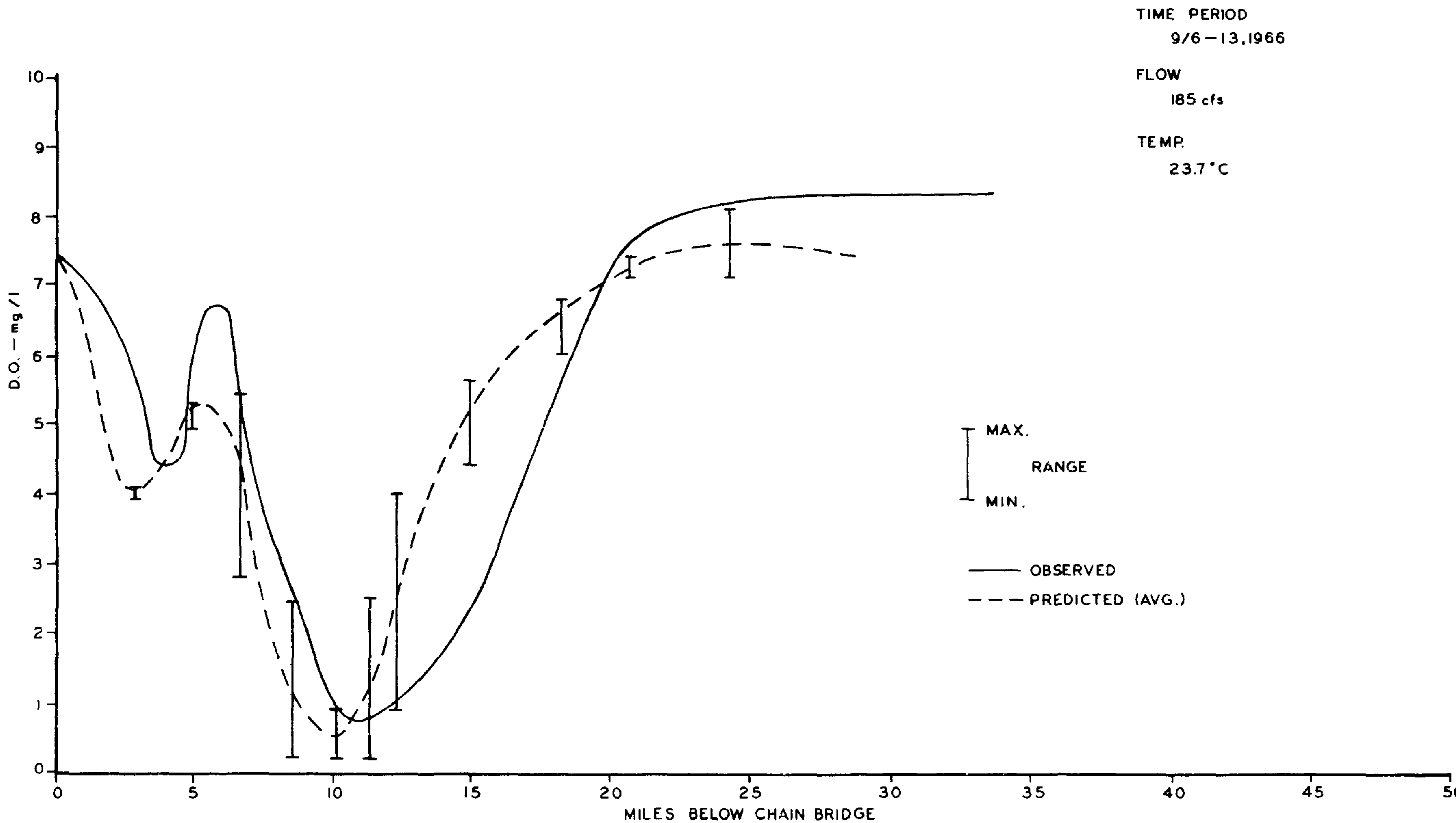


FIGURE VIII–2

DISSOLVED OXYGEN PROFILES
UPPER POTOMAC ESTUARY

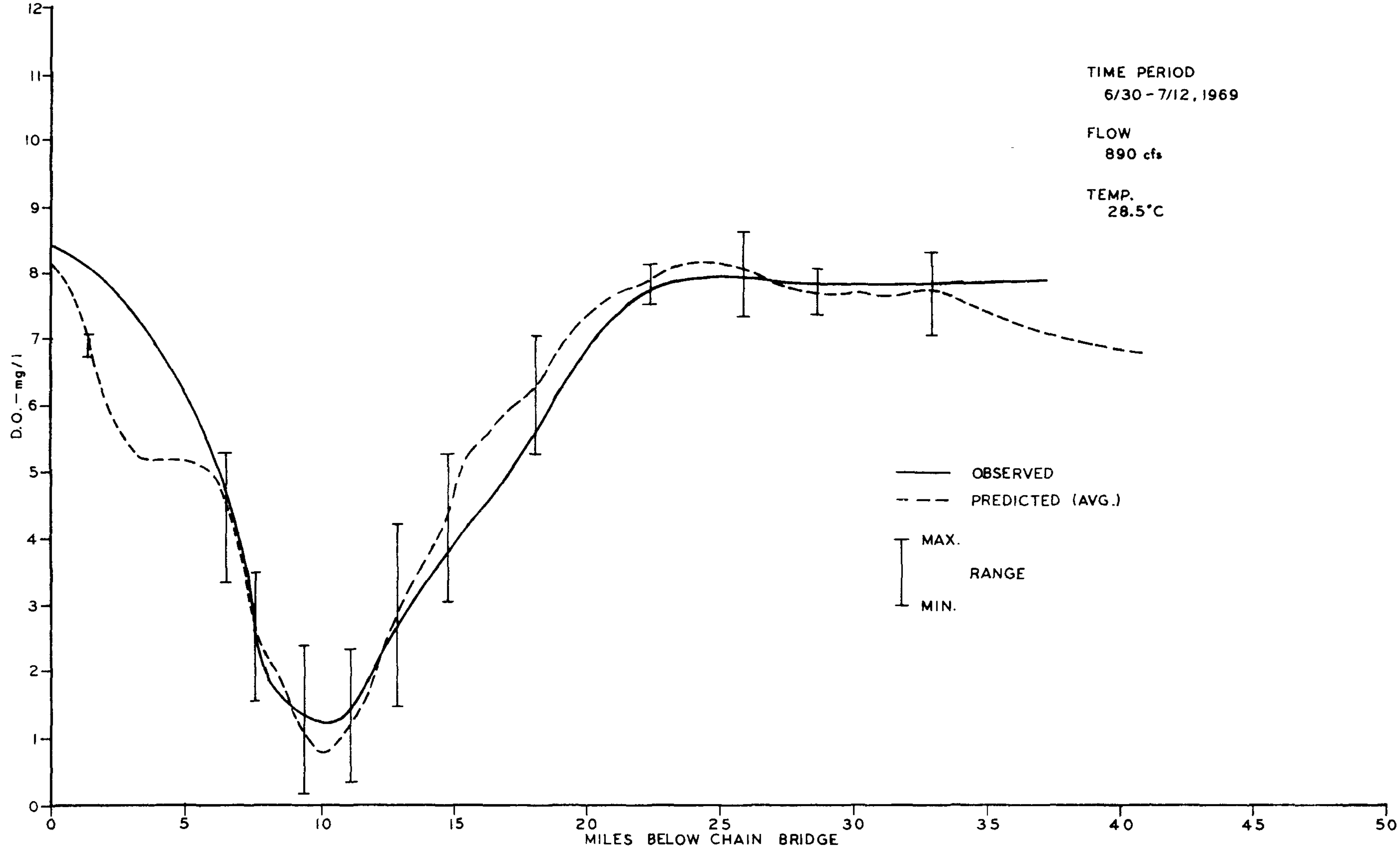


FIGURE VIII-3

DISSOLVED OXYGEN PROFILES
UPPER POTOMAC ESTUARY

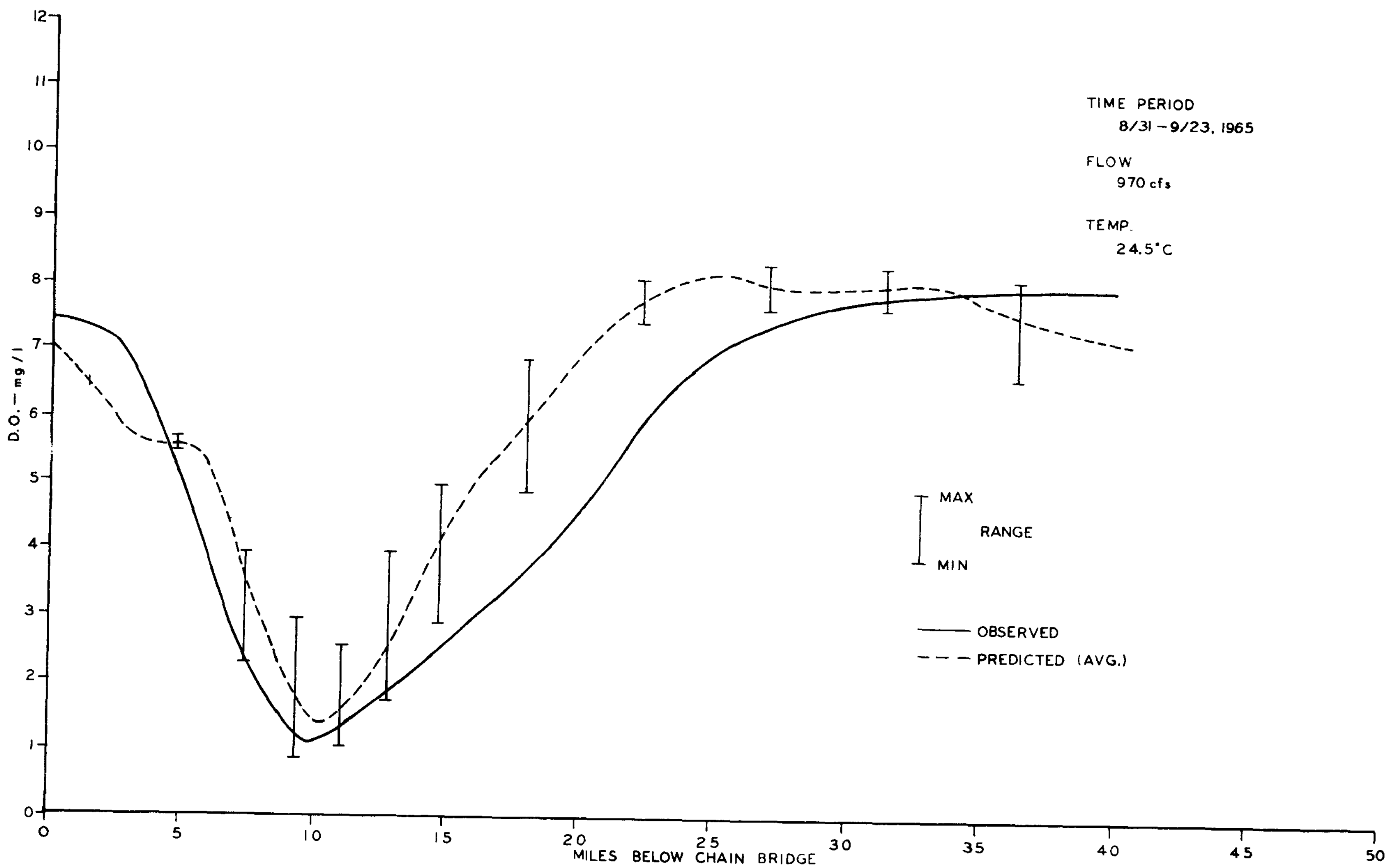


FIGURE VIII–4

DISSOLVED OXYGEN PROFILES
UPPER POTOMAC ESTUARY

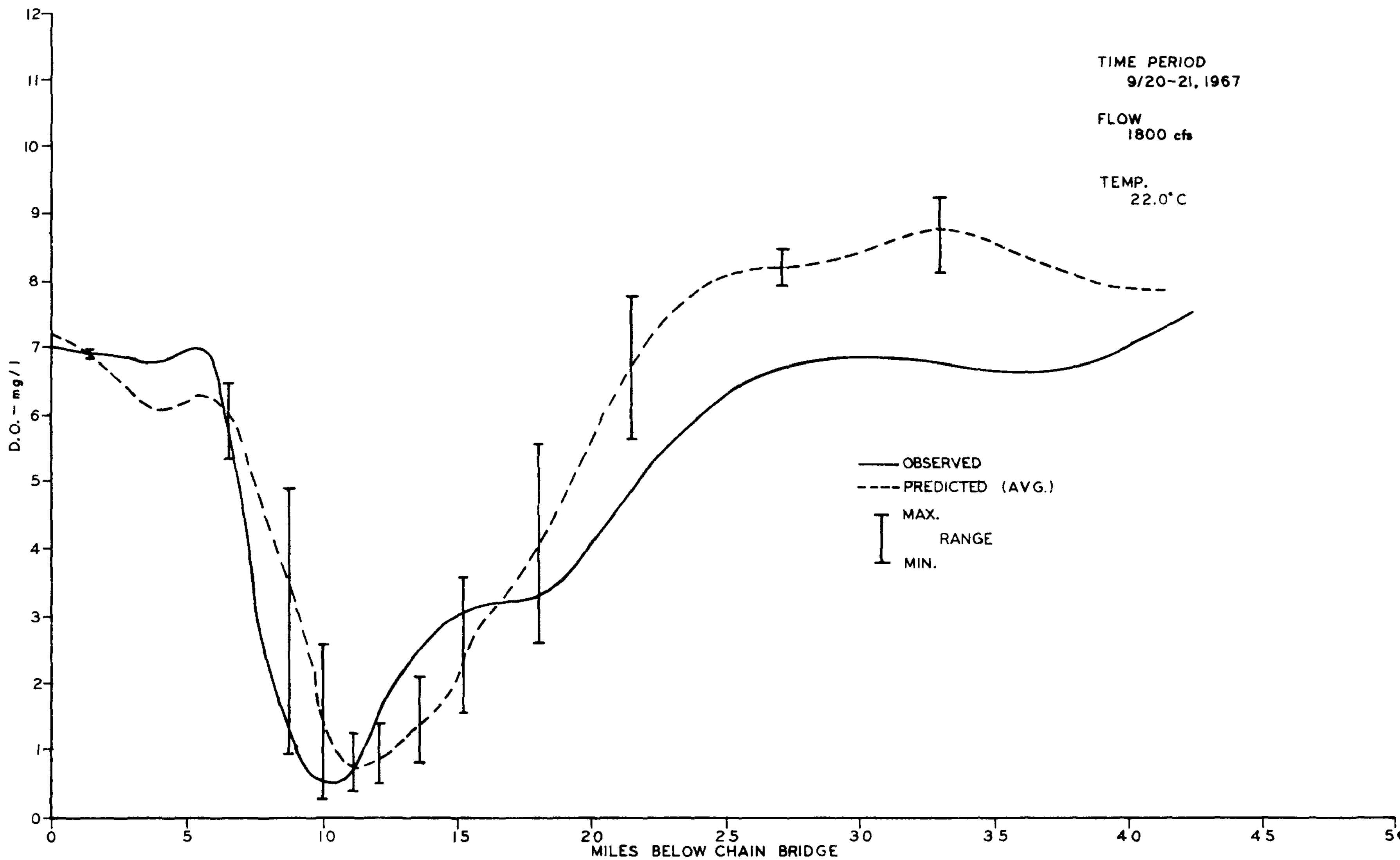


FIGURE VIII-5

DISSOLVED OXYGEN PROFILES
UPPER POTOMAC ESTUARY

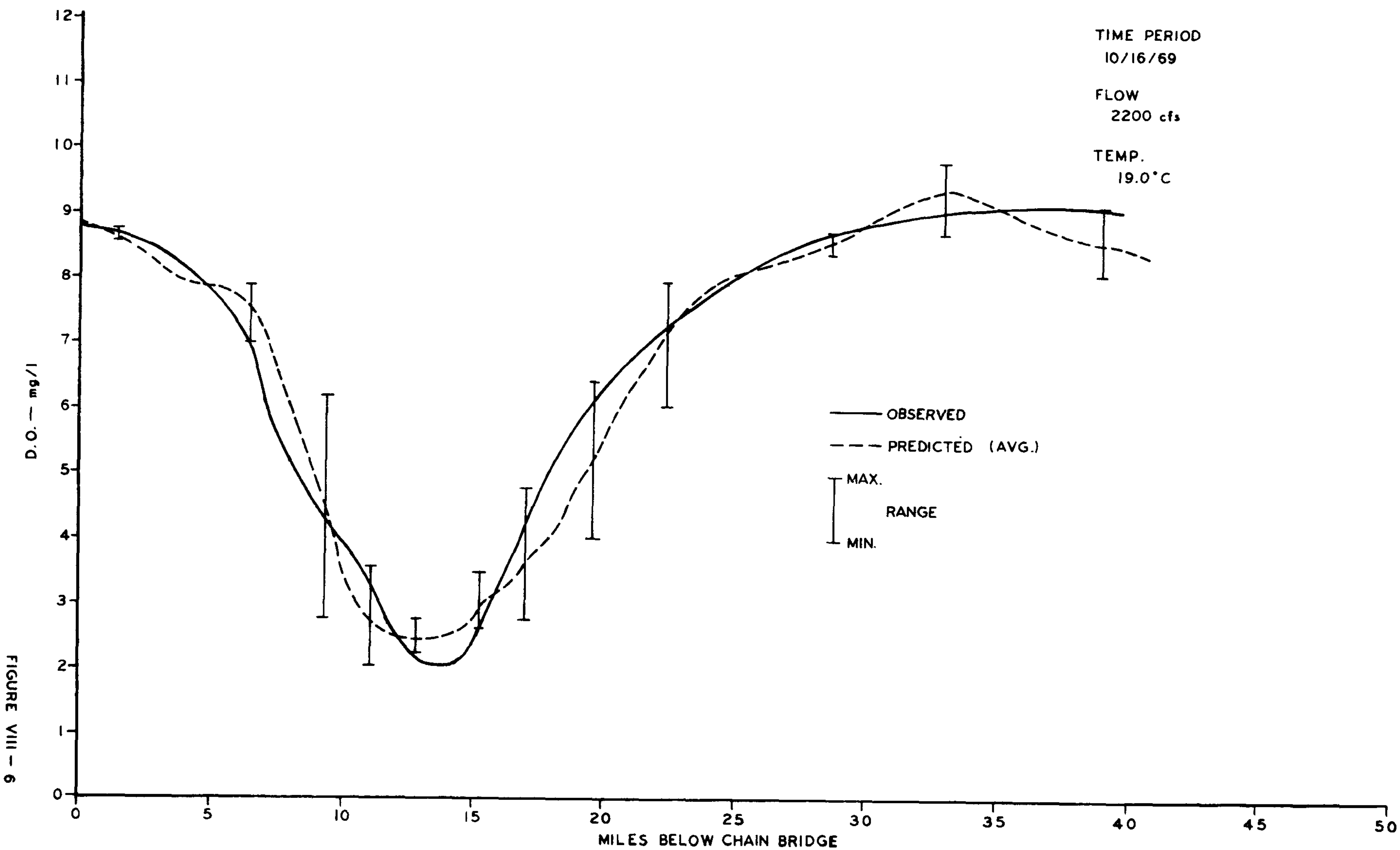


FIGURE VIII – 6

DISSOLVED OXYGEN PROFILES

UPPER POTOMAC ESTUARY

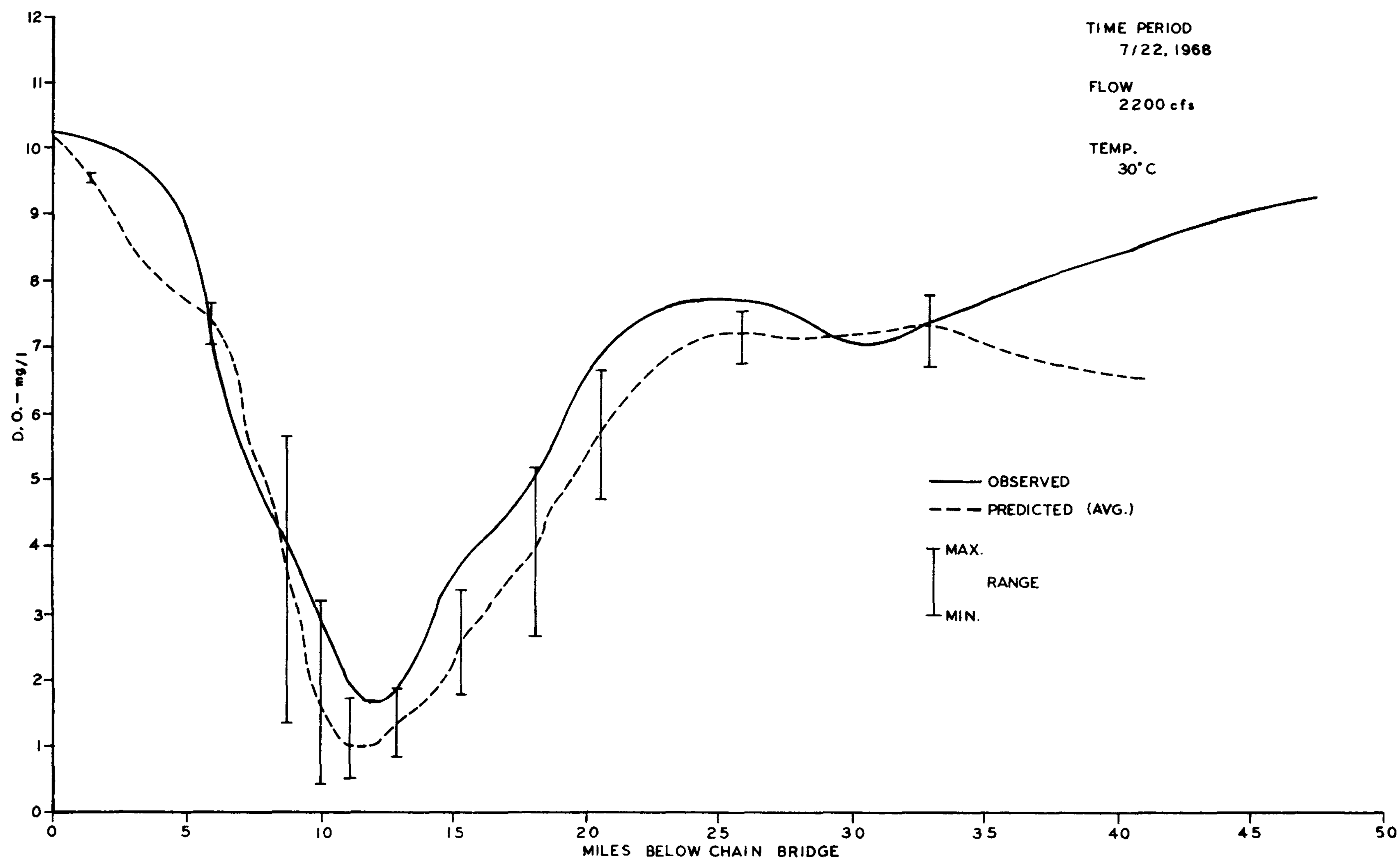


FIGURE VIII-7

DISSOLVED OXYGEN PROFILES

UPPER POTOMAC ESTUARY

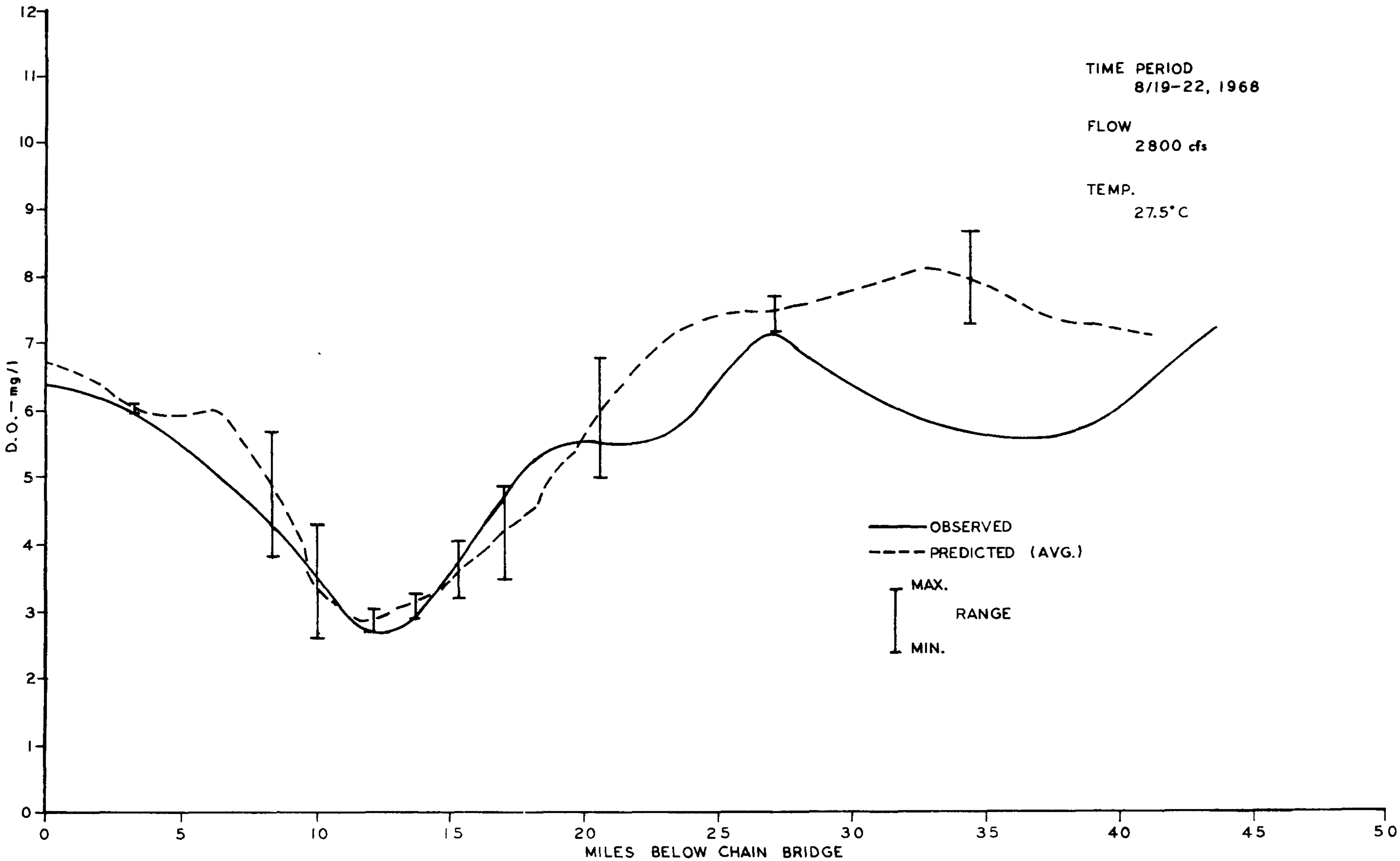


FIGURE VIII-8

DISSOLVED OXYGEN PROFILES
UPPER POTOMAC ESTUARY

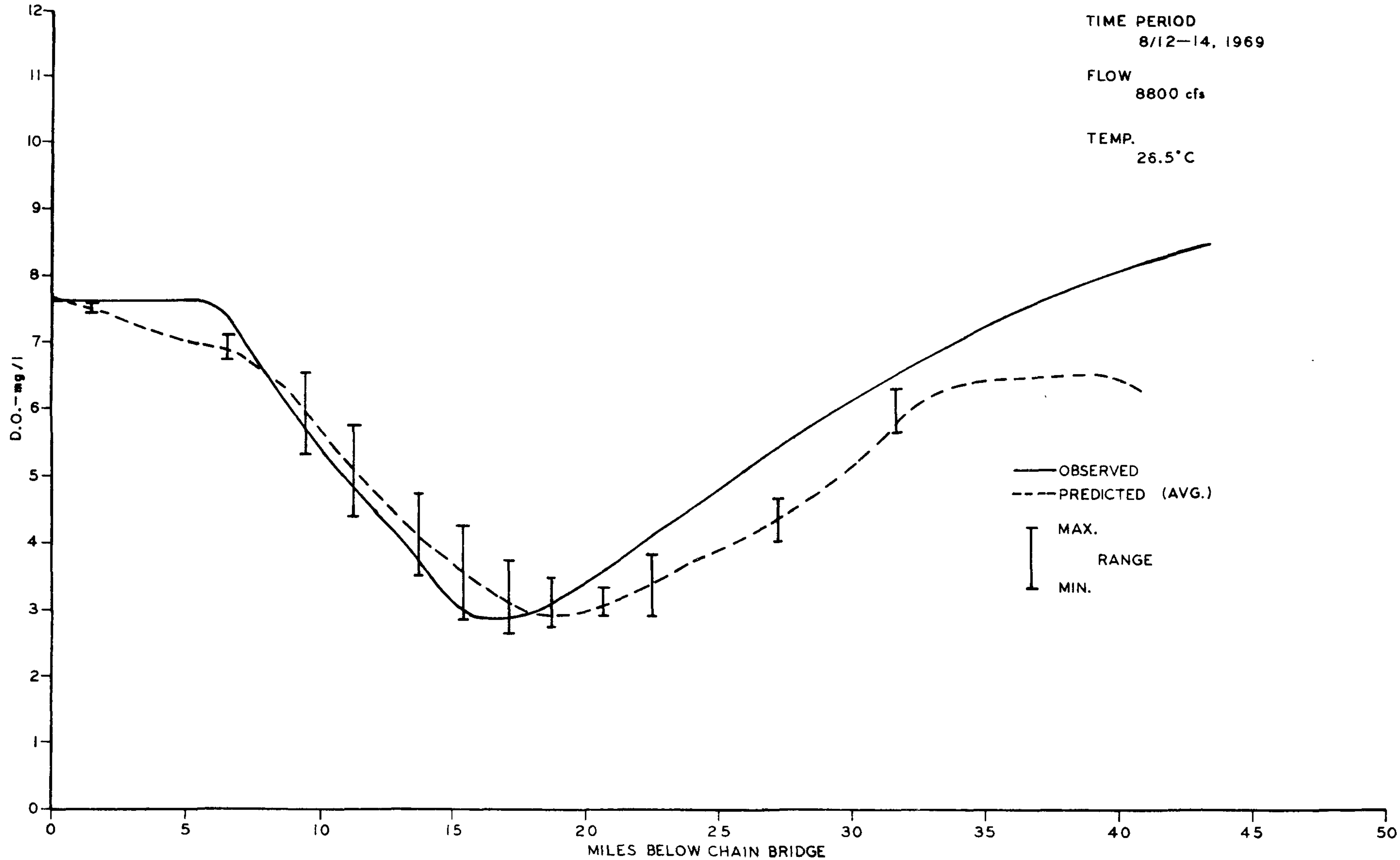


FIGURE VIII—9

DISSOLVED OXYGEN PROFILES

UPPER POTOMAC ESTUARY

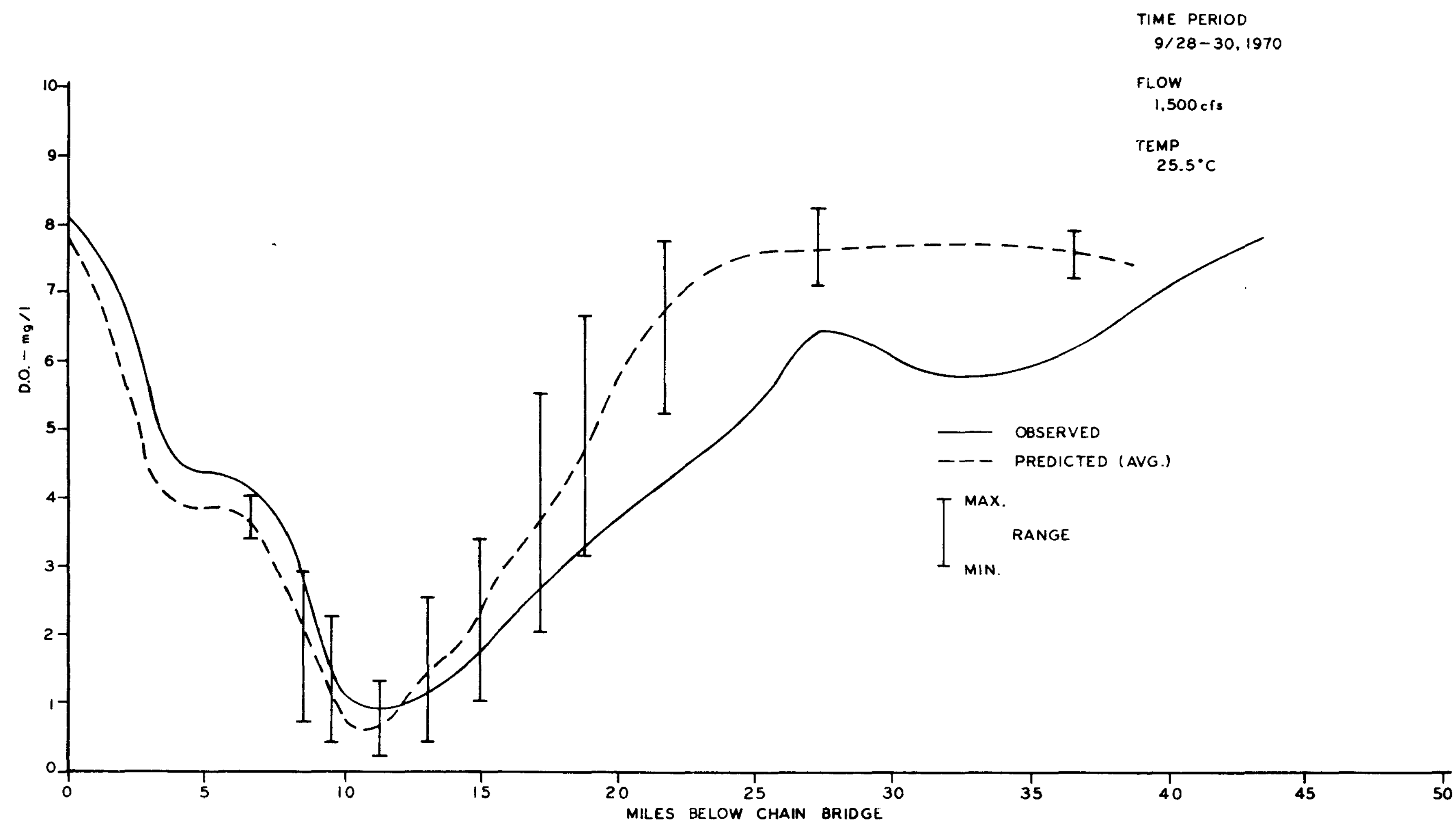


FIGURE VIII-10

C. SENSITIVITY ANALYSIS

A study was performed to determine the Potomac Estuary DO model's sensitivity to the various input rates. A knowledge of the relative importance of each rate in the DO budget offers assistance for (1) model verification, (2) the design of field and laboratory studies to define a particular rate by suggesting the necessary degree of accuracy required, and (3) the relation of the gross effect of each rate to the estuary's physical and biological parameters such as depth, surface area, and algal productivity.

The general approach adopted in this sensitivity analysis was to assume two values for each rate--one approximately one-half and the other twice the verified value. All of the model runs simulated the October 1969 loading condition that had been previously verified.

1. Effects of Oxidation Rates (Carbon and Nitrogen)

The simulated DO profiles based on carbonaceous and nitrogenous oxidation rates of 0.1/day and 0.3/day are shown in Figures VIII-11 and VIII-12. Figure VIII-11 illustrates the considerable effect that the carbonaceous rate exerts on the DO distribution, and in particular on the magnitude of the maximum deficit. Increasing the oxidation rate threefold results in a lowering of the critical sag point from 4.0 mg/l to 0.2 mg/l.

A comparison of Figures VIII-11 and VIII-12 clearly shows that the DO model is markedly less sensitive to the rate of nitrogenous oxidation than to the carbonaceous rate. A variation in K_n comparable to that of K_c produced a change in the critical DO deficit of only about 1.0 mg/l. The reason for this difference in model sensitivity can be attributed to the greater masses of carbon in the system, and hence a greater range in the amount of oxidized material and DO demand for a given range in rates.

2. Effects of Photosynthesis and Respiration Rates

The effects of changing the algal photosynthesis or respiration rates in the DO model are quite extreme, particularly in the recovery region of the upper Potomac Estuary where algal growth is usually excessive. As shown in Figures VIII-13 and VIII-14, the model predictions behaved similarly when either the photosynthesis rate was increased or the respiration rate was decreased.

According to the DO profiles in Figure VIII-13, increasing the rate of photosynthesis fourfold, from 0.006 to 0.024 mg O_2/hr/μg chlorophyll, increased the critical sag point by 4.0 mg/l and greatly accelerated the rate and degree of DO recovery. Figure VIII-14 shows a similar occurrence when the respiration rate was lowered from 0.0016 to 0.0004 mg O_2/hr/μg chlorophyll. It should be noted that the maximum chlorophyll concentrations observed during the simulation period were approximately 100 μg/l. Of course, both the individual effects of photosynthesis and respiration as well as the net effect will be dependent upon the quantity of algae present.

The model's sensitivity to euphotic depth was also investigated and the results closely paralleled to those presented for the photosynthesis rates.

3. Effects of Benthic Demand Rate

Since the units of benthic demand rate include an areal term (ft^2), its effects are closely related to the surface area of the Potomac Estuary. Figure VIII-15 illustrates the resulting DO profiles when benthic rates of 0.0 and 2.0 gr/meter^2/day were assigned. As can be seen, the higher rate significantly lowered the entire profile with the most pronounced differences occurring in the wider downstream areas. However, it did not drastically alter the DO gradients or the rates of depression and recovery.

4. Effects of Reaeration Rate

Of the various DO budget components investigated in this sensitivity analysis, the method by which the reaeration rate is computed, i.e. O'Connor-Dobbins equation, Churchill equation, or USGS (Langbein) equation, was the least important in terms of affecting model output. In fact, the three profiles shown in Figure VIII-16 are coincident, indicating that any of the more commonly used equations for determining reaeration rates should prove equally successful.

EFFECTS OF CARBONACEOUS OXIDATION RATE

DEM D.O. SIMULATIONS

OCT. 1969 DATA

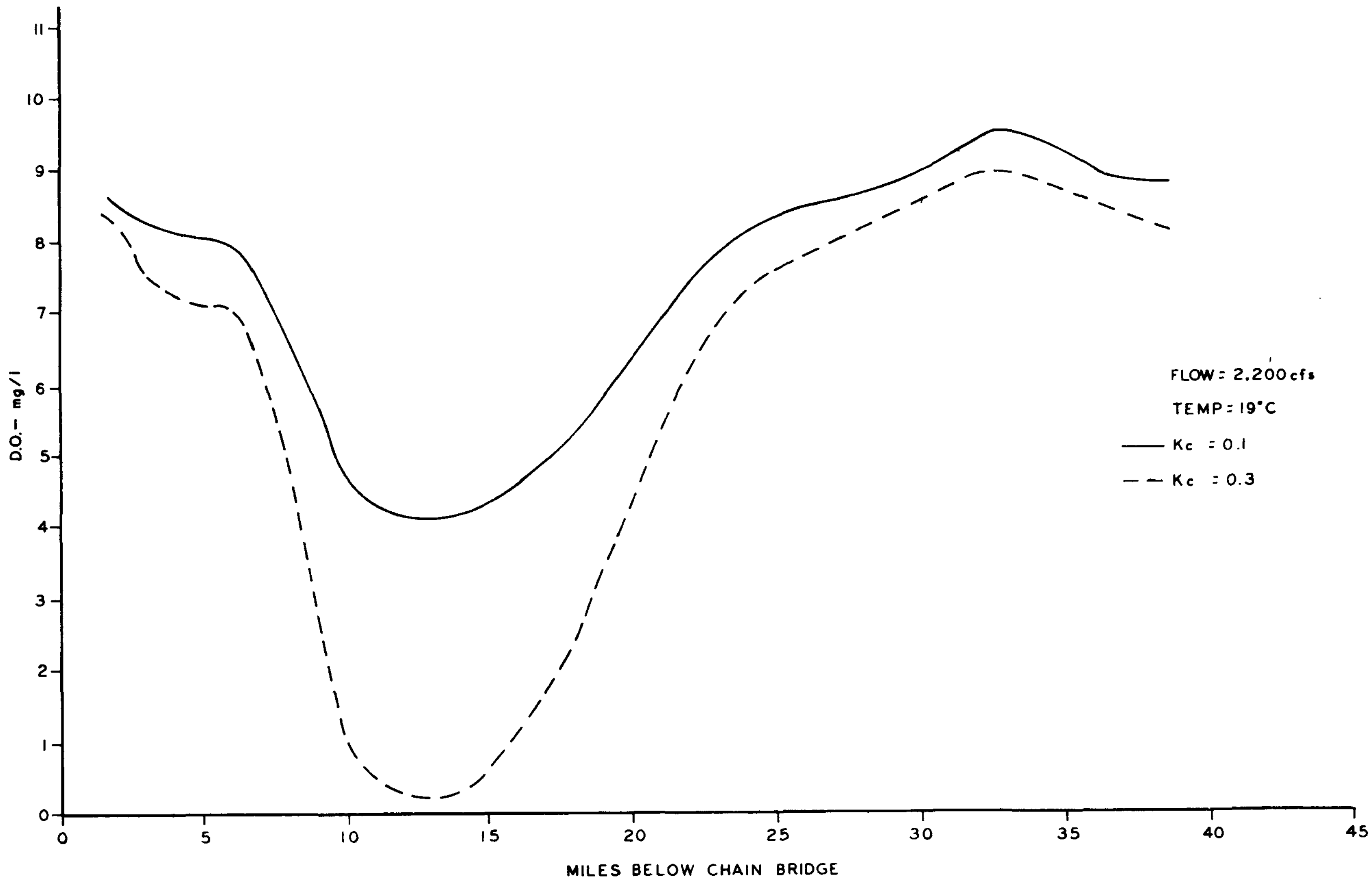


FIGURE VIII-11

EFFECTS OF NITROGENOUS OXIDATION RATE

DEM D.O. SIMULATIONS

OCT. 1969 DATA

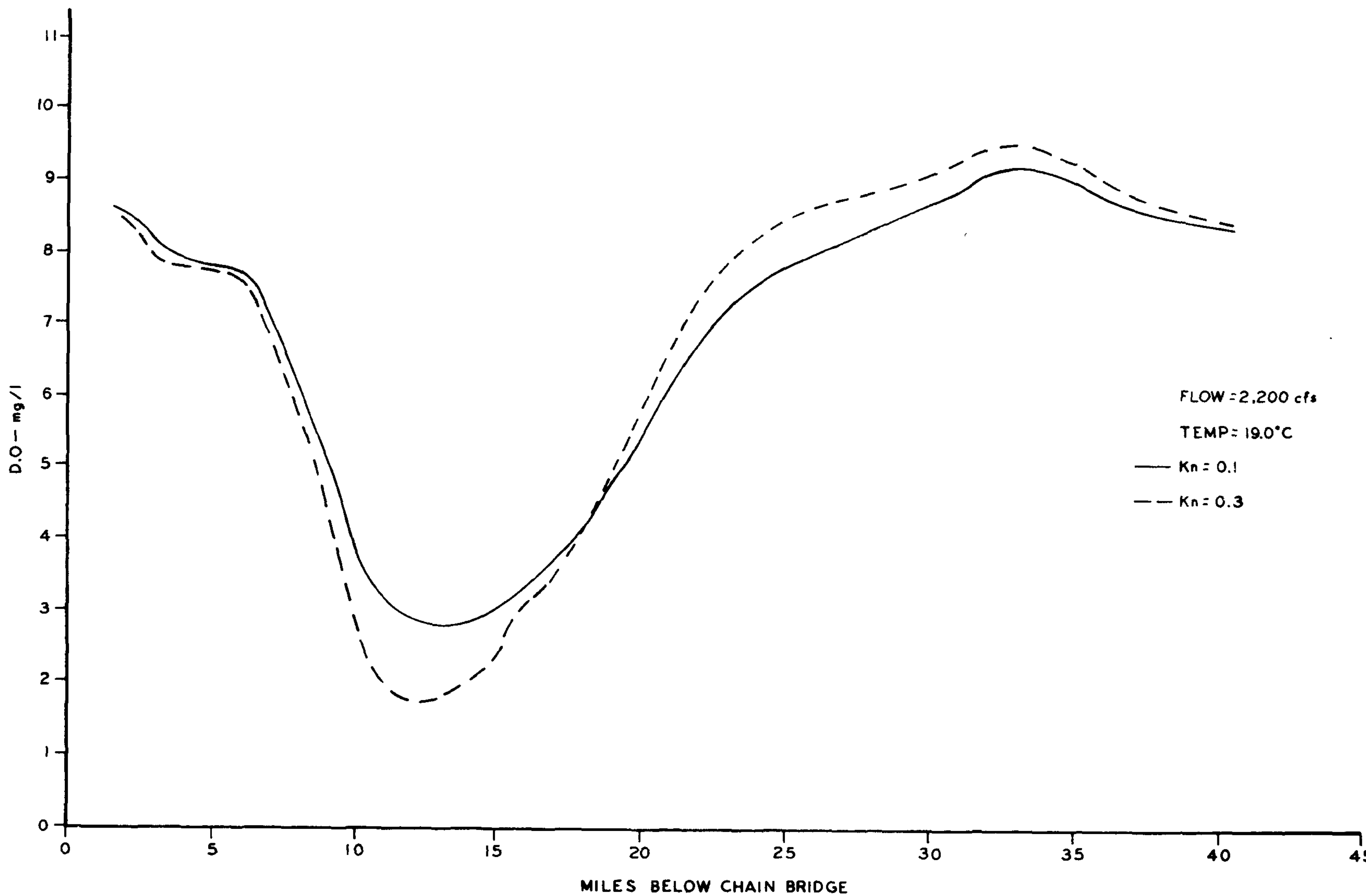


FIGURE VIII – 12

EFFECTS OF PHOTOSYNTHESIS RATE
DEM D.O. SIMULATIONS

OCT 1969 DATA

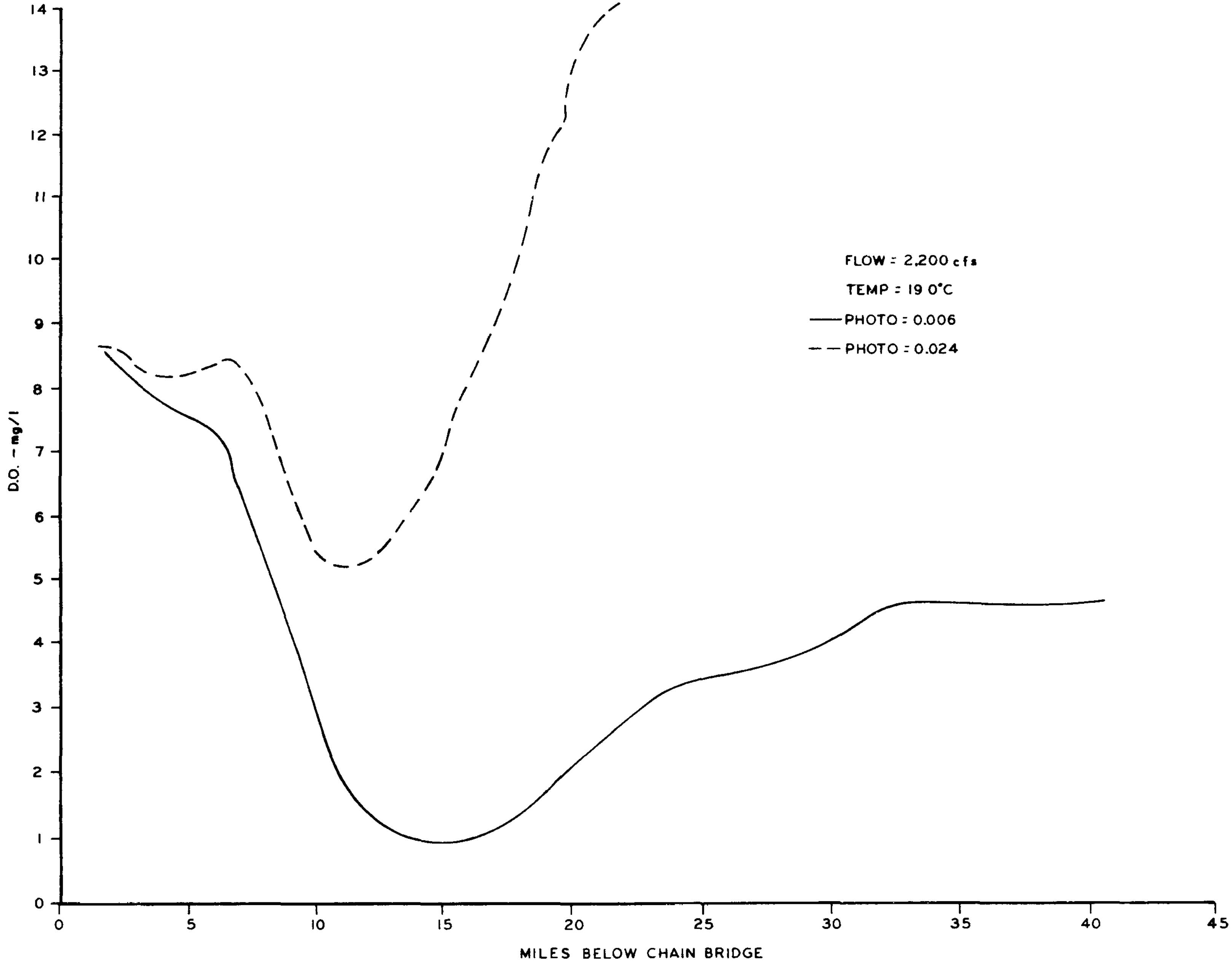


FIGURE VIII—13

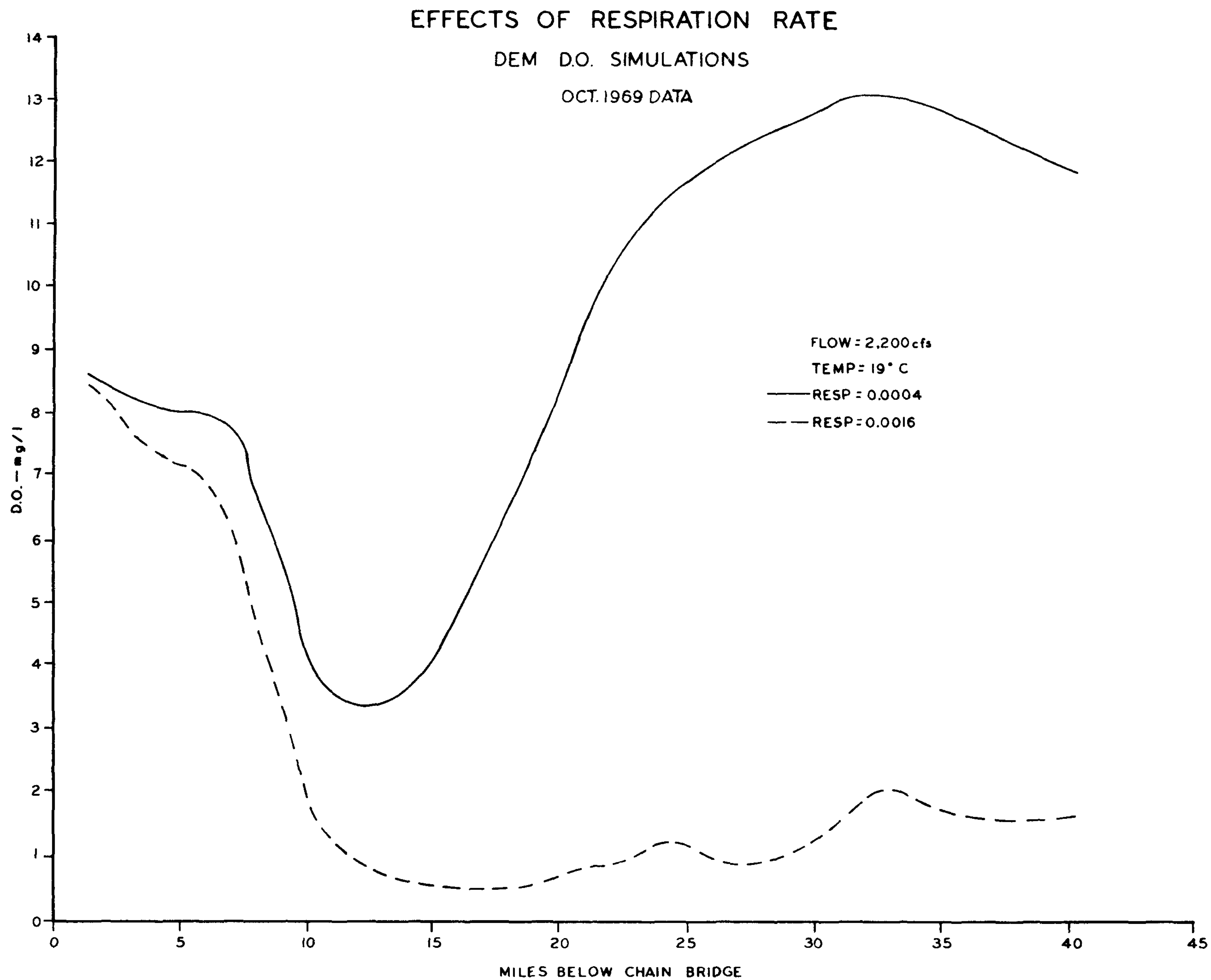


FIGURE VIII-14

EFFECTS OF BENTHIC RATE

DEM D.O. SIMULATIONS

OCT. 1969 DATA

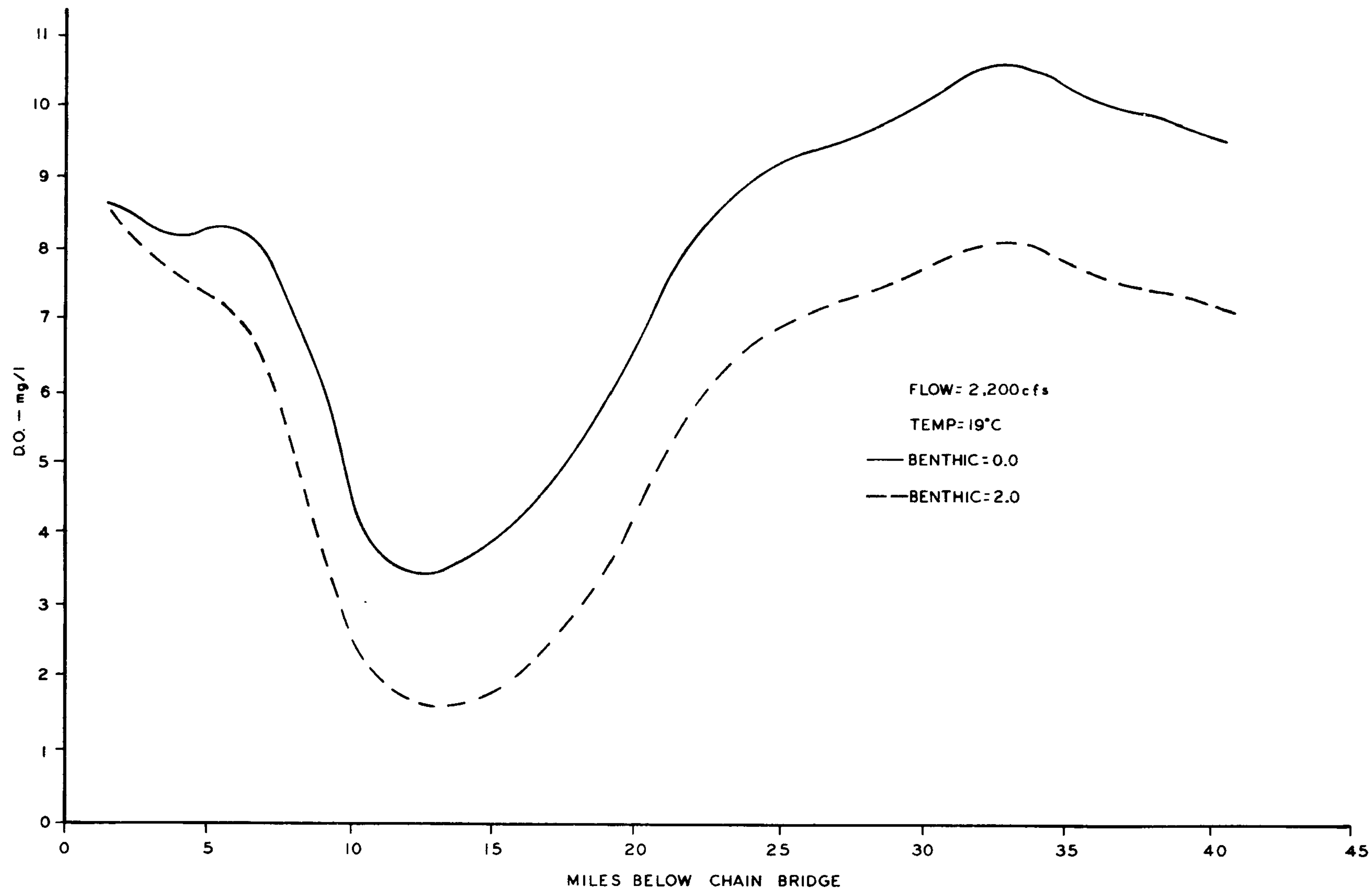


FIGURE VIII—15

EFFECTS OF REAERATION RATE FORMULATION

DEM D.O. SIMULATIONS

OCT. 1969 DATA

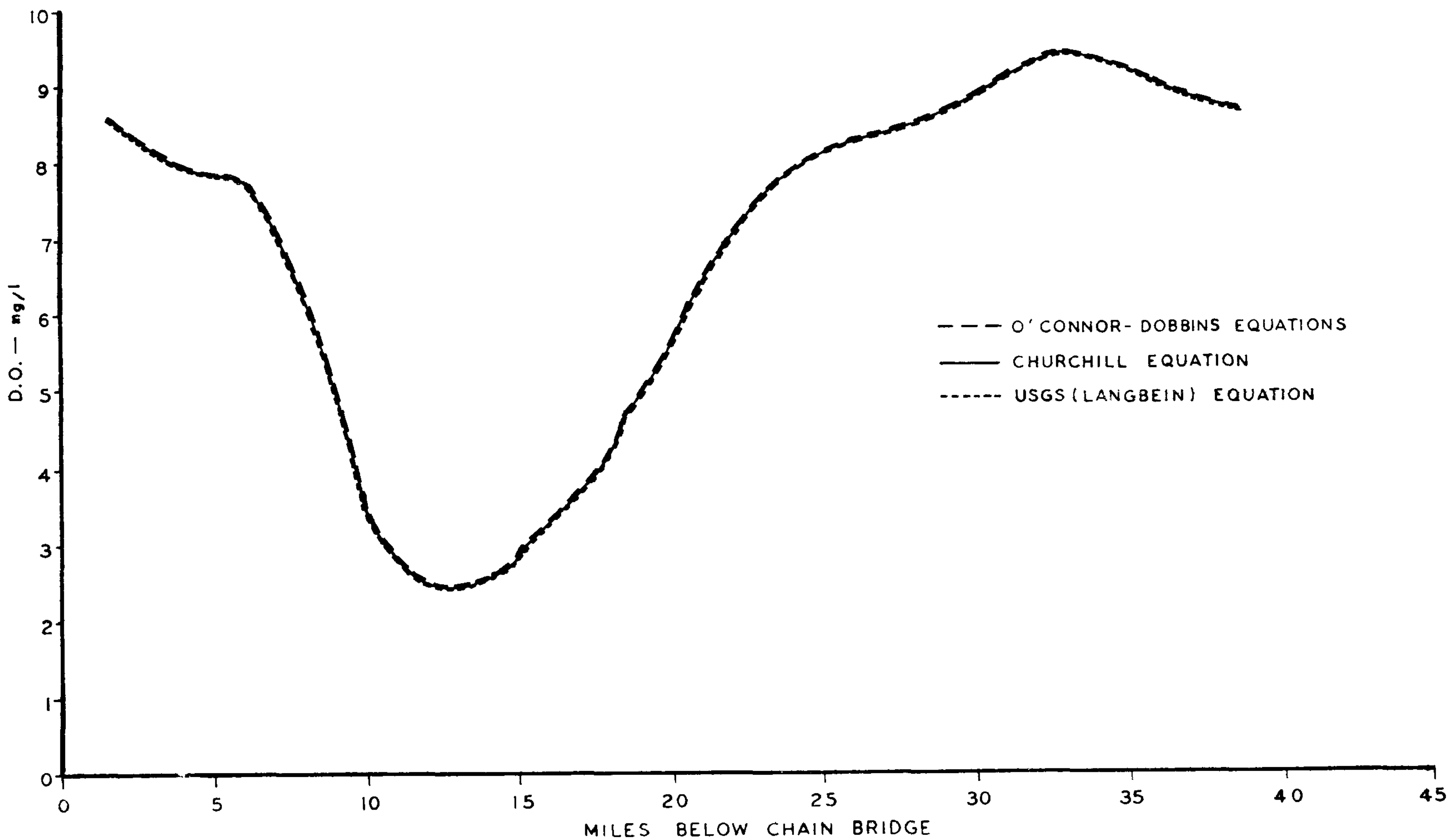


FIGURE VIII-16

D. NUTRIENT REGENERATION - SPECIAL DO MODEL

Realizing the inherent limitations of the dissolved oxygen model heretofore discussed, a further revision of the DEM to incorporate organic nitrogen and nutrient regeneration was investigated. Unfortunately, these inclusions complicated the "feedback-feedforward" linkage within the model somewhat and created a problem by simultaneously evaluating several reaction rates. Prior to this, there had been only a single unknown rate to be evaluated through each series of model verification runs. A considerable amount of background information relating to the nutrient regeneration process was, however, provided by Jewell [13].

Organic nitrogen was treated in two distinct forms in the model: (1) dissolved or soluble and (2) particulate. The latter, or course, would comprise organic nitrogen within algal cellular material. The dissolved fraction was "decayed" by first-order kinetics to ammonia nitrogen (hydrolysis), while a portion of the particulate form was regenerated to inorganic nitrogen (NH_3) and carbon (BOD), thereby creating an additional oxygen demand. Based on a subjective appraisal of existing information, it was assumed that 50 percent of the organic nitrogen and carbon in the dead algal cells, as computed from the mass of chlorophyll decayed, was regenerated; the remaining 50 percent was assumed to be deposited to the bottom sediment. Ratios of chlorophyll to nitrogen and chlorophyll to carbon were estimated using 1970 algal composition analysis data.

Upon completion of this "surrogate" DO model and estimation of the necessary reaction coefficients, a verification run was performed based on September 1970 data. This particular set of data was selected because it pertained to a time of year when algal death was prevalent, as indicated by the relatively high chlorophyll decay rate (0.07/day) required for model verification. Furthermore, a review of Figure VIII-10 shows that the recovery portion of the observed DO profile was not accurately simulated with the existing DO model, presumably because the effects of nutrient regeneration were omitted.

Figure VIII-17 illustrates the improved comparison that resulted from predictions using the mathematical model described herein. Both the rate of recovery and the secondary DO sag farther downstream were satisfactorily simulated. Due to an inadequacy of organic nitrogen data and uncertainties in decay rates, no serious attempt was made to verify the model for prediction of this parameter.

SPECIAL DEM D.O SIMULATION

UPPER POTOMAC ESTUARY

SEPT 28-30,1970

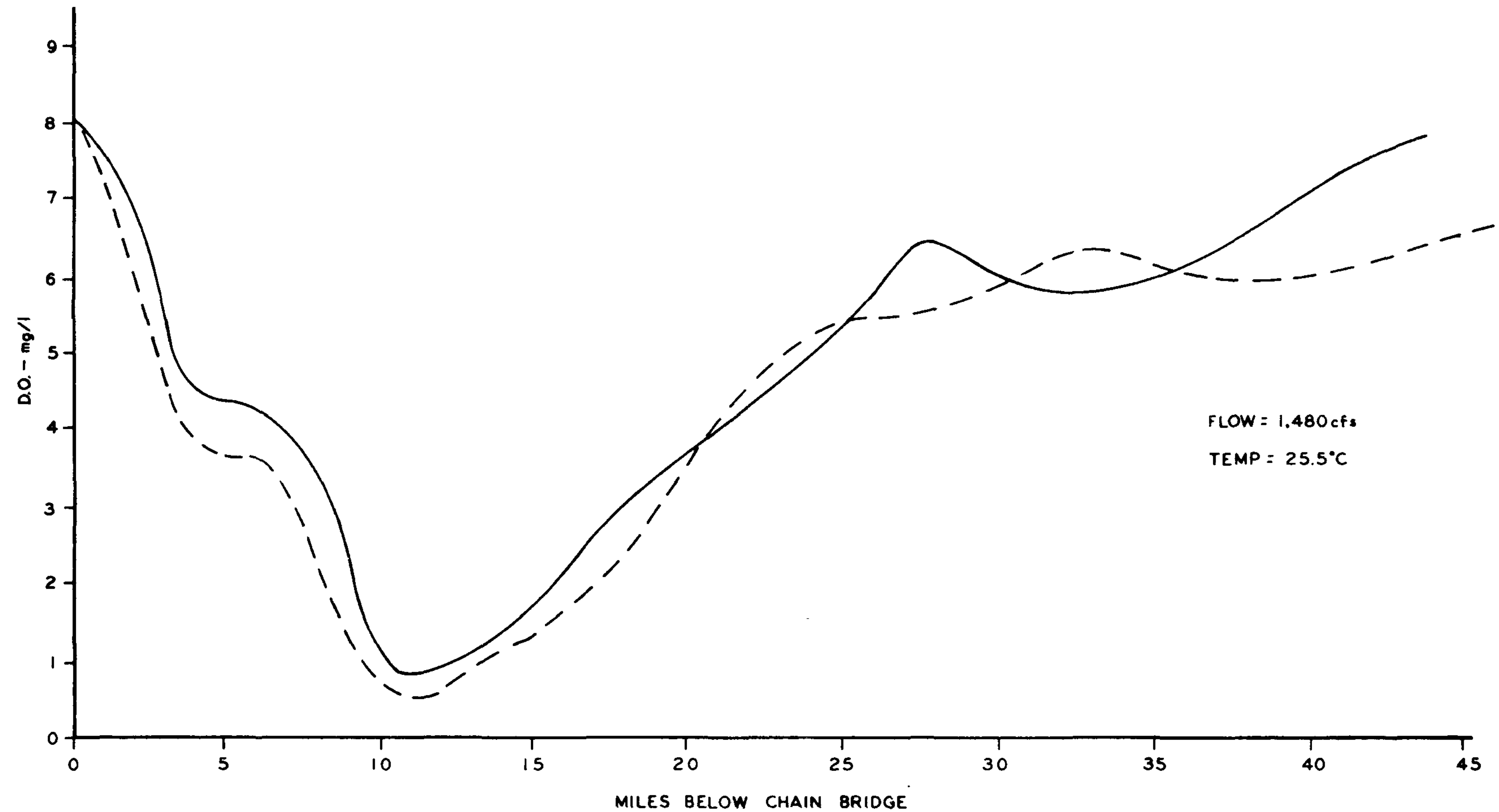


FIGURE VIII-17

CHAPTER IX

ADDITIONAL STUDY REQUIREMENTS

Recognizing the basic limitations of existing data and their subsequent effects on model structure and verification, the following areas are suggested for continued study of the Potomac Estuary:

1. The use of either laboratory or field studies to acquire a better understanding of algal decomposition rates and extent of nutrient regeneration,

2. The use of either laboratory or field studies to determine nutrient transfer rates between the bottom sediments and the overlying water for consideration in the overall nitrogen and phosphorus budgets,

3. Perform additional algal composition studies (laboratory) during various times of the year in order to relate biological uptake rates of both nitrogen and phosphorus to seasonal bloom conditions,

4. Develop techniques to acquire a better understanding of the nutrient-phytoplankton relationship in the saline portion of the Potomac Estuary where water quality stresses are becoming increasingly pronounced and where biological communities are quite different from those encountered upstream, and

5. Incorporation of data from the above, and other special studies, into a truly biological model; one not only capable of predicting algal standing crop levels but also capable of simulating algal species succession, including their causes and effects, zooplankton grazing

rates and other well established biological reactions. The development of this type of model would not only serve a definite purpose in the Potomac Estuary, but more importantly it would provide a significant foundation for any mathematical modeling effort in the Chesapeake Bay itself.

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Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Quality Administration
U. S. Department of the Interior

PRELIMINARY ANALYSES OF THE WASTEWATER AND ASSIMILATION CAPACITIES OF THE ANACOSTIA TIDAL RIVER SYSTEM

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Leo J. Clark
Kenneth D. Feigner*

Technical Report No. 39
April 1970

* Federal Water Quality Administration, Washington, D. C.

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CHAPTER I

INTRODUCTION

To provide information to assist in decision making as requested by Assistant Secretary of the Interior Carl Klein, a study of wastewater assimilation and transport capabilities of the tidal portion of the Anacostia River was initiated by the Chesapeake Technical Support Laboratory (CTSL) during April of 1970. This study was designed to investigate the effects of a wastewater discharge into the Anacostia River at or near the site of the abandoned Washington Suburban Sanitary Commission (WSSC) Plant near Bladensburg, Maryland. Currently, wastewater flows from the Anacostia Valley are conveyed to the Blue Plains Treatment Plant of the District of Columbia.

The Blue Plains plant is presently overloaded and plans are currently being developed to expand the facility. If this plant is to accomodate the projected wastewater volumes using current renovation processes, more land will be required for expansion. Other alternatives could be process changes that would allow increased volumes to receive required treatment within the same area or development of facilities to treat the wastewater at other locations such as the Anacostia Valley.

The major emphasis of this study was to determine the effect of a wastewater discharge on the water quality in the tidal portion of the Anacostia in the vicinity of the D. C.-Maryland Line (See Figure I).

Presented in this report are: (1) an assessment of the current water quality conditions, (2) a hydrologic analysis, and (3) preliminary results of the assimilation and transport capacities of the Anacostia tidal system.

UPPER POTOMAC AND ANACOSTIA
TIDAL RIVER SYSTEM

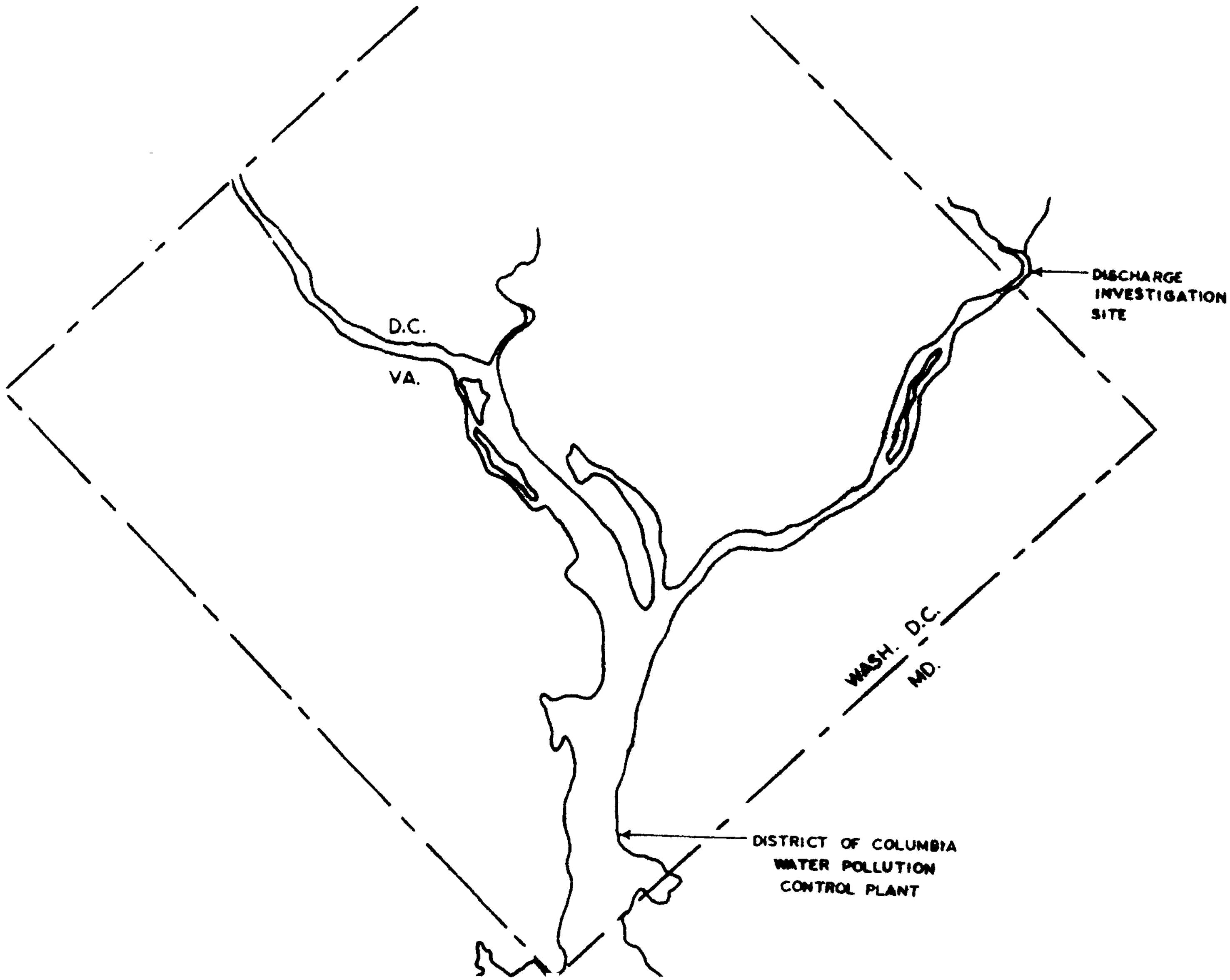


Figure I

CHAPTER II

SUMMARY AND CONCLUSIONS

A preliminary analysis of the wastewater assimilation and transport capacities of the tidal portion of the Anacostia River has been made. The findings of this report, which are limited to predicting the possible effect on water quality in the Anacostia tidal river system of discharging treated wastewater from a service area comprising the Anacostia Valley in Maryland, are summarized below.

1. The Anacostia watershed, tributary to the Potomac Estuary near Washington, D. C., has a drainage area of 184 square miles, 30 square miles within the District of Columbia and 154 square miles within the State of Maryland.

2. The mean stream flow in the basin is about 122 cfs and the 7-day low flow with a recurrence interval of once-in-ten-years is 8 cfs.

3. The lower portion of the Anacostia River is a tidal freshwater system having a mean volume of about 540,000,000 cubic feet.

4. Based on 1969 sampling data, the water quality conditions in the tidal river under summer conditions are typified by:

   a. Low dissolved oxygen concentrations often falling below 2.0 mg/l,

   b. High fecal coliform densities often above 10,000 MPN/100 ml,

   c. High turbidity levels especially during periods of high runoff, and

d. High nutrient concentrations.

While some of the above water quality indicators which fall below accepted stream standards can be attributed to urban runoff, the most pronounced degradation results from storm sewer and combined sewer overflows and defective sanitary sewer systems.

5. The projected populations and wastewater flows of the water quality renovation facility investigated, at a site above the D.C.-Md. border and serving the Anacostia Valley in Maryland, are given below:

Year	Population	Wastewater Flows (mgd)
1970	466,000	55
1980	661,000	78
2000	744,000	88
2020	837,000	99

6. A comparison of the projected wastewater flows to the Blue Plains Treatment Plant of the District of Columbia excluding Anacostia flows and the flows from the Anacostia Valley is shown below:

Year	Blue Plains (mgd)	Anacostia Valley (mgd)	% of Blue Plains Flow (mgd)
1970	177	55	31
1980	231	78	34
2000	331	88	27

7. The ratio of projected Anacostia wastewater flows to the designated low stream flow criterion of 8 cfs, as presented below, vividly shows that most of the advective flow in the tidal system would be from the wastewater renovation facility.

Year	Stream Flow (cfs)	Wastewater Flow (mgd)	Ratio of Wastewater/Stream Flow
1980	8	78	15.1
2000	8	88	17.0
2020	8	99	19.2

8. Mathematical model investigations of the Anacostia River indicate that wastewater assimilation and transport capabilities for large advective flows are most sensitive to the decay rate of a pollutant and not to the dispersion effect of the tidal system. The sensitivity of the decay rate is a result of the long detention time of the tidal system while the effect of the dispersion coefficient is diminished by the pronounced advective movement.

9. Based on mathematical model studies and analysis of 1969 water quality data, it was concluded that the tidal system capability to assimilate oxygen demanding wastewater is currently being exceeded and that any wastewater discharged would have to be of better quality than that currently existing in the Anacostia.

10. The discharge of low turbidity effluents into the highly turbid Anacostia is expected to create nuisance algal blooms due to increased light penetration. Therefore, a high degree of nutrient removal will also be required.

11. Incorporating the need for enhancing the dissolved oxygen levels, preventing nuisance algal growth, and considering the large flow of wastewater compared to stream flow, effluent standards were used to determine wastewater renovation requirements. Renovation requirements for a discharge into the Anacostia are presented below:

Parameter	Before Treatment (mg/l)	Effluent Criteria (mg/l)	Percent Removal Range
BOD_5	200.0	2.0 - 4.0	98 - 99
T. Phosphorus as P	11.0	0.1 - 0.2	98 - 99
T. Nitrogen as N	22.0	0.5 - 1.0	96 - 98

12. An important requirement of the renovation process is an aerated effluent. Since most of the net advective flow will be wastewater, the effluent must have as a minimum 4.0 mg/l of dissolved oxygen to meet the DO standard in the Anacostia at the discharge site.

13. If the wastewater were subjected to high carbonaceous and nitrogenous BOD removal and if the effluent is aerated to 6.0 mg/l, the present water quality of the Anacostia River would be enhanced. The additional 2.0 mg/l in the effluent is expected to raise the DO to meet the standard of 4.0 mg/l at the critical point downstream.

14. The greatest uncertainty, even at high removal requirements, is the algal growth potential. The effluent, which would be the result of ultimate wastewater treatment (UWT) and would be considered suitable for many water uses, might still contain nutrients at concentrations capable of producing excessive algal blooms.

15. A dye tracer study was conducted in late April 1970, during preparation of this report, to ascertain tidal dispersion characteristics and residence times in the Anacostia tidal system. Other continuing studies will involve (1) water quality interactions between Kingman Lake and the Anacostia River, and (2) reaeration rates and benthic oxygen demands along the Anacostia. Results of these studies will be reported in progress statements of the Potomac Washington Metropolitan Area Enforcement Conference.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

A. GENERAL

The Anacostia watershed, tributary to the Potomac River, lies within Montgomery and Prince Georges Counties in Maryland and the District of Columbia. The drainage area of the basin is 184 square miles and presently contains a population of approximately 993,000.

The tidal portion of the river extends from the Potomac River near Hains Point to the confluence of the Northeast and Northwest Branches, a distance of 8.75 miles. The mean volume of the tidal portion of the Anacostia is approximately 540,000,000 cubic feet. The nontidal portion of the watershed has a drainage area of 125 square miles. The 1967 population of the nontidal area was approximately 466,000.

The river mile locations of pertinent land features of the tidal system are presented below:

Item	River Mile
Hains Point	0.00
Douglas Bridge	1.45
11th and 12th Street Bridge	2.45
Sousa Bridge	3.10
Lower End of Kingman Lake	3.80
East Capitol Street Bridge	4.35
Benning Road Bridge	4.90
Upper End of Kingman Lake	5.65
U. S. Route 50 Bridge	6.90
WSSC Marina	8.10
Bladensburg Road Bridge	8.45
Confluence of Northeast and Northwest Branches	8.75

B. STREAM FLOW ANALYSIS

The nontidal stream flow of the Anacostia River comes primarily from the Northeast and Northwest Branches. Mean monthly flows of the two branches and their totals are presented in Table I.

Table I

Mean Monthly River Discharge

Month	Northeast Br. (cfs)	Northwest Br. (cfs)	Total (cfs)
January	89.6	51.6	141.2
February	110.4	64.1	174.5
March	128.0	73.4	201.4
April	108.2	64.1	172.3
May	78.6	50.9	129.5
June	57.5	39.7	97.2
July	48.1	32.6	80.7
August	66.4	40.8	107.2
September	42.6	28.1	70.7
October	44.5	24.8	69.3
November	63.4	38.0	101.4
December	75.3	43.0	118.3

The average daily discharge of the combined branches is 122 cfs with a 7-day low-flow recurring once-in-ten-years of 8 cfs. While the average flow is 122 cfs, the median flow (that flow occurring 50 percent of the time) is 66 cfs, indicating that stream discharge is flashy.

C. WATER QUALITY CONDITIONS

The water quality condition of the tidal portion of the Anacostia is monitored by the Department of Sanitary Engineering, District of Columbia and by the Chesapeake Technical Support Laboratory, Federal Water Quality Administration. Special studies of the entire basin were conducted by CTSL in 1967 and 1969.

The major sources of water quality degradation are land runoff, storm drainage, defective sanitary sewers, and combined sewers. There are no significant discharges from wastewater treatment facilities in the basin.

1. Dissolved Oxygen and Biochemical Oxygen Demand

The dissolved oxygen (DO) concentration in 1969 was depressed below 5.0 mg/l in most of the tidal system during most of July, August, and September. As can be seen in Figure II, the lowest concentration, between 1.0 and 2.0 mg/l, occurred in a reach near the Pennsylvania Avenue Bridge. A slight recovery occurred near the confluence with the Potomac.

The biochemical oxygen demand (BOD) of the tidal system ranged from approximately 2.0 to 7.0 mg/l (See Figure III). The concentrations were slightly higher near the D.C.-Md. Line, especially during high runoff periods.

Data from a special two-day survey made within the boundaries of Kingman Lake in June 1969 also show dissolved oxygen concentrations below 2.0 mg/l (See Appendix C). High BOD concentrations were also measured during that survey.

The water quality standard for DO for this reach of the Anacostia is a minimum of 3.0 mg/l with an average of 4.0 mg/l. This standard was not met in July, August, and September of 1969 in the tidal portion of the Anacostia. June 1969 surveys indicated the same to be true for the Kingman Lake area and the Pennsylvania Avenue sampling point.

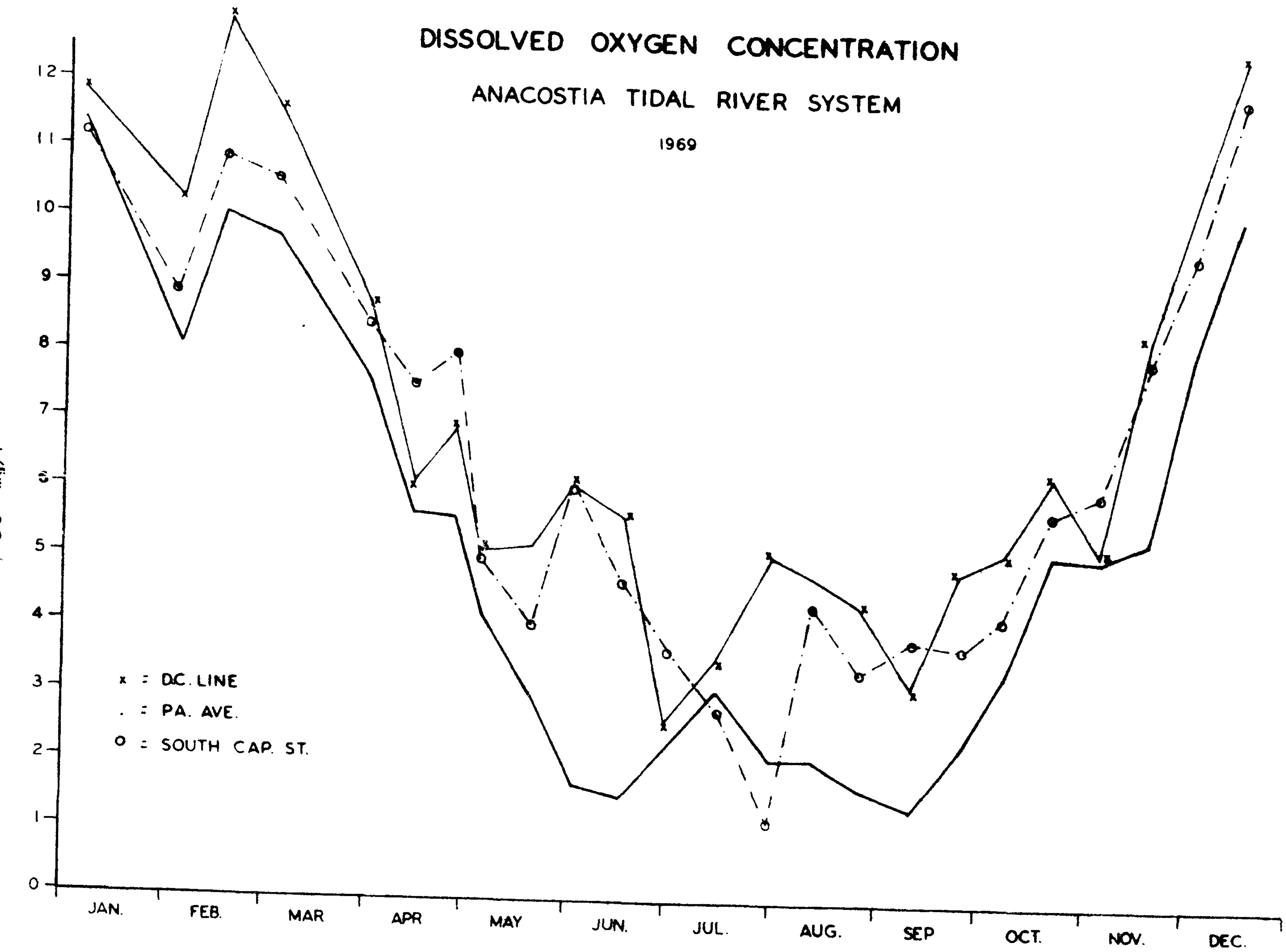

DISSOLVED OXYGEN CONCENTRATION
ANACOSTIA TIDAL RIVER SYSTEM
1969
DO = mg/l
0
1
2
3
4
5
6
7
8
9
10
11
12
x = DC. LINE
. = PA. AVE.
o = SOUTH CAP. ST.
JAN.
FEB.
MAR
APR
MAY
JUN.
JUL.
AUG.
SEP
OCT.
NOV.
DEC.

Figure II

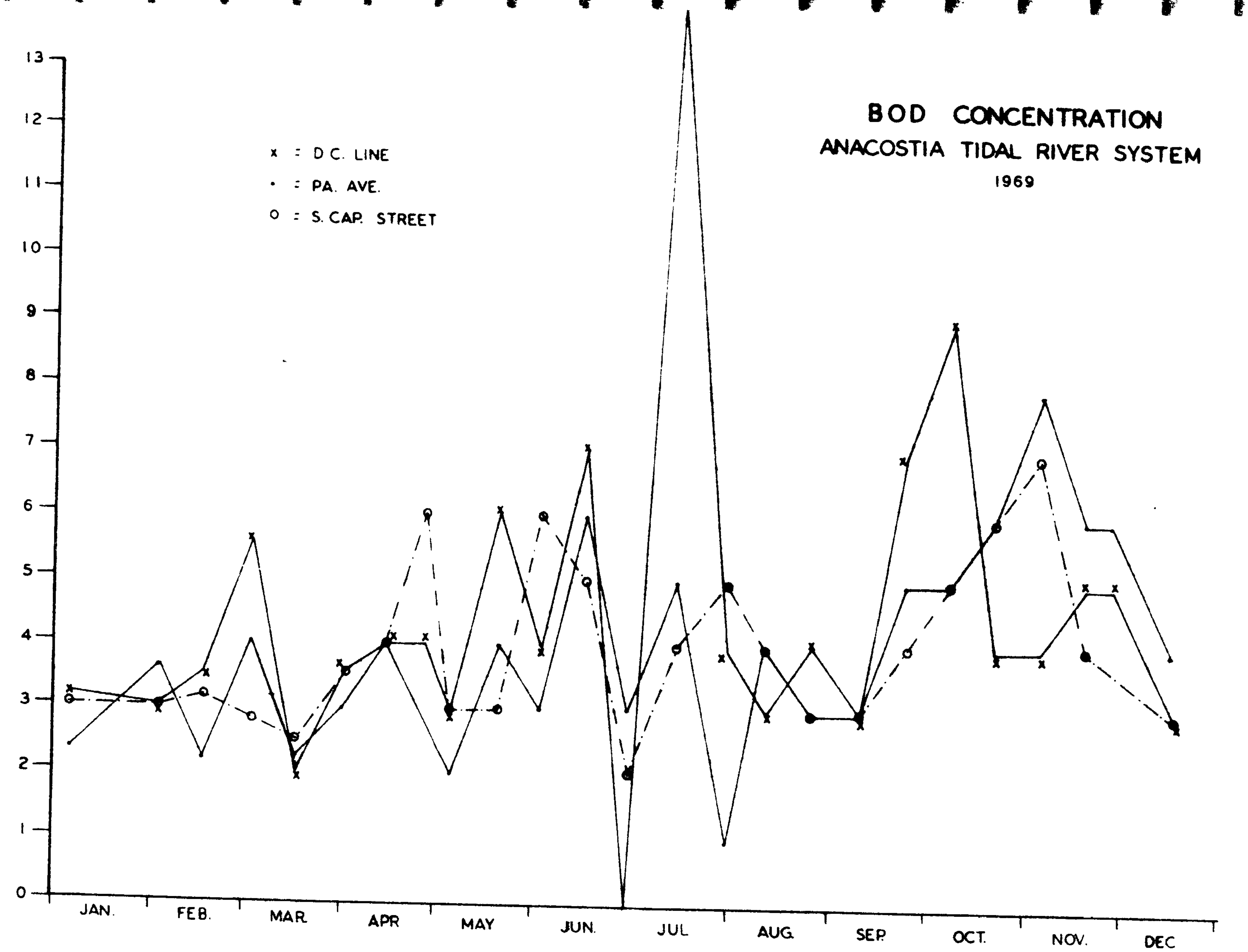

BOD CONCENTRATION
ANACOSTIA TIDAL RIVER SYSTEM
1969
x = D.C. LINE
• = PA. AVE.
o = S. CAP. STREET
BOD - mg/l
0
1
2
3
4
5
6
7
8
9
10
11
12
13
JAN.
FEB.
MAR.
APR
MAY
JUN.
JUL
AUG.
SEP.
OCT.
NOV.
DEC

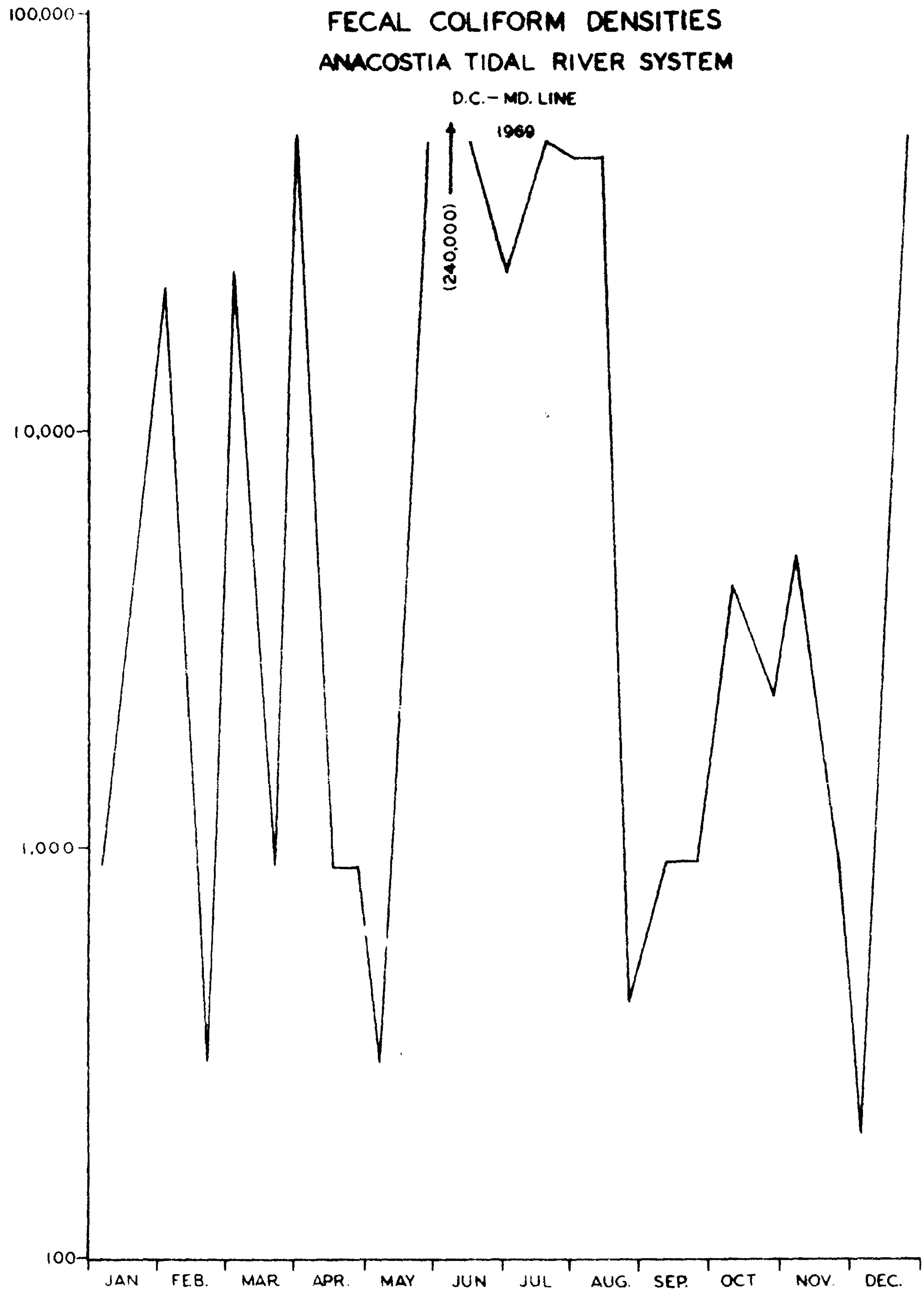
Figure III

2. Bacteriological Densities

Figures IV, V, and VI present the fecal coliform densities for the water quality sampling stations at the D.C.-Md. Line, Pennsylvania Avenue, and South Capitol Street Bridge. The data obtained by the District of Columbia Department of Sanitary Engineering indicate that fecal densities are higher near the D.C.-Md. Line. Densities over 10,000 MPN per 100 ml were measured frequently at the D.C.-Md. Line during 1969.

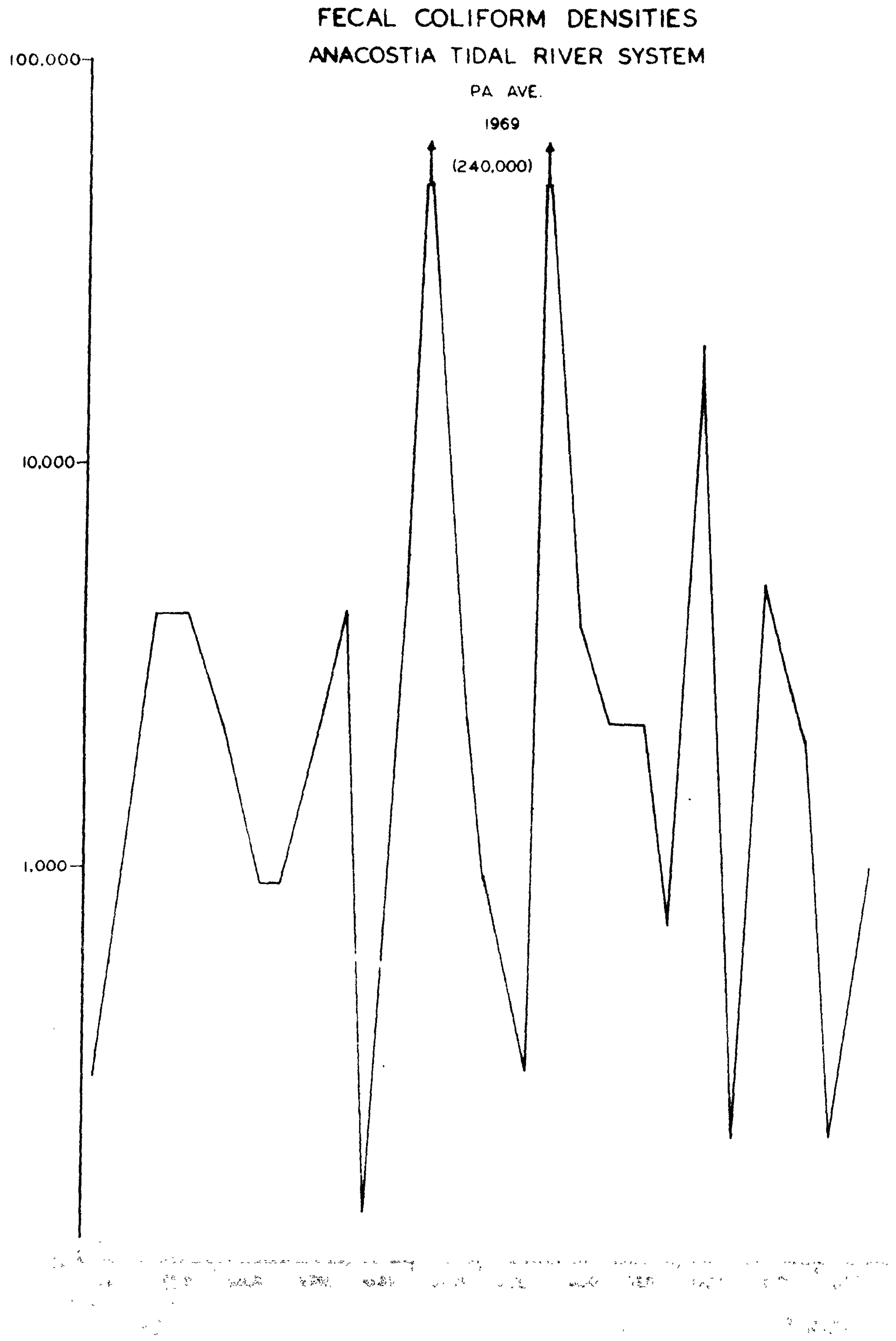
Data for the Kingman Lake study also indicate high fecal densities with counts ranging from 2,100 to 93,000. The fecal coliform standards, which are a geometric mean of 1000/100 ml and 10 percent of samples not to equal or exceed 2000/100 ml, are not currently being met in the tidal portion.

During the survey of the entire watershed in 1967, the Sligo Creek station at Chillum Manor and the Northwest Branch at Queens Chapel Road had the highest bacterial densities. Of the fifteen stations sampled, none had consistently higher densities than were found at the stations located in the tidal portion of the basin during 1969 (See Appendix A). This indicates that the high densities in the tidal portion are from local sources such as the sewer systems and not runoff originating in the upper drainage area.



FECAL COLIFORM DENSITIES
ANACOSTIA TIDAL RIVER SYSTEM
D.C. – MD. LINE
1969
(240,000)
100,000
10,000
1,000
100
JAN
FEB.
MAR.
APR.
MAY
JUN
JUL
AUG.
SEP.
OCT
NOV.
DEC.

Figure IV


FECAL COLIFORM DENSITIES
ANACOSTIA TIDAL RIVER SYSTEM
PA AVE.
1969
(240,000)
100,000
10,000
1,000

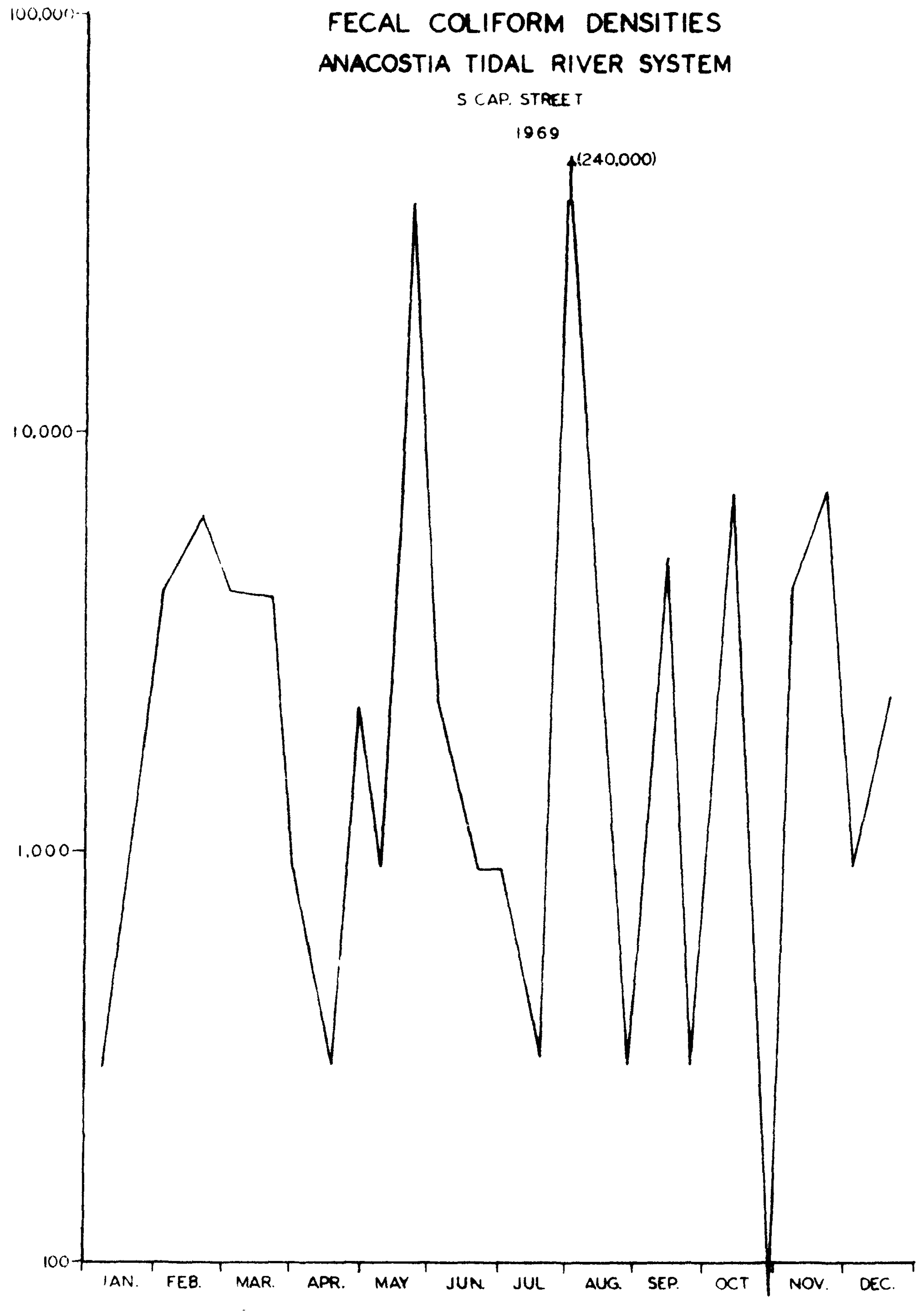

FECAL COLIFORM DENSITIES
ANACOSTIA TIDAL RIVER SYSTEM
S CAP. STREET
1969
(240,000)
100,000
10,000
1,000
100
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL
AUG.
SEP.
OCT
NOV.
DEC.

Figure VI

3. Nutrients

During the 1966 nutrient survey of the Potomac River Basin, phosphorus and nitrogen concentration data were obtained by CTSL, FWQA (See Appendix B). For 1966, the mean monthly nutrient concentrations and their loadings are summarized in Table II.

As presented in Table II, the average concentrations of phosphorus as PO_4, NO_3 as N, and TKN as N were 0.80, 0.86, and 1.24 mg/l for the Bladensburg station during 1966. The resulting loadings for the stations in 1966 were 374, 513, and 633 lbs/day of phosphorus as PO_4, NO_3 and TKN, respectively.

Phosphorus concentrations as high as 8.7 mg/l as PO_4 have been observed in the tidal portion near the D.C.-Md. Line. This large increase, especially during high flows, can be attributed to defective sewerage systems of the Washington Suburban Sanitary Commission. Data for the month of June 1969, presented in Table III, document these high concentrations.

Associated with decreases in turbidity or suspended sediments in the tidal system is a decrease in phosphorus which is also shown in Table III. This adsorption phenomonon of phosphorus onto silt particles has also been demonstrated recently in both laboratory and field measurement by the Chesapeake Technical Support Laboratory as part of a nutrient transport study in the Potomac Estuary.

TABLE II

NUTRIENT CONCENTRATIONS AND LOADINGS
BLADENSBURG ROAD BRIDGE, ANACOSTIA RIVER
1966

Month	Average Monthly River Discharge (cfs)	T. PO_4 as PO_4 (mg/l)		NO_3 as N (mg/l)		TKN (mg/l)	
		(mg/l)	(lbs/day)	(mg/l)	(lbs/day)	(mg/l)	(lbs/day)
January	50	1.27	342	1.17	315	1.44	387
February	200	0.67	721	1.12	1205	1.54	1657
March	88	0.38	180	0.93	440	1.40	663
April	132	0.47	334	0.63	447	1.45	1030
May	125	0.74	498	1.11	746	1.11	746
June	42	0.31	70	0.66	149	1.10	249
July	18	0.96	93	0.52	50	1.33	129
August	15	0.96	77	0.52	42	1.32	107
September	232	0.50	624	0.90	1123	0.46	574
October	163	1.04	912	1.27	1114	1.68	1473
November	46	1.79	443	0.57	141	1.45	359
December	71	0.51	195	1.00	382	0.59	225
Monthly Average	98.5	0.80	374	0.86	513	1.24	633

TABLE III

Anacostia Tidal River System
D.C. Water Pollution Control Division Data

MONTHLY REPORT
June 1969

Sampling Station	Total P as PO_4 (mg/l)	TKN as N (mg/l)	NO_2+NO_3 as N (mg/l)	NH_3-N (mg/l)	Turb (units)
D. C. Line	6.10	2.14	0.59	1.18	226
Ben. Rd.	4.81	2.23	0.41	0.63	197
E. Cap. St.	2.74	2.18	0.40	1.10	161
Pa. Ave.	1.16	1.85	0.30	1.80	53
11th St.	1.03	1.97	0.33	1.80	40
S. Cap. St.	1.09	2.15	0.20	1.41	18
Wash. Ch.	0.81	1.73	0.31	0.86	9

4. Sediments and Turbidity

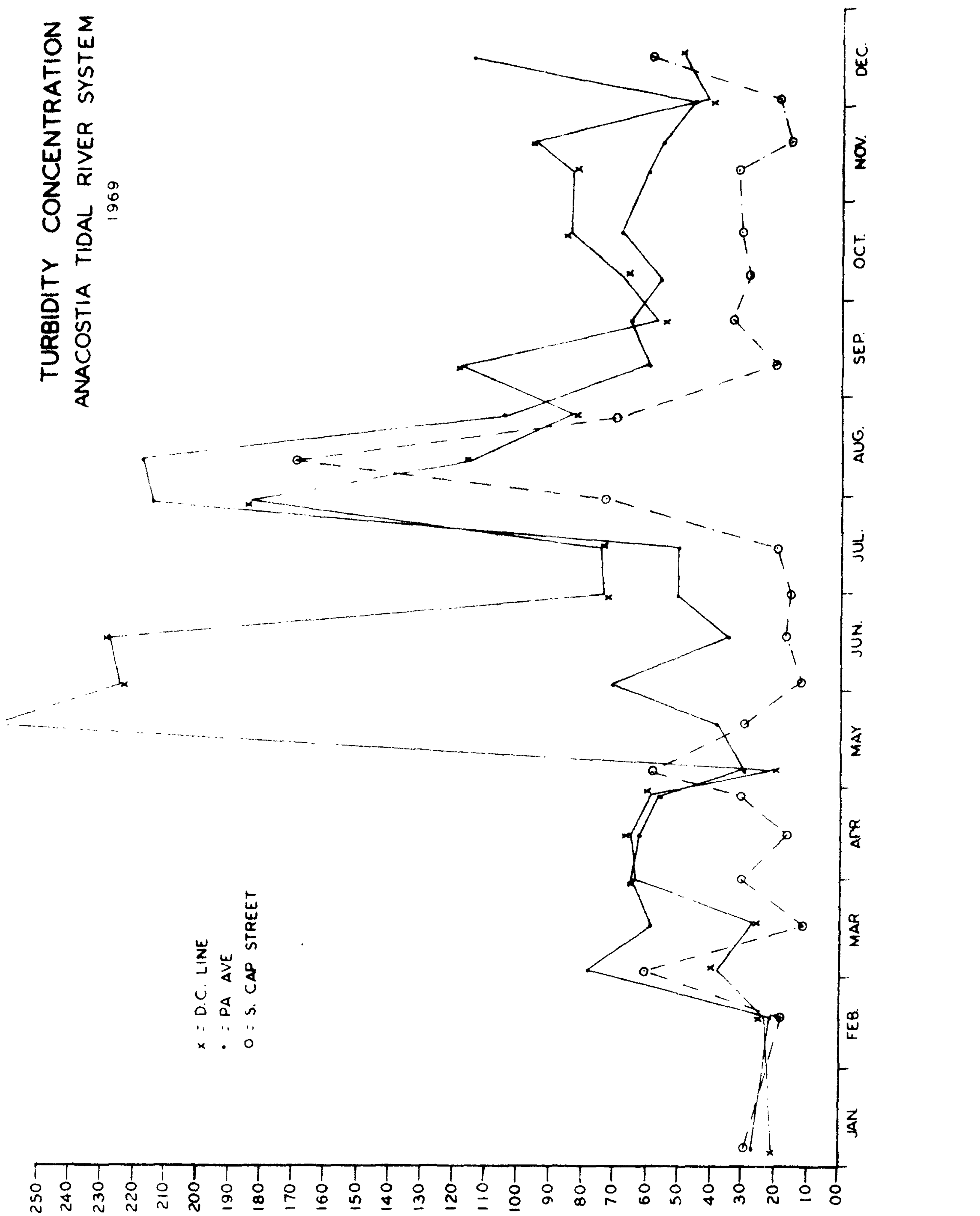
The Anacostia River can usually be characterized as a muddy stream. During periods of high stream flow, large quantities of silt and debris are carried downstream to the Potomac.

Sediment data obtained by USGS for the Colesville, Maryland station, located in the Northwest Branch, indicate concentrations over 4,300 ppm at times. The 1967 to 1968 sediment yield for the Colesville station, which has a drainage area of 21.1 square miles, is given below:

Year	River Discharge (cfs-day)	Sediment (tons/year)
1963	5387	16811
1964	6844	11596
1965	5068	15889
1966	5137	14402
1967	6738	15009
1968	6188	10498

Using an average sediment tonnage of 14,000 at this station, the estimated silt contribution for the entire watershed is about 114,000 tons/year.

The effect of the sediment loadings on the turbidity in the tidal system is shown in Figure VII. The higher concentrations of turbidity near the D.C.-Md. Line are decreased significantly downstream, especially at the South Capitol Street Bridge station. The decrease in turbidity is also reflected in the monthly summary as shown in Table III.



TURBIDITY CONCENTRATION
ANACOSTIA TIDAL RIVER SYSTEM
1969
x : D.C. LINE
• : PA AVE
O : S. CAP STREET
JAN.
FEB.
MAR
APR
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
00
TURBIDITY mg/l

Figure VII

D. POPULATION AND WASTEWATER PROJECTIONS

1. Anacostia Valley

The area which could be served by a wastewater renovation facility located upstream from the D.C.-Md. Line would be the Anacostia Valley located in Prince Georges and Montgomery Counties. Population projections for the Anacostia and Beaverdam Valleys of the two counties have been developed jointly by the Washington Suburban Sanitary Commission and the Maryland-National Capital Park and Planning Commission and are given below:

Year	Montgomery (Anacostia)	Prince Georges (Anacostia)	Prince Georges (Beaverdam)	Total Population
1967	131,400	197,400	64,200	393,000
1980	167,800	237,700	81,800	487,300
2000	228,600	313,800	100,900	643,300
Capacity	453,400	390,500	122,700	966,600

These figures were obtained from the current "Ten Year Water and Sewerage Plan" of the Washington Suburban Sanitary Commission for Prince Georges County.

Data from a 1968 report prepared for WSSC by Whitman, Requardt, and Associates indicate that the population for the Anacostia Valley is considerably higher. Their analysis shows the following:

Year	Population
1968	500,000
1980	850,000
2000	1,000,000

A request was made to the Maryland-National Capital Park and Planning Commission to update their projections. Their recent projections are given below:

Year	Population
1970	466,000
1980	661,000
2000	744,000
2020	837,000

Utilizing an average of the wastewater volumes and constituents obtained in the 1969 surveys [1] and the above populations, discharge volumes, BOD, phosphorus and nitrogen loadings before treatment were projected as follows:

Year	Population	Volume (mgd)	BOD (lbs/day	Phosphorus as P (lbs/day)	T. Nitrogen as N (lbs/day)
1970	466,000	55	69,200	4,320	9,830
1980	661,000	78	99,150	5,949	13,881
2000	744,000	88	111,600	6,696	15,624
2020	837,000	99	125,550	7,533	17,577

2. District of Columbia

The projected population, wastewater volume, and BOD loadings, as determined by Metcalf and Eddy, Engineers, in February 1969 for the Blue Plains Treatment Plant of the District of Columbia are presented below:

Year	Population	Volume (mgd)	BOD (lbs/day)	Suspended Solids
1970	1,750,000	232	304,000	378,000
1980	2,227,000	309	490,000	537,000
2000	3,122,000	419	718,000	843,000

If the wastewater from the Anacostia Valley is treated by a separate facility, the following reductions in flow at the Blue Plains Treatment Plant were estimated:

Year	Blue Plains* (mgd)	Anacostia Valley (mgd)	% of Blue Plains Flow
1970	177	55	31
1980	231	78	34
2000	331	88	27

* Excluding Anacostia Flows

CHAPTER IV

WASTEWATER ASSIMILATION AND TRANSPORT ANALYSIS

The five major physical factors which govern the wastewater assimilation and transport capabilities are:

1. Stream flow conditions including flow-wastewater volume ratio,
2. Residence flushing time of the tidal system,
3. Tidal hydrodynamics including dispersion,
4. Reaeration and decay rates on dissolved oxygen budget, and
5. Turbidity and algal growth.

Factors which affect the assimilation and transport capacities other than waste loadings are:

1. Storm sewer discharges,
2. Combined sewer discharges located between East Capitol Street and Sousa Bridges and near the 11th Street Bridge,
3. Defective sanitary sewerage systems,
4. Benthic demand of organic deposits in the bottom muds, and
5. Land runoff.

Water quality data presented in the previous chapter indicate that under current sanitary practices, the tidal portion of the Anacostia River is receiving more oxygen demanding wastes than it can assimilate during the months of July, August, and September.

While nutrient concentrations, both nitrogen and phosphorus, are manyfold above the minimum level associated with excessive algal blooms, the growths are not as pronounced as those of the 1950's as reported by Bartsch [2] and Stotts and Longwell [3]. Reduction in algal growths can be primarily attributed to lack of light penetration resulting from high turbidities and to the elimination of discharges from the Bladensburg wastewater treatment facility of WSSC.

Preliminary analysis of the assimilation and transport capacity of the tidal system was made using two separate mathematical models developed by Thomann [4] and by Water Resources Engineers, Inc. (WRE) [5]. The segmentation of the tidal system for the Thomann model is shown in Figure VIII with detailed data presented in Table IV. Detailed explanation of the two mathematical models is beyond the scope of this report.

A. STREAM FLOW - WASTEWATER FLOW ANALYSIS

Water quality standards are applicable to river discharges equal to or greater than the 7-day low flow with a recurrence interval of once-in-ten-years. For the Anacostia tidal system this flow is 8 cfs.

For 1968 and the three population benchmarks, the wastewater and river discharges including the ratio of wastewater stream discharge are presented below:

Year	River Discharge* (cfs)	Wastewater Discharge (mgd)	Ratio of Waste to/Stream Discharge
1970	8	55	19.6
1980	8	78	15.1
2000	8	88	17.0
2020	8	99	19.2

* 7-day low flow with recurrence interval of once-in-ten-years

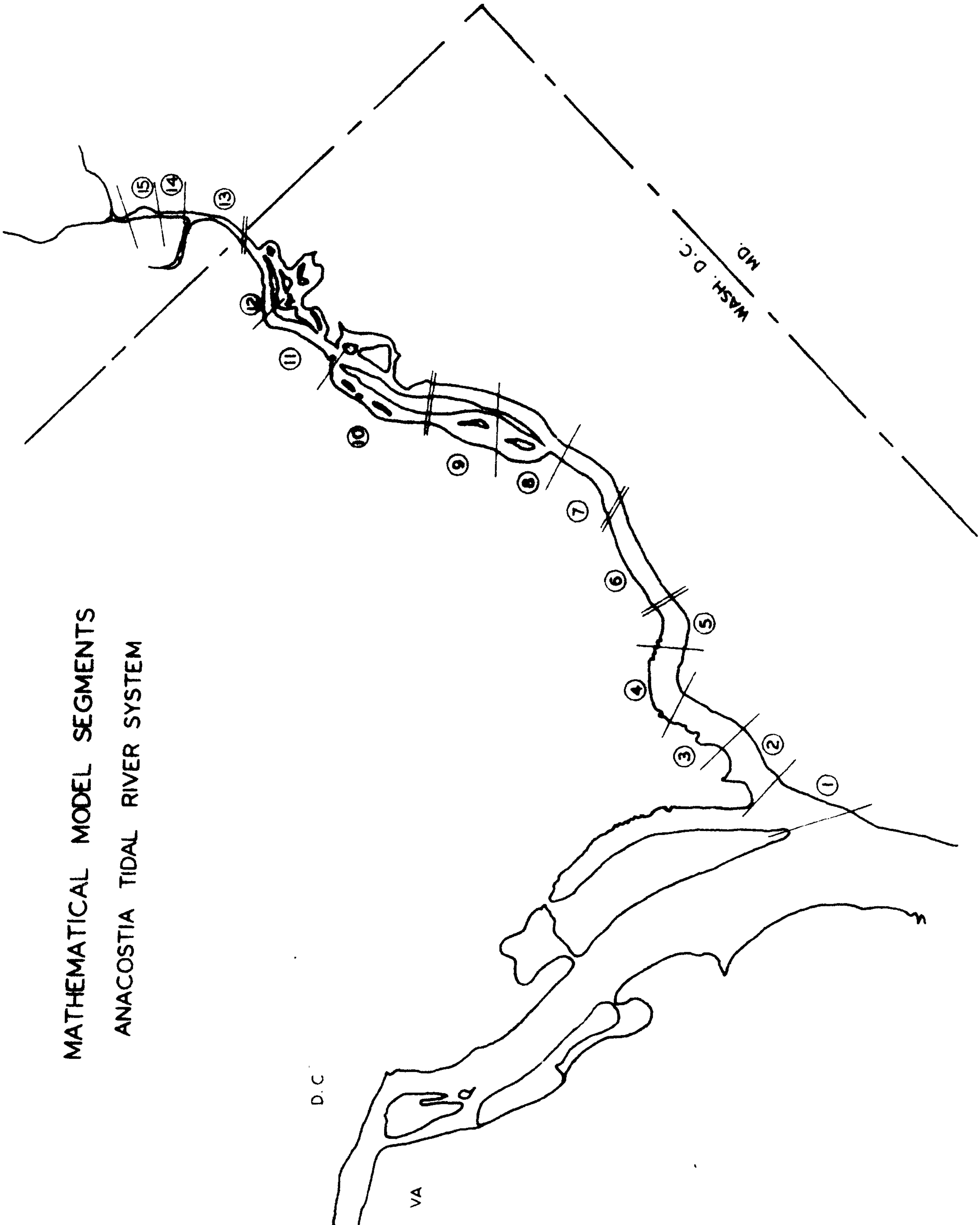

MATHEMATICAL MODEL SEGMENTS
ANACOSTIA TIDAL RIVER SYSTEM
WASH. D.C.
MD.
D.C
VA
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure VIII

TABLE IV

MATHEMATICAL MODEL SEGMENTATION

Anacostia Tidal River System

Mean Water Data *

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Interface Widths Upper (ft)	Interface Widths Lower (ft)	Length (ft)	Volume ($ft^3 x10^6$)	Surface Area ($ft^2 x10^6$)	Depth (ft)
1	31,[illegible]90	58,060	1500	3200	2900	1[illegible]9.55	4.96	26.11
2	27,100	31,290	1250	1500	2380	69.48	3.24	21.44
3	27,100	27,100	1250	1250	2380	64.49	2.68	24.06
4	24,710	27,100	1150	1250	2[illegible]40	68.38	3.20	21.3[illegible]
5	14,450	24,710	750	1150	2640	51.69	2.36	21.90
6	8,580	14,450	750	750	3430	39.84	2.80	14.22
7	8,645	8,580	750	750	3430	29.53	2.44	12.10
8	3,095	8,645	550	750	3170	18.60	1.[illegible]	10.[illegible]
9	4,8[illegible]	3,09[illegible]	400	550	2900	11.45	1.36	8.41
10	2,840	4,805	350	400	3960	1[illegible].13	1.32	11.4[illegible]
11	3,195	2,840	300	350	3170	9.56	1.00	9.56
12	3,000	3,195	300	300	3430	10.62	1.04	10.21
13	3,030	3,000	250	300	2900	8.74	0.80	10.92
14	1,775	3,030	250	250	[illegible]640	6.34	0.60	10.57
15	775 **	1,775	200	250	2640	5.20	1.00	5.20

* Data based on soundings made April 1970.

** Marina 2,710
@1,500

1,000
@1,140

B. RESIDENCE OR FLUSHING TIME

Assuming a base flow of 8 cfs and wastewater discharges of 50, 100, and 150 mgd and the volume of the tidal system of 540,000,000 cubic feet, the residence time of the Anacostia as given below has been computed by a volume displacement analysis and by using the WRE mathematical model:

River Flow (cfs)	Wastewater Discharge (cfs)	Wastewater Discharge (mgd)	Total Flow (cfs)	Computed Residence Time (days)	WRE Model Residence Time (days)
8	0	0	8	781	20
8	77	50	85	73	19
8	154	100	162	38	15
8	231	150	239	27	12

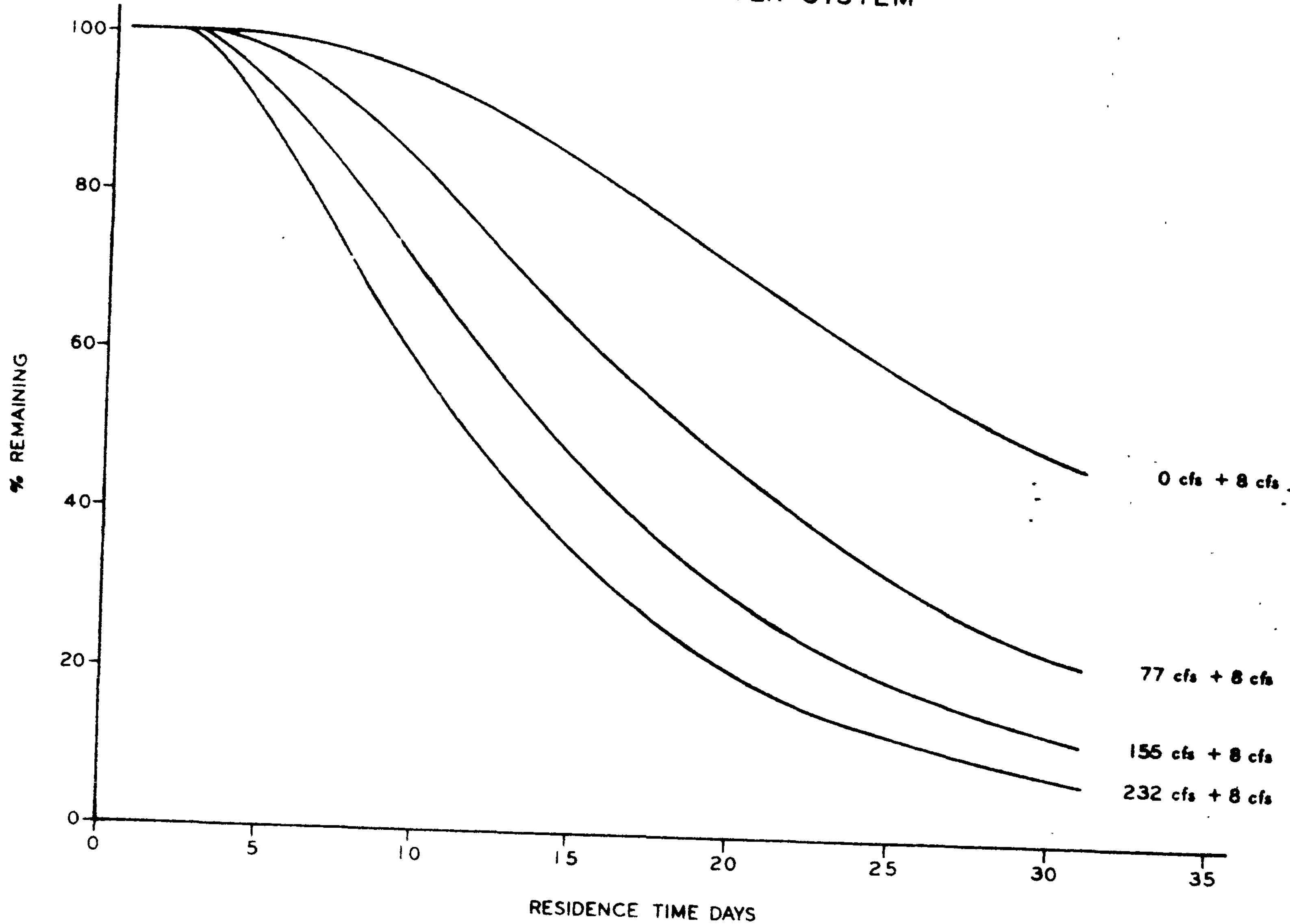
The effect of the increase in river discharge on the WRE model residence time for the entire system is shown in Figure IX.

The computed residence time based on complete volume displacement ignores all mixing and transport of quality constituents due to tidal action and thus only provides an extremely rough estimate of the actual residence time. Such a computation is particularly misleading at very low inflow rates (as indicated by the 781 days residence time for the 8 cfs flow rate). As the inflow approaches zero the computed residence time approaches infinity while in the prototype there is always significant mixing and transport due solely to tidal action. The residence times predicted by the model include these factors.

With the residence time of two weeks, nearly all of the nitrogenous and carbonaceous BOD will be exerted in the Anacostia tidal system.

Therefore, there will be very little effect under low flow conditions on the oxygen resources of the main Potomac from a discharge in the Anacostia at the site investigated.

RESIDENCE TIME FOR VARIOUS WASTEWATER FLOWS
ANACOSTIA TIDAL RIVER SYSTEM



C. TIDAL HYDRODYNAMICS

The cross-sectional area of the Anacostia tidal system can be mathematically expressed by the following equation:

$$A_x = A_c e^{ax}$$

where:

A_x = cross-section at point x

A_o = cross-section at x = o

a = exponent (slope of curve describing A as function of x)

x = distance along the river

Using the above expression, the steady-state equation for a conservative substance was used to determine the dispersion coefficient required in the Thomann mathematical model. The equation is given below:

$$Cx = Co\ e\ \frac{Q}{a \quad A_o\ E}\ (1-e^{-ax})$$

where:

C_x = concentration at point x

C_o = concentration at x = o

E = dispersion coefficient

Other variables as previously defined

Two methods of determining the dispersion coefficients are by use of either salinity or dye tracer data. However, since this area is not saline and since the dye study, which was initiated in the latter part of April 1970 would not be completed in time for this report, alkalinity data were utilized for dispersion studies. The natural alkalinity difference of about 50 mg/l between the Potomac and the Anacostia was adequate for this purpose and incorporated into the above formulations. Dispersion coefficients, for the various model segments throughout a range of river discharges, are given in Figure X.

For total river discharges of 58, 108, and 208 cfs, the effect of the dispersion coefficient on the simulated profiles using the Thomann steady state model can be seen in Figures XI, XII, and XIII, respectively. At the higher flows, the effect on the simulated profile is not as significant as during lower flows.

Figure XIV shows simulated profiles for various wastewater discharge rates using the Thomann model with the dispersion coefficients as given in Figure X and considering a conservative pollutant. A sharp decrease in the simulated profile occurs at model segment 8 or at the lower end of Kingman Lake. The volume of the tidal system increases rapidly in this reach.

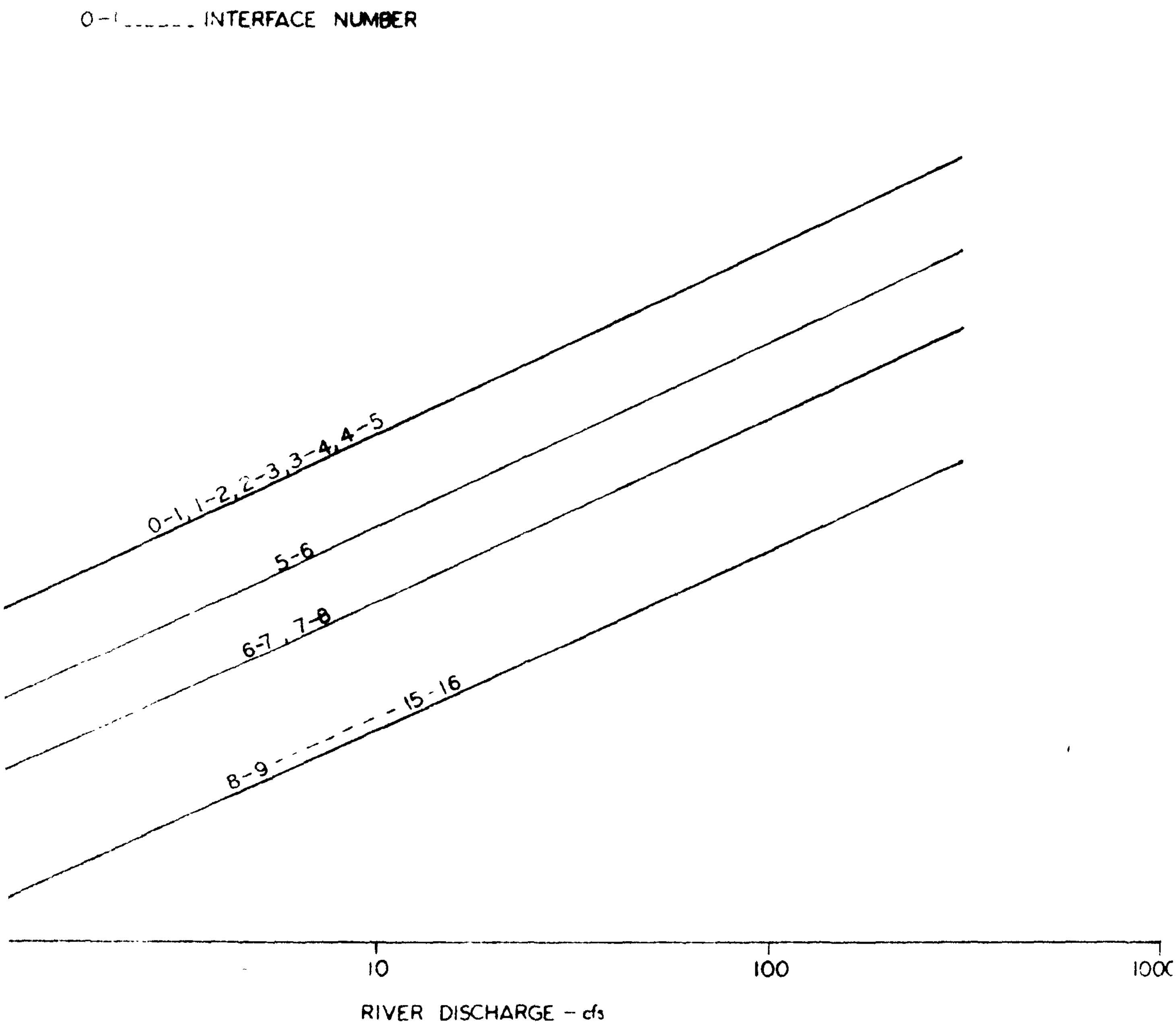
Simulated profiles for a nonconservative pollutant such as BOD, as presented in Figure XV, show an even smaller response to the dispersion coefficient. The sensitivity of the nonconservative simulated profile to the decay rate of a pollutant is also an indication of a high residence time in the tidal system.

Expanded scale simulated profiles for conservative and nonconservative pollutants are shown in Figure XVI. A 1000 lbs/day discharge at the site investigated will increase the concentrations of conservative and nonconservative pollutants in model segment 8 to approximately 0.5 and 0.2 mg/l, respectively. Dissolved oxygen in this segment is the most depressed, often with concentrations near 1.0 mg/l under summer conditions.

DISPERSION COEFFICIENT vs FLOW

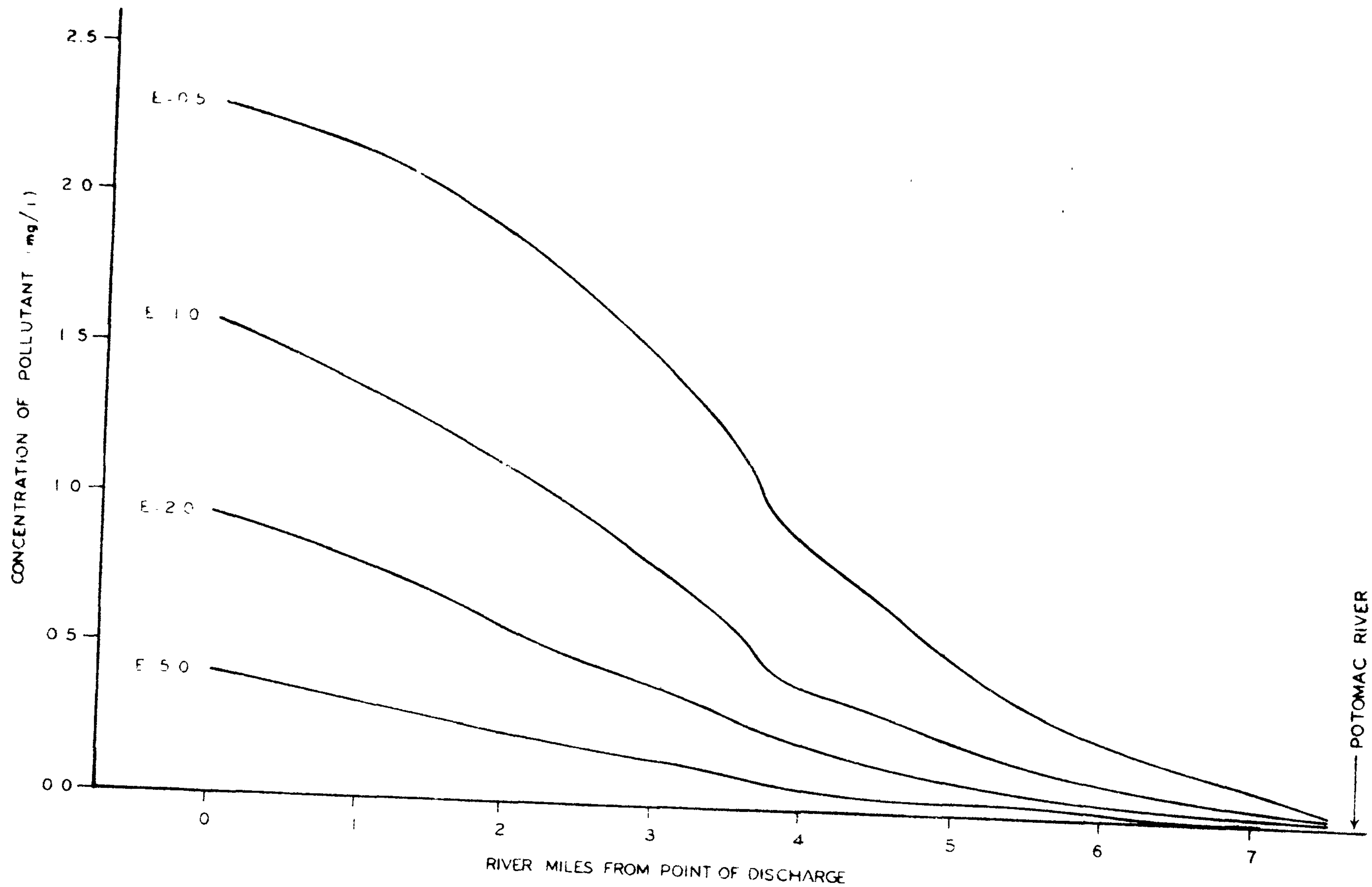
ANACOSTIA TIDAL RIVER SYSTEM

1969 D.C ALKALINITY DATA



Figure

DISCHARGED AT A RATE OF 1000



[illegible] PROFILES FOR VARIOUS DISPERSION COEFFICIENTS [illegible]
DISCHARGED AT A RATE OF [illegible] lbs/day
[illegible] ANACOSTIA TIDAL RIVER SYSTEM ABOVE [illegible]

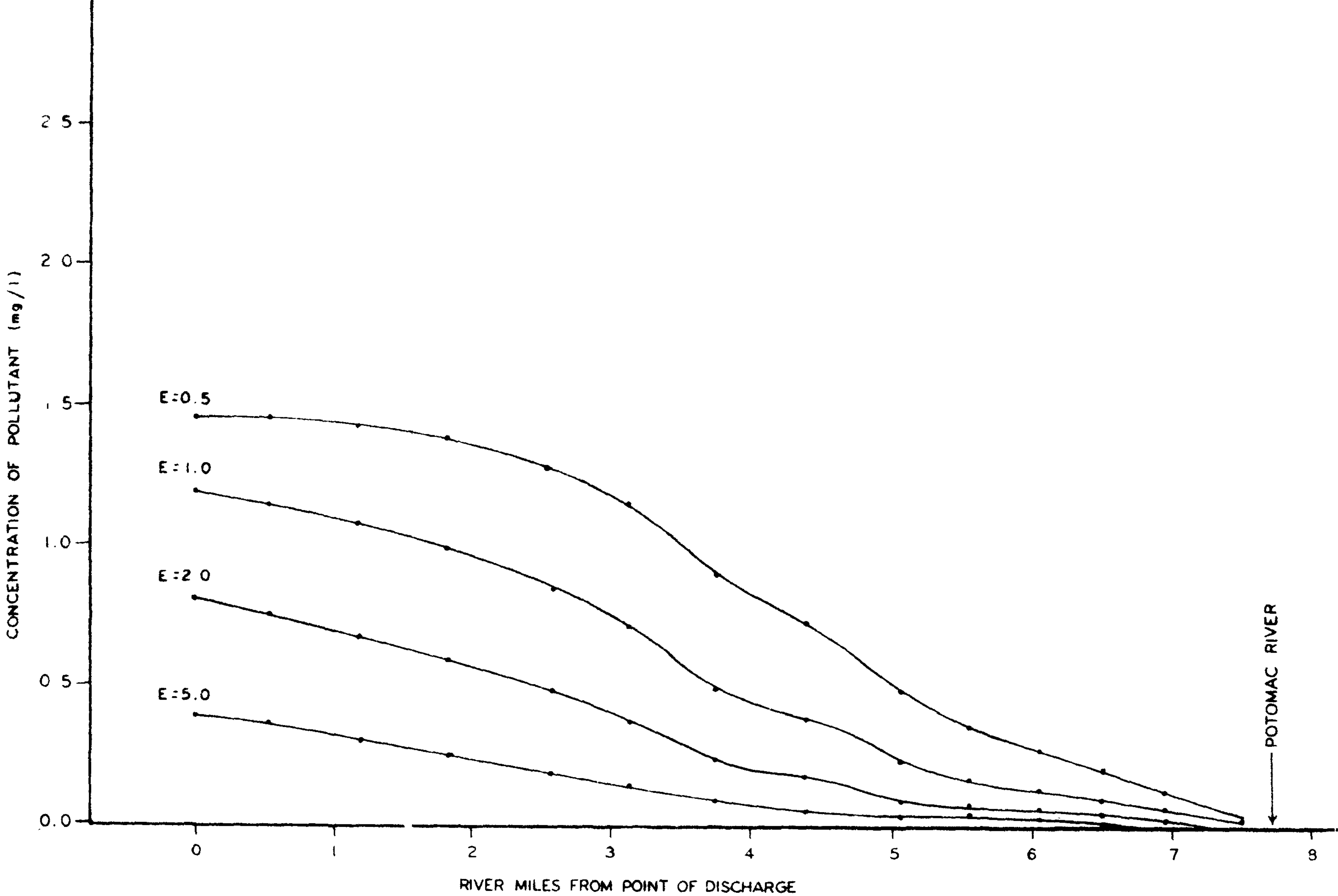


Figure XII

... PROFILES FOR VARIOUS DISPERSION COEFFICIENTS OF A CONSERVATIVE POLLUTANT
DISCHARGED AT A RATE OF ... ...s day
INTO THE ANACOSTIA TIDAL RIVER SYSTEM ABOVE ...
... cfs

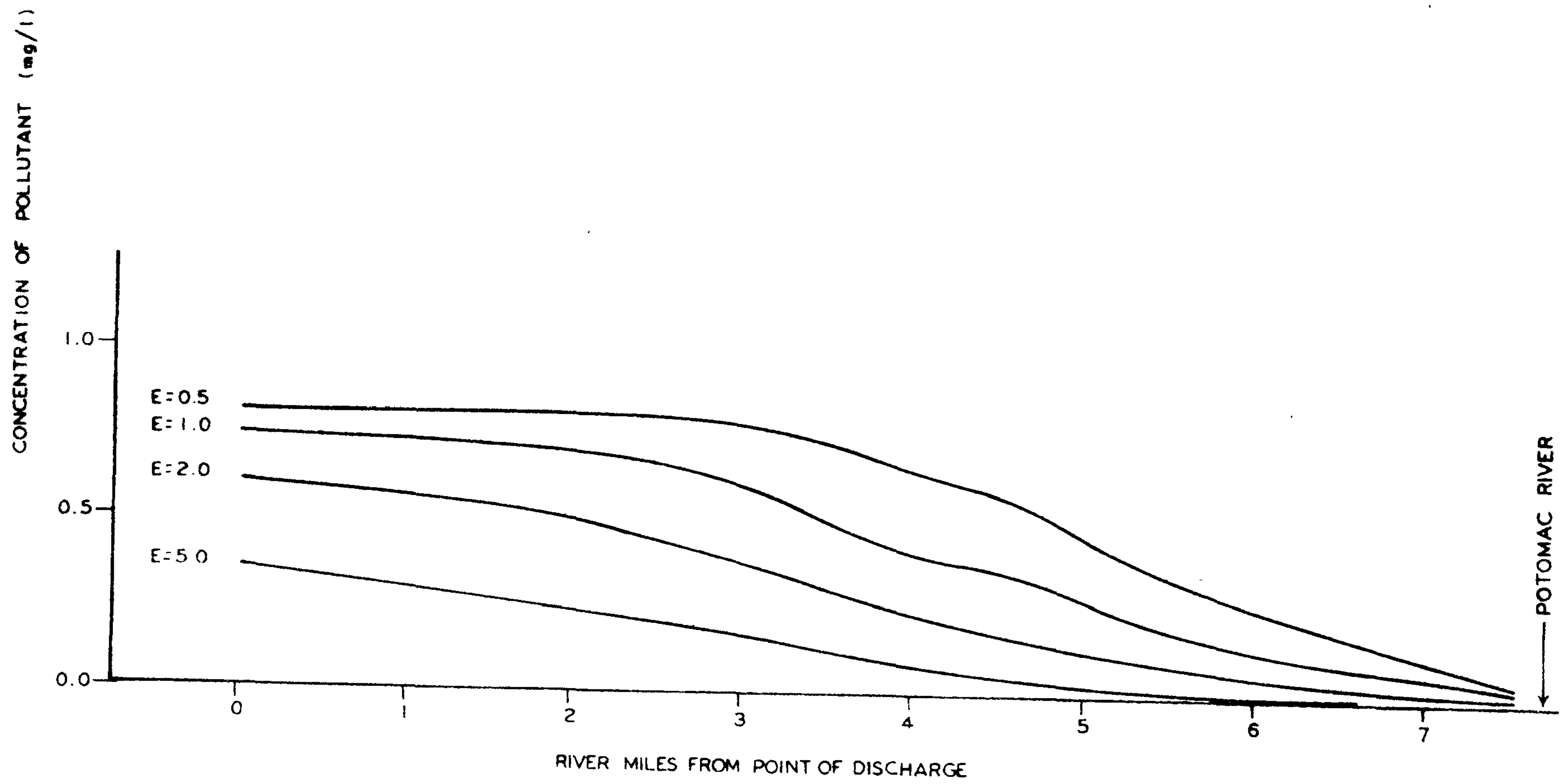


Figure VIII

SIMULATED PROFILES FOR VARIOUS WASTEWATER DISCHARGE RATES FOR CALCULATED DISPERSION COEFFICIENTS OF A CONSERVATIVE POLLUTANT DISCHARGED AT A RATE OF 1000 lbs/day INTO THE ANACOSTIA TIDAL RIVER SYSTEM ABOVE DC-MD LINE

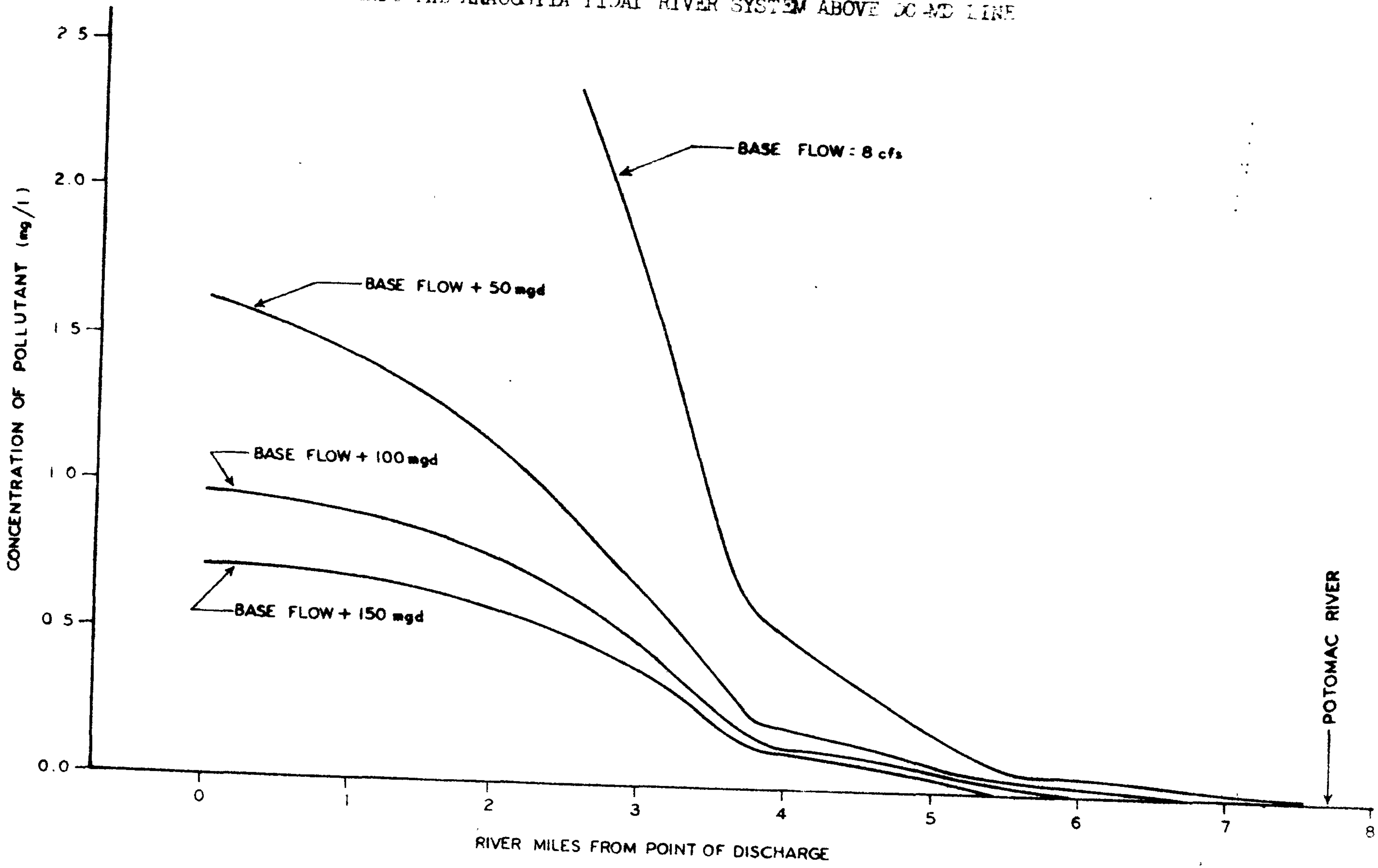


Figure XIV

DISCHARGED AT A RATE OF 1000 lbs/day
INTO THE ANACOSTIA TIDAL RIVER SYSTEM ABOVE THE DC-MD LINE
Q = 108 cfs
Decay Rate = 0.3 (base e)

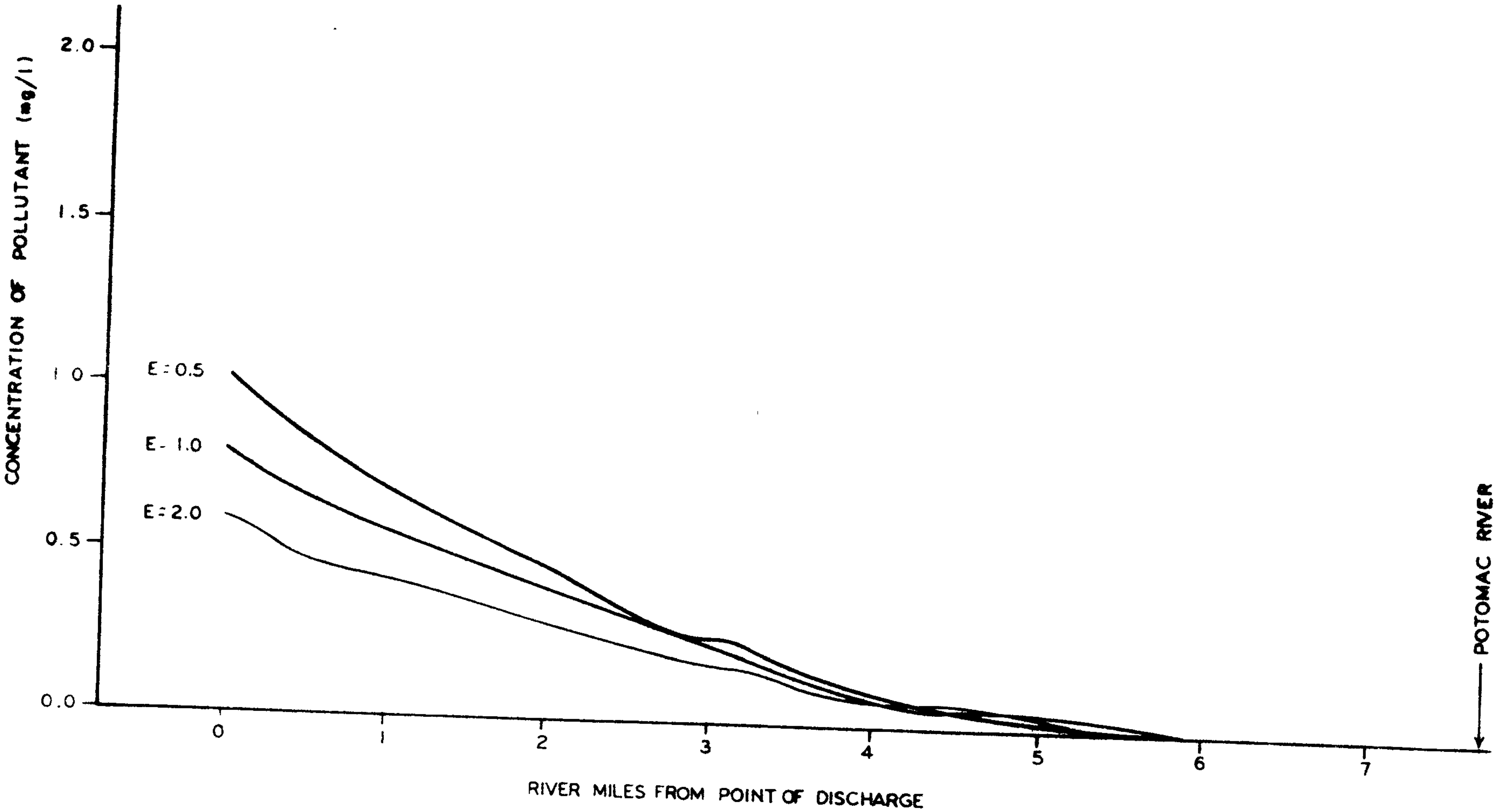


Figure XV

D. SELF-PURIFICATION AND THE DISSOLVED OXYGEN BUDGET

In the tidal system, carbonacecus and nitrogenous BOD from land runoff, storm sewers, defective sanitary systems was large enough at times to depress the DO below 2.0 mg/l in the area of Kingman Lake.

Preliminary model studies using the WRE hydrodynamic model indicate that even with large wastewater discharges, there would be no appreciable increase in self-purification or reaeration rates because of insignificant changes in the advective tidal velocities. Hence, it appears that a discharge into the Anacostia would have to contain a BOD (both carbonaceous and nitrogenous) concentration equal to or lower than that currently found in the tidal system. For the critical months, the effluent should be renovated to have a BOD_5 of 2.0 to 4.0 and an unoxidized nitrogen concentration of 0.5 to 1.0 mg/l.

Another important aspect of the wastewater treatment facility in terms of water quality enhancement of the receiving water will be the DO in the final effluent. For a wastewater discharge of 100 mgd, nearly all of the advective river flow will be from the wastewater. Therefore, a minimum of 4.0 mg/l should be maintained in the final effluent at all times. If a 6.0 mg/l concentration of DO is maintained in the effluent, along with a low oxygen demand, the wastewater could enhance present water quality in the Anacostia River.

An example of this enhancement can be readily shown by utilizing the simulated curves in Figure XVI. With an effluent DO of 4.0 mg/l, the DO at the critical sag point will be increased by 2.0 mg/l (0.5 x 4.0) with resulting DO being about [illegible].0 mg/l. If the effluent

PROFILES FOR A CONSERVATIVE AND NONCONSERVATIVE POLLUTANT
DISCHARGED AT A RATE OF 1000 lbs/day
INTO THE ANACOSTIA TIDAL RIVER ABOVE THE [illegible] LINE
Wastewater Flow [illegible]
River [illegible]

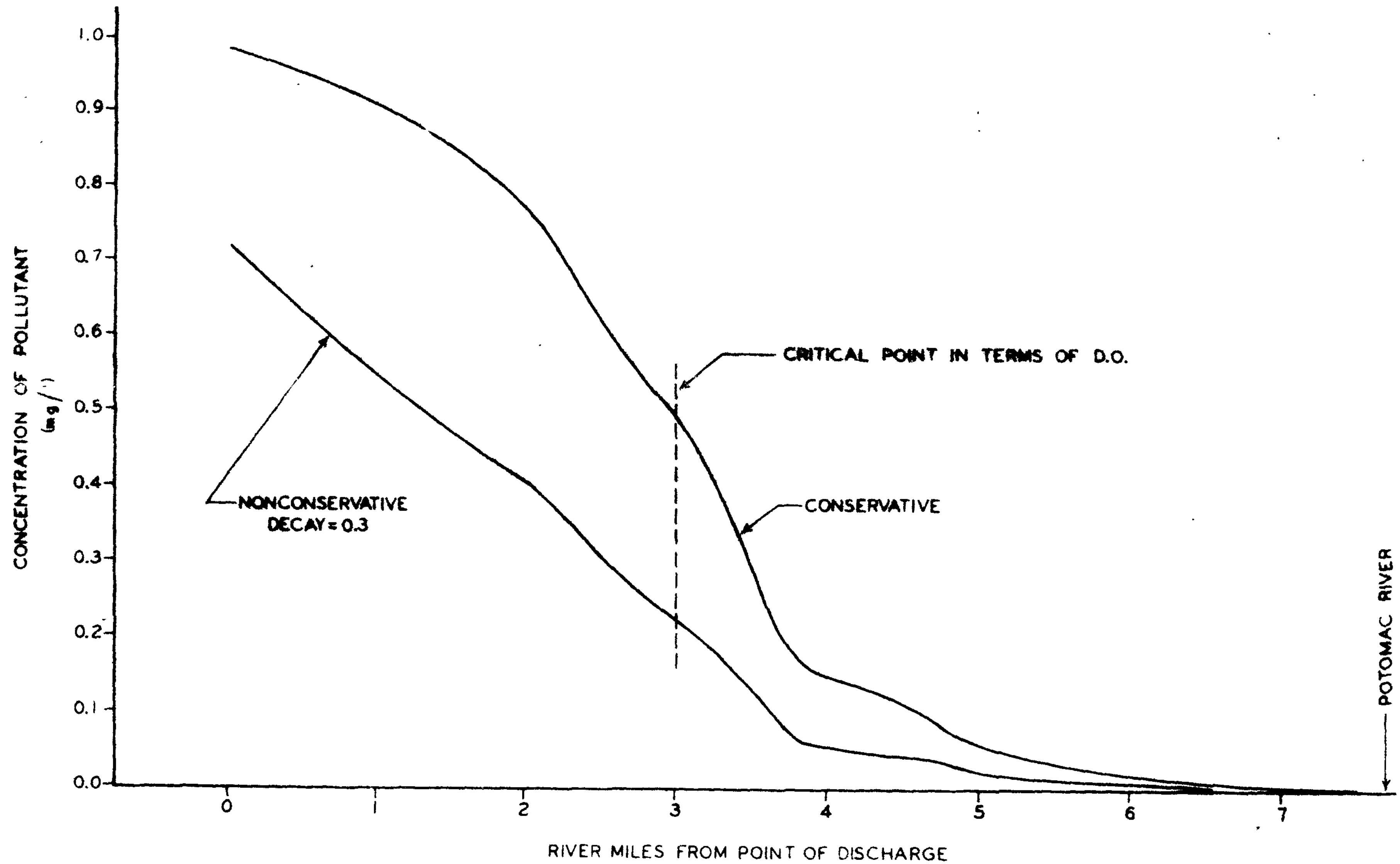


Figure XVI

has 6.0 mg/l, or approximately 5,000 lbs/day of oxygen, the DO at the critical point will be increased by approximately 3.0 mg/l. This assumes that reaeration from the atmosphere is equal to the oxygen demand of the wastewater (The DO during the summer months of 1969 was about 1.0 mg/l in this area). The resulting DO in the system from the 6.0 mg/l would then be approximately 4.0 mg/l (3.0 + 1.0), thus meeting the DO water quality standard.

E. NUTRIENTS AND ALGAL GROWTH

As indicated earlier in this chapter, algal growths were abundant in the Anacostia in the 1950's. Lack of nuisance blooms during the spring and summer months in the 1960's appear to have been a result of low light penetration and the elimination of the Bladensburg Wastewater Treatment Facility.

If a wastewater effluent of 100 mgd of highly treated effluent including low turbidities were to be discharged into the Anacostia above the D.C.-Md. Line, a significant increase in light penetration will occur. Such an increase could cause nuisance algal growth in the Anacostia.

To reduce the incidence and magnitude of nuisance algal growth in the upper Potomac tidal system, upper limits of 0.1 and 0.5 mg/l of phosphorus as P and nitrogen respectively were used to calculate maximum permissible nutrient loadings from wastewater discharges. Since most of the advective flow would be from wastewater, the nutrient concentrations in any Anacostia effluent should be similar to these limits. Allowing for possible continued reduction in light penetration, a range of these nutrient limits was utilized. The phosphorus limits used were 0.1 to 0.2 mg/l with nitrogen limits of 0.5 to 1.0 mg/l.

F. TREATMENT AT THE BLUE PLAINS PLANT VERSUS CONSTRUCTING A FACILITY IN THE ANACOSTIA VALLEY

The Potomac River-Washington Metropolitan Area Enforcement Conference on May 8, 1969, agreed upon a BOD loading of 16,500 lbs/day, a nitrogen loading of 8,000 lbs/day, and a phosphorus loading of 740 lbs/day. Based on 1968 contributions, the Blue Plains Treatment Plant was allocated 12,700, 6,130, and 560 lbs/day of BOD_5, nitrogen, and phosphorus respectively. Using the current loading rates and population projections, the removal percentage and effluent concentrations were determined as given below:

	1970 Q = 232 mgd		1980 Q = 309 mgd		2000 Q = 419 mgd	
	Removal (%)	Conc. Effl. (mg/l)	Removal (%)	Conc. Effl. (mg/l)	Removal (%)	Conc. Effl. (mg/l)
BOD_5	95.8	6.50	97	4.90	98	3.60
Nitrogen	86.6	3.20	90	2.40	93	1.80
Phos. as P	96.6	0.28	97	0.22	98	0.16

The effluent from the 419 mgd facility would have to be renovated to such a high degree, except for nitrogen, that it could be considered as approaching ultimate wastewater treatment (UWT*).

* Ultimate wastewater treatment can be defined as renovation of the wastewater to such a degree that it can be discharged into the receiving stream in unlimited quantities without restriction of intended use of the water resource due to the lack of needed assimilative or transport capability of the stream.

Wastewater constituents before treatment, effluent concentrations, and percent removal requirements for a discharge into the Anacostia at the site investigated are presented below:

Parameter	Wastewater Consitituents Before Treatment (mg/l)	Effluent Concentrations (mg/l)	Percent Removal Requirements
BOD_5	200.0	2.0 - 4.0	98 - 99
T. Phosphorus as P	11.0	0.1 - 0.2	98 - 99
T. Nitrogen as N	22.0	0.5 - 1.0	96 - 98

In incorporating UWT into a water quality management program, the effluent standard concept is utilized. For receiving waters such as the tidal portion of the Anacostia River, this concept appears to be realistic under present conditions to enhance the dissolved oxygen resources and to prevent nuisance algal growths.

If an effluent of this quality is maintained during the critical times of the year, the UWT concept can be applied to the tidal portion of the Anacostia River. With this concept, the effluent will be of higher quality than the existing water quality in the Anacostia and thus will enhance the water quality providing a positive water quality management approach.

Even with the high waste removal requirements, a major uncertainty is the possibility of nuisance algal blooms stimulated by favorable growing conditions in the tidal system. Data obtained by CTSL from the tidal waters of the Anacostia, which are shallow, with little freshwater inflow and insignificant transport indicate that such areas have higher growths at the same nutrient levels for a given area than along the main stem of the Potomac. While light penetration inhibition may reduce this potential somewhat in the Anacostia, nevertheless, the potential remains. Discharges into the main Potomac have a decreased algal growth potential per square foot area because of the greater depths.

G. Continuing Studies

Additional studies relating to (1) tidal dispersion characteristics of the Anacostia River, (2) water quality interactions between Kingman Lake and the Anacostia River, and (3) further definition of the DO budget including reaeration rates and benthic demands are already in progress or will be initiated by CTSL in the coming months.

As mentioned earlier in this report, a dye tracer investigation of the Anacostia River was conducted from April 22-28, 1970. While the data collection phase of this study has not been completed, preliminary analyses indicate that (1) dye movement and residence time closely parallels mathematical model predictions, and (2) a considerable dye buildup was observed in Kingman Lake which further demonstrates that its water quality is significantly dependent on the Anacostia's quality. The final results of this dye study will be incorporated into the next progress report for the Potomac River-Washington Metropolitan Area Enforcement Conference. They will also be published in a separate report entitled "Potomac-Anacostia Rivers Dye Studies."

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APPENDIX A

ANACOSTIA RIVER STUDY
CHESAPEAKE FIELD STATION
1967

Date Sample Taken	DO mg/1	Turb. JTU	LAS/ABS mg/1	BOD mg/1	Susp. Sol. mg/1	Vol. Sol. mg/1	Coliform MPN	Fecal Coliform MPN
			INDIAN CREEK - BELTSVILLE					
4-17	9.19	4.0	ND	4.55	8.4	[illegible]	17,200	1,090
4-18	9.25	13.0		8.26	12.0	5.5	7,000	1,300
4-19	8.25	5.3		8.27	7.2	3.6	< 200	< 200
4-20	10.85	5.2	.300	8.16	4.0	5.0	790	170
4-20	8.17		.450					
4-21	8.51	6.7		8.04	5.0	--	50	< 20
			LITTLE PAINT BRANCH - CHERRY HILL					
4-17	10.17	6.8	ND	2.30	10	[illegible]	490	230
4-18	10.87	15.0	.250	1.94	10.5	2.0	17,200	1,720
4-19	10.50	13.0		1.81	5.0	1.5	3,300	1,410
4-20	11.21	6.1	ND	1.53	9.6	4.4	200	< 200
4-20	9.84		.250					
4-21	10.65	5.6		1.31	4.8	2.0	80	< 20
			PAINT BRANCH - PLANT INDUSTRY STATION					
4-17	10.79	2.7	.250	1.80	8.8	[illegible]	310	130
4-18	9.95	10.0		2.04	9.0	7.5	2,200	330
4-19	11.73	4.4		1.52	4.0	1.0	790	220
4-20	11.97	6.7	ND	1.30	11.6	4.8	490	230
4-20	11.29		ND					
4-20	10.92		.230					
4-21	11.46	5.7		1.21	5.6	2.0	220	130
			PAINT BRANCH - STEWART CHAPEL					
4-17	10.26	2.7	ND	1.54	11.6	[illegible]	170	20
4-18	10.79	10.0	ND	1.06	3.0	--	17,200	790
4-19	10.70	3.4		1.41	3.5	[illegible]	940	330
4-20	11.02	2.3	ND	.85	.8	--	260	40
4-20	9.88		.240					
4-21	10.53	13.0		1.20	2.5	--	490	20

ND - Not detectable

Date Sample Taken	DO mg/1	Turb. JTU	LAS/ABS mg/1	BOD mg/1	Susp. Sol. mg/1	Vol. Sol. mg/1	Coliform MPN	Fecal Coliform MPN
			PAINT BRANCH - COLLEGE PARK					
4-17	10.80	4.6	.250	2.46	8.4	3.2	7,900	1,300
4-18	10.49	13.0		2.43	20.0	2.0	> 7,900	> 790
4-19	11.49	7.6		1.85	7.0	.5	13,000	3,480
4-20	12.00	7.2	.200	1.17	14.0	8.8	13,000	9,180
4-21	11.26	5.5		1.41	2.8	--	1,720	170
			INDIAN CREEK - BERWYN HEIGHTS					
4-17	8.77	43.0	LA	3.61	44.0	5.4	700	700
4-18	8.17	49.0	.260	3.33	67.0	11.0	10,900	3,300
4-19	9.40	60.0		7.63	61.0	10.0	940	330
4-20	9.82	33.0	ND	3.97	38.0	11.0	790	330
4-21	9.06	78.0		3.19	74.0	5.0	2,400	140
			NORTHWEST BRANCH - COLESVILLE					
4-24	10.48	4.2	ND	2.54	.8	2.0	1,090	170
4-25	12.36	4.9	ND	2.10	6.4	1.2	80	80
4-26	11.56	4.8		1.86	2.6	.8	490	490
4-27	10.57	21.0		2.21	16.4	4.4	5,420	1,090
4-28	11.88	6.8		1.91	6.0	.8	2,400	790
			NORTHWEST BRANCH - NEW HAMPSHIRE AVE.					
4-24	11.13	4.6	.513	2.80	--	2.4	3,480	460
4-25	12.35	5.4	ND	1.81	7.2	4.4	1,300	500
4-26	11.87	3.5		1.69	5.2	4.8	170	< 20
4-27	11.08	14.0		2.58	10.0	10.0	3,300	3,300
4-28	12.42	6.7		1.61	5.6	3.6	460	210
			NORTHWEST BRANCH - LEWISDALE (E.W. HWY)					
4-24	10.79	4.0	ND	2.60	--	--	700	230
4-25	12.22	3.2		1.94	4.0	--	330	130
4-26	11.71	2.9		1.84	--	2.4	130	130
4-27	10.69	17.0		2.64	9.6	2.4	3,480	3,480
4-28	11.83	7.2		2.53	10.4	6.0	790	490

ND - Not detectable
LA - Lab accident

Date Sample Taken	DO mg/1	Turb. JTU	LAS/ABS mg/1	BOD mg/1	Susp. Sol. mg/1	Vol. Sol. mg/1	Coliform MPN	Fecal Coliform MPN
				SLIGO CREEK - SLIGO				
4-24	8.63	17.0	.600	9.46	4.0	3.6	54,200	9,180
4-25	12.57	7.4	.688	3.48	--	1.6	2,700	1,300
4-26	11.87	4.8		2.03	4.0	2.4	1,300	50
4-27	9.83	31.0	.500	4.65	21.6	2.8	13,000	2,400
4-28	12.01	7.5	.368	2.05	8.0	5.2	34,800	1,090
				SLIGO CREEK - CHILLUM MANOR				
4-24	12.07	4.5	.388	5.30	8.8	4.0	> 160,900	160,900
4-25	13.32	6.8	.732	4.86	3.2	.4	>1,609,000	>1,609,000
4-26	12.86	4.5		3.25	2.0	2.0	130,000	50,000
4-27	9.97	27.0	.535	5.96	19.6	3.2	230,000	58,000
4-28	9.89	7.6	.545	4.15	10.4	6.4	3,480,000	290,000
				BLADENSBURG MARINA				
4-24	6.05	26.0	.288	4.60	13.2	2.4	34,800	9,180
4-25	7.61	39.0	.258	3.75	44.4	4.8	46,000	17,000
4-26	7.16	35.0		3.93	38.8	6.4	24,000	200
4-27	8.10	49.0	.523	8.77	30.0	5.0	210,000	63,000
4-28	9.89	26.0	.291	3.20	25.6	9.6	32,000	7,000
				US 50 BRIDGE				
4-24	5.31	57.0	.525	6.68	73.2	12.4	5,420	130
4-25	6.72	74.0	.537	5.08	103.6	15.2	13,000	1,700
4-26	4.23	56.0		5.13	66.8	12.8	1,300	330
4-27	5.83	150.0	.198	6.23	103.2	18.0	13,000	5,420
4-28	9.45	42.0	.265	4.59	82.0	18.0	24,000	3,480
				NORTHEAST BRANCH - RIVERDALE				
4-17	10.65	23.0	.252	3.38	22.0	5.2	22,100	1,090
4-18	10.51	34.0		4.19	35.0	4.0	4,900	1,720
4-19	10.95	25.0		2.89	26.0	10.0	7,000	1,300
4-20	11.64	23.0	ND	3.52	21.0	13.0	2,300	800
4-21	11.22	27.0		4.33	18.0	3.0	1,300	220

ND - Not detectable

Date Sample Taken	DO mg/1	Turb. JTU	LAS/ABS mg/1	BOD mg/1	Susp. Sol. mg/1	Vol. Sol. mg/1	Coliform MPN	Fecal Coliform MPN
NORTHEAST BRANCH - RIVERDALE								
4-24	11.11	33.0		3.15	36.0	3.6	5,420	> 90
4-25	12.16	22.0		2.17	14.8	4.0	1,300	490
4-26	11.51	31.0		2.35	29.2	6.4	1,090	20
4-27	10.32	46.0		4.17	50.0	5.6	10,900	3,480
4-28	11.24	17.0		1.63	12.8	2.0	2,400	1,300
NORTHWEST BRANCH - QUEENS CHAPEL RD.								
4-17	10.32	5.8	.252	6.09	21.2	8.8	700	70
4-18	11.22	17.5	.150	5.22	20.0	14.0	>160,900	91,800
4-19	11.68	11.0		8.87	5.0	3.0	34,800	16,090
4-20	12.17	5.6	.450	3.21	--	--	14,000	7,000
4-21	12.31	5.3		3.17	6.4	2.0	4,900	< 200
4-24	12.00	3.8		3.28	3.2	4.0	4,900	330
4-25	13.09	7.9		2.67	26.0	6.0	1,720	790
4-26	12.56	4.9		2.24	3.2	2.0	2,400	110
4-27	10.24	21.0		3.35	14.0	3.6	13,000	5,420
4-28	11.99	7.1		1.57	7.2	2.8	5,420	790

APPENDIX B

NUTRIENT CONCENTRATIONS
AT
BLADENSBURG BRIDGE ROAD
ANACOSTIA RIVER
1966

Sampling Date	River Flow (cfs)	NO_3 as N mg/l	Total PO_4 as PO_4 mg/l	TKN as N mg/l
1-13	15	1.306	0.240	
1-20	14	1.171	1.360	1.510
1-25	20	1.036	2.220	1.950
2-05	19	1.511	0.460	0.860
2-09	20	1.123	0.560	1.460
2-14	375	0.965	1.940	1.650
2-21	34	0.842	0.210	
2-28	358	1.149	0.190	
3-07	38	1.552	0.530	
3-07	38		0.500	
3-14	30	0.790	0.380	
3-16	25	0.723	0.370	
3-28	25	0.756	0.120	
3-30	22	0.832		
4-19	34	0.747	0.470	
4-26	52	0.512	0.470	1.421
5-02	147	0.540	0.560	1.047
5-09	38	0.453	0.630	1.242
5-16	27	3.074	0.540	0.847
5-23	28	0.381	1.230	1.309
6-06	21	0.590	0.190	1.148
6-13	15	1.429	0.390	1.046
6-20	14	0.351	0.340	
6-22	10	0.295	2.370	
7-05	45	0.702	0.410	1.000
7-13	8	0.340	0.090	1.630
9-08	1	1.050	0.480	0.630
9-16	557	1.200	0.830	0.390
9-22	115	0.600	0.320	
9-29	143	0.745	0.360	0.360
10-06	40	1.480	0.640	0.640

APPENDIX B (continued)

Sampling Date	River Flow (cfs)	NO_3 as N mg/1	Total PO_4 as PO_4 mg/1	TKN as N mg/1
10-13	30	2.570	0.580	1.010
10-20	559	0.450	2.210	4.220
10-27	50	0.590	0.730	0.860
11-03	84	0.400	0.980	0.920
11-10	77	0.420	4.270	3.100
11-18	66	0.900	0.130	0.320
12-01	56	0.840	0.480	0.750
12-08	46	0.550	0.480	0.300
12-15	147	0.990	0.500	0.660
12-22	85	0.960	0.570	0.490
12-29	155	1.690	0.540	0.780

APPENDIX C

ANACOSTIA RIVER
Kingman Lake
June 26-27, 1969
CHESAPEAKE TECHNICAL SUPPORT LABORATORY

Date Sample Taken	Time Sample Taken	Station Number	Water Depth Feet	Water Temp °C	Laboratory pH	DO mg/1	BOD mg/1	Coliform* MPN per 100 ml	Fecal Coliform* MPN per 100 ml
6-26	1150	A 1	2	29.5	6.40	2.75	7.44	93,000	93,000
	1340	2	2	29.2	6.38	4.16	7.18	93,000	24,000
	1335	3	-	29.2	6.22	2.41	5.28	43,000	24,000
	1330	4	-	29.3	6.30	2.38	5.68	43,000	24,000
	1320	5	-	29.5	6.25	1.44	4.14	43,000	15,000
	1307	6	10	29.5	6.42	2.24	4.80	93,000	24,000
	1257	7	10	30.0	6.40	1.91	6.34	240,000	4,300
	1247	8	10	29.8	6.30	1.35	4.46	93,000	4,300
	1234	9	6	29.9	6.30	2.14	4.86	43,000	24,000
	1208	10	4.5	30.0	6.30	1.88	5.28	43,000	43,000

Note: Sta A2: Oily smell, soft mucky bottom. No living organisms observed.
Sta A9: Sludge worms, oil odor, very soft bottom.

Date Sample Taken	Time Sample Taken	Station Number	Water Depth Feet	Water Temp °C	Laboratory pH	DO mg/1	BOD mg/1	Coliform* MPN per 100 ml	Fecal Coliform* MPN per 100 ml
6-27	0937	A 1		30.5	6.15	1.91	9.28	93,000	24,000
	0920	2		30.0	6.20	2.56	9.12	43,000	2,300
	1115	3		28.5	6.33	2.75	10.44	24,000	9,300
	1107	4		28.5	6.40	2.20	9.74	43,000	7,300
	1100	5		29.5	6.42	2.20	7.98	15,000	2,300
	1051	6		28.5	6.41	2.53	9.78	15,000	2,100
	1043	7		29.5	6.42	2.04	7.88	43,000	4,300
	1024	8		30.0	6.52	1.98	7.90	43,000	3,900
	1017	9		31.5	6.53	1.69	7.28	24,000	2,100
	0951	10		31.5	6.53	1.84	7.70	93,000	15,000

* Analyses run by D. C. Blue Plains Waste Treatment Plant personnel.

APPENDIX C (continued)

Station Description:

1	Intersection of stream and Anacostia, north of North Kingman Lake bridge.
2	Kingman Lake, north of northmost island.
3	Kingman Lake, northeast corner of third northmost island, first above bridge.
4	Kingman Lake, just north of Benning bridge.
5	Kingman Lake, west side of island, between stone outfall and drainpipe.
6	Kingman Lake, east side of southmost island.
7	Kingman Lake, just south of East Capitaol Street Bridge.
8	Kingman Lake, north of locks, east of hospital.
9	Anacostia River, south of locks.
10	Anacostia River, south of Benning bridge.

Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Quality Administration
U. S. Department of the Interior

CURRENT WATER QUALITY CONDITIONS AND INVESTIGATIONS IN THE UPPER POTOMAC RIVER TIDAL SYSTEM

Technical Report No. 41

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Donald W. Lear, Jr., Ph.D.

May 1970

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CHAPTER I

INTRODUCTION

During the November 1969 progress meeting of the Potomac Washington Metropolitan Area Enforcement Conference, information was presented on water quality conditions and wastewater loadings in the upper Potomac tidal system during 1969. At the spring meeting of the Interstate Commission on the Potomac River Basin (ICPRB) at Indian Head, Maryland, April 16-17, 1970, a summary statement was presented giving data on waste loadings, water quality, and studies by the Chesapeake Technical Support Laboratory on the middle and lower Potomac estuaries as part of the joint study proposed in Recommendation 14 of the conference. A detailed oral presentation was also given by Dr. Lear on the "Ecology of a Eutrophic Estuarine Discontinuity."

Since there were no significant changes in water quality conditions and wastewater loadings as of November 1969, this report will concentrate on the status of investigations currently being conducted by the Chesapeake Technical Support Laboratory. Specific references will be made to the Potomac-Piscataway and the Anacostia wastewater assimilation and transport studies. Separate reports on both of these studies have been prepared and are available.

CHAPTER II

SUMMARY

Based on data obtained by personnel of the U. S. Geological Survey, Dalecarlia Filtration Plant, U. S. Army Corps of Engineers, D. C. Department of Sanitary Engineering (DCDSE), D. C. Department of Public Health (DCDPH), Chesapeake Technical Support Laboratory (CTSL) of the Federal Water Quality Administration (FWQA) and the several wastewater treatment agencies in the Washington metropolitan area, a statement on current water conditions and investigations of the upper Potomac River tidal system was prepared and is summarized below:

1. Fecal coliform densities in the area of Woodrow Wilson Bridge continue to be significantly lower as a result of the increased chlorination of treated waste discharges initiated in June-September 1969. For example, during the months of June, July, and August 1965, the median density was about 90,000 MPN/100 ml, while from September 1969 to April 1970, over 50 percent of the samples had fecal coliform densities less than 1000.

2. High fecal coliform densities were prevalent at times of high stream flow in the portion of the Potomac from Chain Bridge to Memorial Bridge, which is above the major wastewater discharges. These high densities can be attributed to a combination of land runoff from the upper Potomac basin, urban runoff, storm sewers and combined sewer overflows.

3. Tributaries of the Potomac in the Washington metropolitan area also contained very high fecal coliform densities at times. Cabin John

Creek had consistently high counts in 1969 with 25 out of 28 samples showing fecal coliform densities over 10,000.

4. A Potomac Estuary Technical Committee was formed to provide guidance and coordination in the study of water quality problems of the upper Potomac River tidal system.

5. Studies by CTSL are continuing in three major areas: (1) nutrient ecological responses, (2) nutrient transport, and (3) oxygen budget resources.

6. During February and March in 1969 and again in 1970, extensive phytoplankton blooms were detected in the Potomac from Smith Point to Gunston Cove.

7. Under summer conditions massive blooms of blue-green algae were prevalent from Fort Washington to Maryland Point. The densities of these blooms were about 5 to 10 times that reported in most other eutrophic waters.

8. Preliminary results of ecological studies of the Potomac estuary in the area immediately above the Route 301 Potomac River Bridge indicate that the decrease in the massive blue-green algae, Anacystis, is inter-related to (1) the increase of salinity from about 2,000 to 10,000 p.p.m. (2) the decline in nutrients, mainly phosphorus and nitrogen, and (3) the competition for available nutrients by the dominant marine communities in the area below the Route 301 Bridge.

9. Since the late 1930's the amount of phosphorus entering the Potomac from wastewater discharges in the Washington metropolitan area has increased about tenfold and nitrogen increased about fivefold.

The amount of BOD (carbon) since then, although increasing to about 200,000 lbs/day in 1957, has decreased to about 129,000 lbs/day in 1969.

10. The major shift from the balanced ecological communities in the Potomac toward nuisance blue-green algal growths appears to be related to increases in nitrogen and phosphorus, and not BOD (carbon). This shift in ecological communities has also been simulated in controlled studies.

11. Nutrient data from March 1967 suggest that while large phosphorus loadings enter the Potomac estuary during extremely high discharge from the river upstream, the effect appears to be a decrease rather than an increase in concentration in the upper Potomac tidal system. Most of the phosphorus which entered the tidal system from the upper basin, plus some in the system from the wastewater discharges, was adsorbed and deposited in the bottom sediments of the estuary.

12. Studies of nitrification rates suggest that the oxidation of ammonia nitrogen is not a significant factor in the oxygen budget when the water temperature is below 10° C. Studies are continuing to determine the effects of nitrogen on the eutrophication aspects.

13. Dye and mathematical model investigations of the Piscataway embayments and the Anacostia tidal system indicate that wastewater assimilation and transport rates are very low. Wastewater discharges into the embayments of the Potomac may require higher removal rates than those required by the enforcement conference.

14. An analysis of each individual embayment will be required before wastewater treatment levels can be determined.

CHAPTER III

DESCRIPTION AND LOCATION INDEX OF THE POTOMAC RIVER TIDAL SYSTEM

A. GENERAL DESCRIPTION

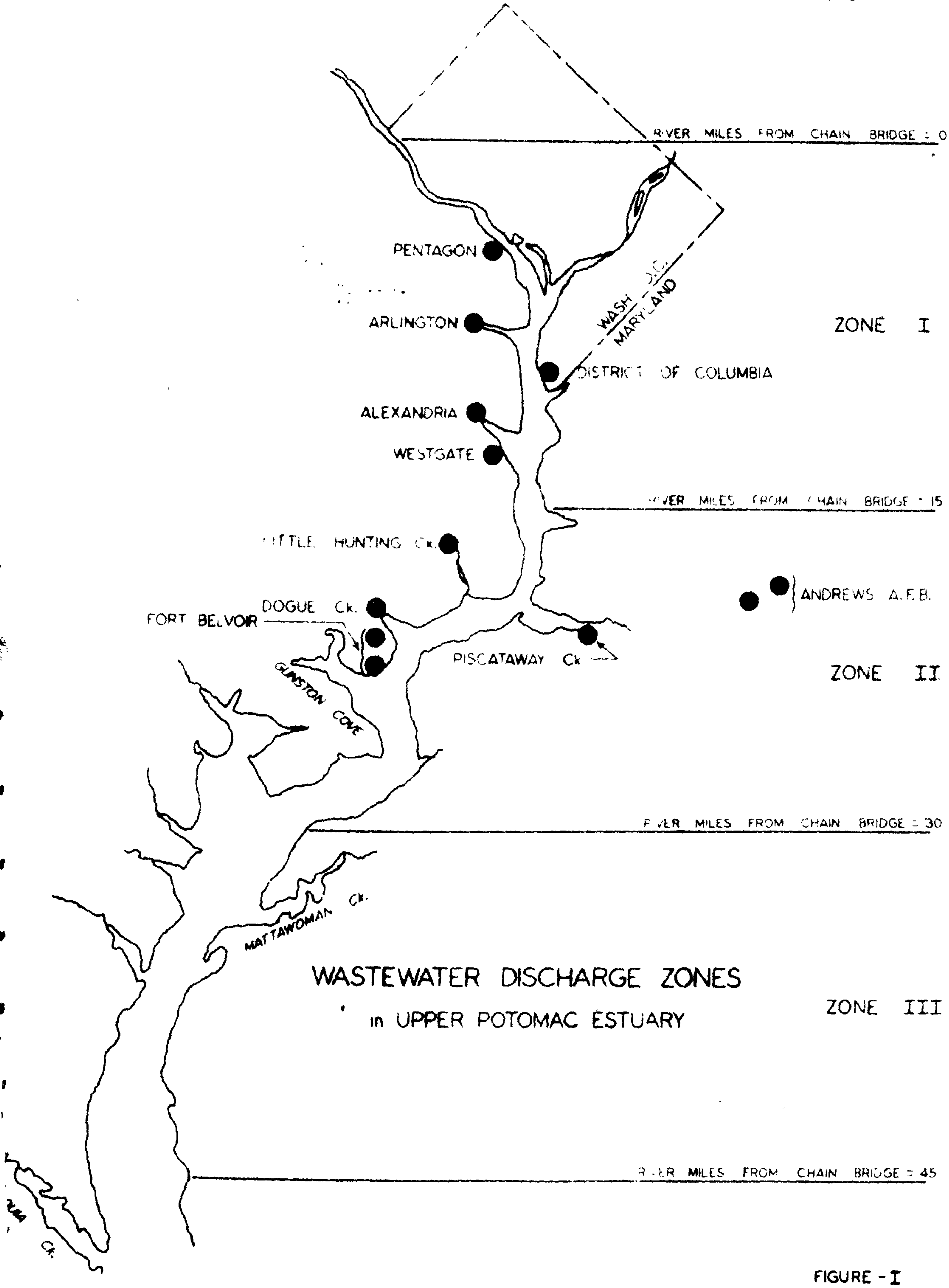
The Potomac River Basin is the second largest watershed in the Middle Atlantic States. Its tidal portion begins at Little Falls in the Washington metropolitan area and extends 114 miles southeastward to the Chesapeake Bay.

The tidal system is several hundred feet in width at its head near Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained upstream to Washington. Except for the channel and a few short reaches where depths up to 100 feet are found, the tidal system is relatively shallow with an average depth of about 18 feet.

Effluents from twelve major wastewater treatment plants, with a thirteenth under construction, serving a population of about 2,500,000 people, are discharged into the upper tidal system. The locations of the discharges from these treatment facilities are shown in Figure I.

B. LOCATION INDEXES

To achieve uniformity in locating water quality sampling stations, wastewater effluents and related activities, a detailed location index was developed for the entire Potomac River tidal system. A starting point at the confluence of the Potomac with the Chesapeake Bay was established. Uniform river mile locations using statute miles have been developed for the primary sampling stations, landmarks, navigation buoys, etc. The data will be published by the CTSL in the near future.



WASTEWATER DISCHARGE ZONES in UPPER POTOMAC ESTUARY

FIGURE - I

1. Reaches of Potomac River Tidal System

For discussion and investigative purposes, the tidal portion of the Potomac River has been divided into three reaches as shown in Figure II and described below:

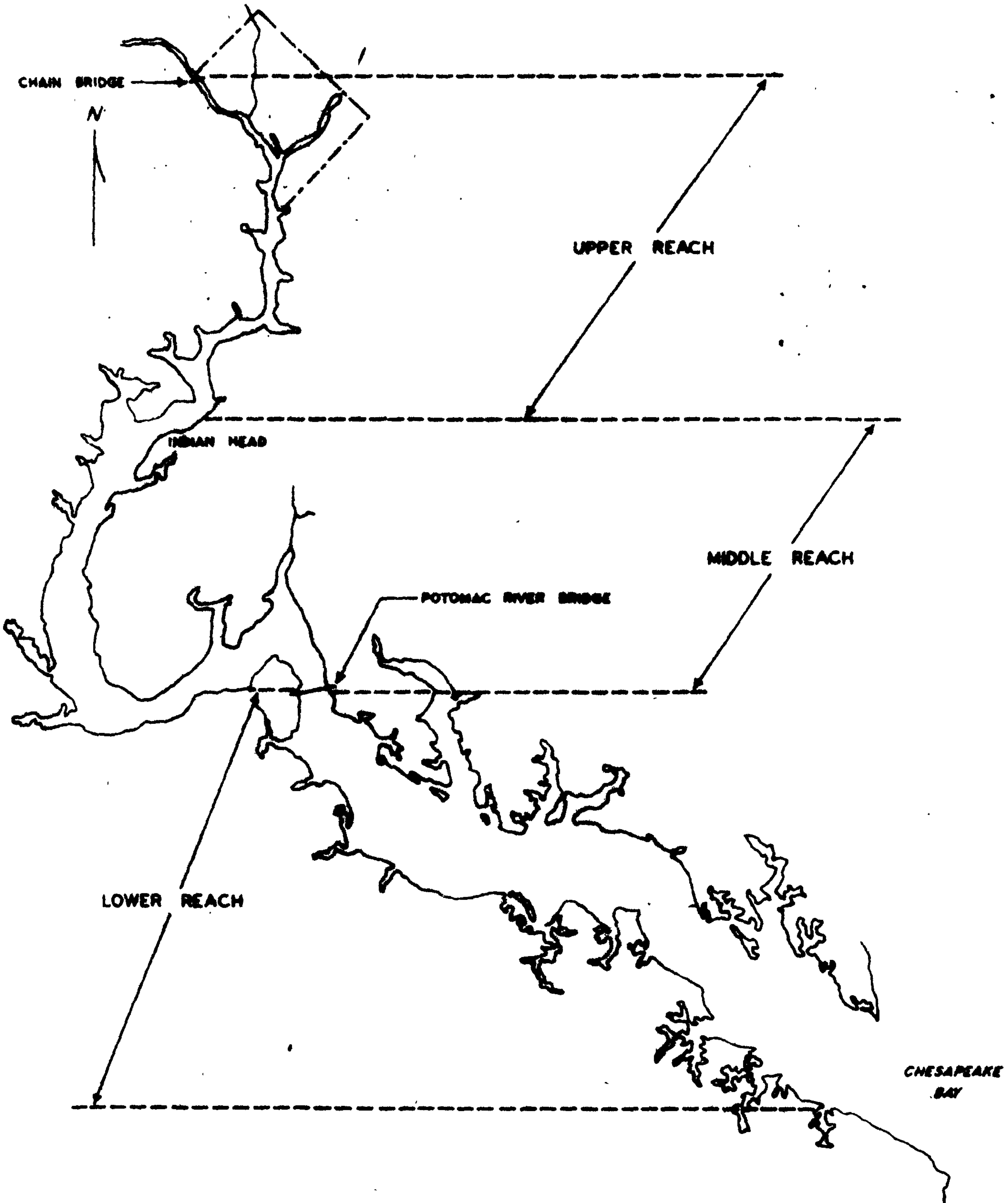
Reach	Description	River Miles	Volume cu. ft. x 10^8
Upper	From Chain Br. to Indian Head	114.4 to 73.8	93.50
Middle	From Indian Head to Rt. 301 Bridge	73.8 to 47.0	362.28
Lower	From Rt. 301 Bridge to Chesapeake Bay	47.0 to 00.0	1754.74

The upper reach, although tidal, contains fresh water. The middle reach is normally the transition zone from fresh to brackish water. In the lower reach, chloride concentrations near the Chesapeake Bay range from about 7,000 to 11,000 mg/l.

2. Zones of Upper Potomac Tidal System

To facilitate determination of water quality control requirements, the upper estuary was segmented by the CTSL into 15 mile zones beginning at Chain Bridge. Establishment of zones similar in physical characteristics allows flexibility in developing control needs. This zone concept was adopted by the conferees of the Potomac Enforcement Conference on May 8, 1969.

River mile distances from both the Chesapeake Bay and Chain Bridge for the upper three zones are given in Table I as well as in Figure II.



POTOMAC RIVER TIDAL SYSTEM

FIGURE - II

TABLE I

ZONES OF UPPER POTOMAC ESTUARY

Zone and Description	River Mile of Upper End of Zone		River Mile of Lower End of Zone	
	from Chain Bridge	from Chesapeake Bay	from Chain Bridge	from Chesapeake Bay
I Chain Bridge to Broad Creek	0.0	114.4	15.0	99.4
II Broad Creek to Indian Head	15.0	99.4	30.0	84.4
III Indian Head to Maryland Point	30.0	84.4	45.0	69.4

CHAPTER IV

WATER QUALITY CONDITIONS

A. UPPER POTOMAC RIVER TIDAL SYSTEM

During the November 1969 progress meeting, it was reported that there had been a significant reduction in the fecal coliform densities in the area of Woodrow Wilson Bridge [1]. This was a result of the installation of effluent chlorination facilities at all major wastewater treatment plants during June-September 1969.

Fecal coliform records at four stations in the Washington metropolitan area of the Potomac River, as summarized in Table II, support this November conclusion. Fecal coliform densities continued to be high during periods of considerable runoff in the area from Chain Bridge to Hains Point. These high counts can be attributed to (1) land runoff from above and below Chain Bridge, (2) storm sewer discharge, and (3) malfunctioning sanitary sewer systems.

Nevertheless, there continues to be a significant reduction in fecal coliforms from previous years in the treatment plant discharge area. As an example, in 1965 the median fecal coliform counts near Woodrow Wilson Bridge was about 90,000 MPN/100 ml for the months of June, July and August. Since September 1969, over 50 percent of the samples had fecal coliform counts of less than 1000.

There has been no significant change in dissolved oxygen readings in the Potomac estuary since November 1969. During the winter and spring months, freshwater flows were near or above normal with the April flows at about twice the median flow. As a result of the higher flows and low winter and spring temperatures, the dissolved oxygen (DO) concentrations were above 8.0 mg/l.

DO concentrations were about 5.0 mg/l for the first week of May 1970 with a river discharge of 15,000-20,000 cfs. This can be compared to DO concentrations of less than 1.0 mg/l at the Woodrow Wilson Bridge in early May 1969 when a fish kill occurred.

TABLE II

FECAL COLIFORM DENSITIES MPN/100 ml

Upper Potomac River Tidal System
D.C. Water Pollution Control Division Data
April 1969 - April 1970

Date	Chain Bridge	Memorial Bridge	Opposite Blue Plains	W.Wilson Bridge
4- 7	--	930	910	9,100
4-21	--	210	93,000	360
5- 5	--	150	2,300	3,600
5-12	--	150	73,000	--
6- 2	--	240,000	4,300	2,300
6-18	--	9,300	9,300	3,600
6-23	--	2,400	230	2,300
6-30	--	750	360	3,600
7- 7	--	11,000	2,300	4,300
7-14	23	36	230	1,500
7-28	4,300	240,000	93,000	24,000
8-11	4,300	4,300	7,300	11,000
8-18	1,100	3,000	1,500	360
8-25	1,500	360	910	230
9- 1*	230	230	360	230
9- 8	2,400	93,000	7,200	9,300
9-15	15,000	4,300	9,300	9,300
9-25	150	230	2,100	360
9-29	360	23	230	230
10- 6	730	110	730	360

TABLE II (continued)

Date	Chain Bridge	Memorial Bridge	Opposite Blue Plains	W.Wilson Bridge
10-20	23	23	9,300	360
10-29	23	36	230	23
11- 3	43	930	930	910
11-11	93	93	1,500	36
11-17	930	430	4,300	23
11-24	4,300	4,300	930	150
12- 1	23	73	910	150
12- 8	2,400	24,000	36	43
12-15	1,200	1,500	2,400	11,000
2- 2	24,000	110,000	110,000	110,000
2- 9	4,300	2,400	4,300	9,300
2-16	2,400	15,000	46,000	92,000
2-23	2,400	2,400	9,300	2,400
3- 2	150	230	240	23
3-16	73	430	1,500	1,500
3-23	930	930	230	4,300
3-30	4,300	2,400	9,300	15,000
4- 6	--	430	430	430
4-13	2,400	430	36	430

* By September 1969, all effluents from the wastewater treatment facilities were continuously chlorinated.

B. POTOMAC TRIBUTARIES

In the previous section, fecal coliform counts were shown to be high during times of high runoff. Sampling data for tributaries of the Potomac taken by the D. C. Department of Public Health in 1969 also show high counts as given in Table III. The locations of the six stations in the table are:

Tributary	Sampling Point	Miles from Potomac
Cabin John (Md.)	G. Washington Parkway	0.3
Rock Run (Md.)	David Taylor Model Basin	0.7
Seneca Creek (Md.)	River Road	0.7
Broad Run (Va.)	Leesburg Turnpike	2.0
Sugarland Run (Va.)	Leesburg Turnpike	0.5
Difficult Run (Va.)	Old Georgetown Road	1.0

For the months of June, July, August, and September, high fecal coliform densities were observed for all six stations. The data for the Cabin John station show high densities the year round, suggesting a periodically overloaded sanitary sewerage system in this watershed.

Data for other urban streams in the Washington metropolitan area, such as Rock Creek as reported by Aalto, et al [2], and Anacostia River by Jaworski et al [3], also indicated high fecal coliform densities. While increases in fecal coliforms occur during periods of high flow, the large increases were usually associated with either combined sewer overflows or defective sewerage systems.

TABLE III

FECAL COLIFORM SUMMARY - MPN/100 ml

Potomac Tributaries
D.C. Department of Public Health Data
1969

Date	Cabin John	Rock Run	Seneca Creek	Broad Run	Sugarland Run	Difficult Run
01-08	250,000+	25,000	--	600	4,000	250
01-15	250,000+	6,000	5,000	4,000	17,000	6,000
02-05	250,000+	1,200	400	500	10,000	400
02-12	400,000	400,000	400,000	250	--	400
02-19	25,000	2,500	1,200	600	2,500	600
04-09	25,000	250	250	400	4,000	400
04-16	250,000	1,200	1,200	250	2,500	600
04-23	25,000	7,000	2,500	2,500	3,000	7,000
04-30	250,000	4,000	500	400	--	600
05-07	250,000	12,000	6,000	--	6,000	1,200
05-14	25,000	500	1,700	1,300	6,000	6,000
05-21	200,000	250	200,000	1,200	5,000	60,000
06-04	250,000	30,000	250,000	60,000	120,000	120,000
06-11	6,000	600	4,000	600	25,000	4,000
06-18	25,000	2,500	2,500	4,000	4,000	4,000
07-09	25,000	6,000	1,700	25,000+	40,000	1,700
07-23	25,000	30,000	250,000+	60,000	250,000+	250,000+
08-13	170,000	25,000	6,000	2,500	25,000	4,000
08-27	120,000	60,000	25,000+	4,000	120,000	12,000

TABLE III (Continued)

Date	Cabin John	Rock Run	Seneca Creek	Broad Run	Sugarland Run	Difficult Run
09-03	4,000,000+	400,000+	250,000+	7,000	250,000+	250,000+
09-10	4,000,000	6,000	25,000+	4,000	6,000	12,000
09-24	120,000	6,000	3,500	1,100	12,000	1,700
10-01	12,000	40,000	1,700	2,900	25,000	2,500
10-08	25,000	6,000	4,000	1,700	60,000	7,000
10-22	12,000	4,000	6,000	4,000	250,000+	4,000
11-04	12,000	0	200	50	4,000	2,500
12-09	1,600	2,500	7,000	1,200	40,000	1,700
12-16	4,000	60	400	1,700	4,000	1,700

CHAPTER V

CURRENT ACTIVITIES

Studies to investigate the nutrients that stimulate algal growth and to determine the major driving forces producing dissolved oxygen stresses are continuing. The objectives of the ecological, nutrient transport, and dissolved oxygen budget studies are to: (1) determine the extent of present water quality degradation, (2) develop predictive capabilities for stresses from projected loadings, (3) determine the corrective actions required, and (4) evaluate the detailed ecological pattern during changes resulting from selective nutrient reductions.

Other tidal waters of the Chesapeake Bay are also currently being monitored to provide a basis for comparison. These waters include the Patuxent, Rappahannock, Chester, and Severn Rivers, and the upper Chesapeake Bay itself.

To provide input and guidance for the CTSL program in studying the Potomac, a Potomac Estuary Technical Coordination Committee (PETCC) was formed, with the first meeting held in November 1969. Members of PETCC include individuals from Maryland Department of Water Resources, Maryland State Department of Health, ICPRB, Maryland-National Capital Parks and Planning Commission, Virginia Water Control Board, Virginia Department of Economic Development, DCDPH, DCDSE, U.S. Army Corps of Engineers, and FWQA.

This chapter presents specific areas currently being investigated. Included are recent findings within each of five study areas: wastewater composition, nutrient response, nutrient transport, dissolved oxygen budget, and discharges into embayments.

A. WASTEWATER COMPOSITION

1. Historical Trends

While the population in the Washington metropolitan area increased eightfold from 1913 to 1969 as shown in Table IV, the phosphorus content in the waste discharges increased almost twentyfold. For the same time period the nitrogen loadings have increased about ninefold, from 6,400 to 52,000 lbs/day, while the BOD's have increased from 58,000 to over 200,000 lbs/day in the late 1950's. Since 1960 the BOD loading has been reduced to 129,000 lbs/day.

The twentyfold increase is a result of the rapid increase in use of detergents high in phosphorus content since the 1940's in place of the soap products formerly used in household cleaning usage. At the present time approximately 50 to 70 percent of all phosphorus in municipal waste discharges can be attributed to the use of detergents [17].

2. Evaluation of Sources

As previously reported [1] CTSL conducted a nutrient survey of the upper estuary during 1969 to determine the relative contributions of critical water quality parameters from the upstream freshwater inflow and wastewater discharges in the metropolitan area. The loadings for the first eight months are given in Table V and a summary of the relative percentages follows:

Parameter	Freshwater Inflow % of total	Wastewater Discharge % of total
BOD	45	55
Organic Carbon	68	32
Inorganic Carbon	89	11
Total Carbon	80	21
Total Phosphorus	14	86
Total Nitrogen	34	66

This summary shows that the parameters in order of most amenable to control measures using wastewater treatment are: (1) phosphorus, (2) nitrogen, and (3) BOD.

TABLE IV

Wastewater Loading Trends*

Discharge to Potomac

Washington Metropolitan Area

Year	Population of Service Area	Wastewater Flow (mgd)	BOD_5 (lbs/day)	T. Nitrogen as N (lbs/day)	T. Phosphorus as PO_4 (lbs/day)
1913	320,000	42	58,000	6,400	3,300
1932	575,000	75	103,000	11,500	6,000
1944	1,149,000	167	141,000	22,980	12,000
1954	1,590,000	195	200,000	31,800	16,700
1957	1,680,000	210	204,000	33,600	26,000
1960	1,860,000	222	110,000	37,200	30,000
1965	2,100,000	285	125,000	42,000	57,000
1968	2,415,000	334	130,000	53,000	61,000
1969	2,480,000	348	129,000	52,000	64,000

* In estimating phosphorus, allowances were made to reflect the effect of detergents.

TABLE V

BOD, CARBON, NITROGEN, AND PHOSPHORUS
SUMMARY OF CONTRIBUTIONS

Upper Potomac Estuary
January-August 1969

Parameter	Unit	Freshwater Inflow	Wastewater Discharge	Total
Flow	mgd	3,500	350	3,850
BOD	lbs/day	108,000	129,000	23[illegible],000
Inorganic Carbon	lbs/day as C	471,000	60,000	531,000
Organic Carbon	lbs/day as C	218,000	102,000	320,000
Total Carbon	lbs/day as C	689,000	162,000	851,000
Total Phosphorus	lbs/day as P	3,600	21,000	24,600
Nitrite and Nitrate	lbs/day as N	11,800	3,300	15,100
Total Kjeldahl Nitrogen	lbs/day as N	15,400	48,200	63,600
Total Nitrogen	lbs/day as N	27,200	51,500	78,700

B. NUTRIENT RESPONSE STUDIES

During 1969, field investigations were continued to further define the nutrient requirements (carbon, nitrogen and phosphorus) for producing nuisance algal growths. Considerable efforts were spent in defining eutrophic conditions in the salinity transition zone.

In the freshwater portions of the tidal system, large blooms of phytoplankton were observed in February and March of 1969 and again in 1970. Water temperatures at the beginning of these blooms were about 4° C. These blooms were primarily in areas between Smith Point and Gunston Cove.

Under 1969 summer and fall conditions as in previous years, large populations of blue-green algae, primarily *Anacystis* sp., were prevalent. An important aspect of these algal growths was that the "standing crop" as measured by chlorophyll *a* had concentrations ranging from approximately 75 to over 200 µg/l. This is about five to ten times that reportedly observed in most other eutrophic waters [15] [16].

The algal populations in the saline water areas were not as dense as those in the fresh water areas. Nevertheless in summer large populations of the dinoflagellates *Gymnodinium* sp. and *Amphidinium* sp. occurred producing the phenomenon known as "red tides."

1. Biological Discontinuity Studies

During the summer of 1969, a special ecological study was undertaken in a 20-mile portion of the Potomac estuary just upstream from the Potomac River Bridge at Morgantown. This area has been observed for several years [10] to be the lower limit in terms of distance from

Chain Bridge of massive blue-green algal blooms. The major purpose of this intensive study was to determine why algal blooms apparently decreased at this location.

The area of investigation was found to be a reach of rapidly increasing salinity downstream, the "salt wedge". An obvious biological discontinuity was found in this reach with marine organisms dominant at the lower end.

Tentative conclusions from this study indicate:

1. The massive blooms of the blue-green alga Anacystis currently terminate in this reach for three interrelated reasons: (1) the increase of salinity from approximately 2 to 12 parts per thousand, (2) a decline in nutrients, especially nitrogen and phosphorus, and (3) the competition for available nutrients by the essentially marine dominated biological community in the lower reach is apparently successful under present conditions.

2. These observations may be useful for predicting the time, duration and extent of a possible similar invasion of blue-green algae in other fresh water tributaries at the head of the Chesapeake Bay, especially the Sassafras, Bohemia, Elk, and Northeast Rivers.

3. When firmer conclusions can be drawn from continued observations, the effects of disposal of nutrients from treated sewage into saline waters as compared to fresh waters may assist in optimizing the increase in estuarine water productivity by controlled addition of nutrients, or at least minimize any stress to the estuarine system caused by these additions.

5. Single sets of daily observations were difficult to interpret, but the aggregate of 15 cruises over a six weeks period showed some statistically significant patterns.

2. Ecological Trends as Related to Nutrient Loadings

A review of past eutrophic trends with estimated nutrient loadings from wastewater discharges into the Potomac was made. In Table IV it can readily be seen that while the present BOD (carbon) loading is the same as in the late 1930's, there is about ten times as much phosphorus and five times as much nitrogen now being discharged.

The effect of these increased nutrient loadings can be seen in Figure III. The change in the ecology from 1913 has been dramatic. Several nutrients and growth stimulants have been implicated as causes of this accelerated eutrophication with nitrogen and phosphorus showing promise of being the most manageable.

The historical plant life cycles in the upper Potomac estuary can be inferred from several studies. Cumming [4] surveyed the estuary in 1913-1914, and noted the absence of plant life near the major waste outfalls with "normal" amounts of rooted aquatic plants on the flats or shoal areas below the urban area. No nuisance levels of rooted aquatic plants or phytoplankton blooms were noted.

In the 1920's an infestation of water chestnut appeared. This was controlled by mechanical removal [5].

In September and October of 1952, another survey of the reaches near the metropolitan area, made by Bartsch [6], revealed that vegetation

NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS
IN THE UPPER POTOMAC TIDAL RIVER SYSTEM

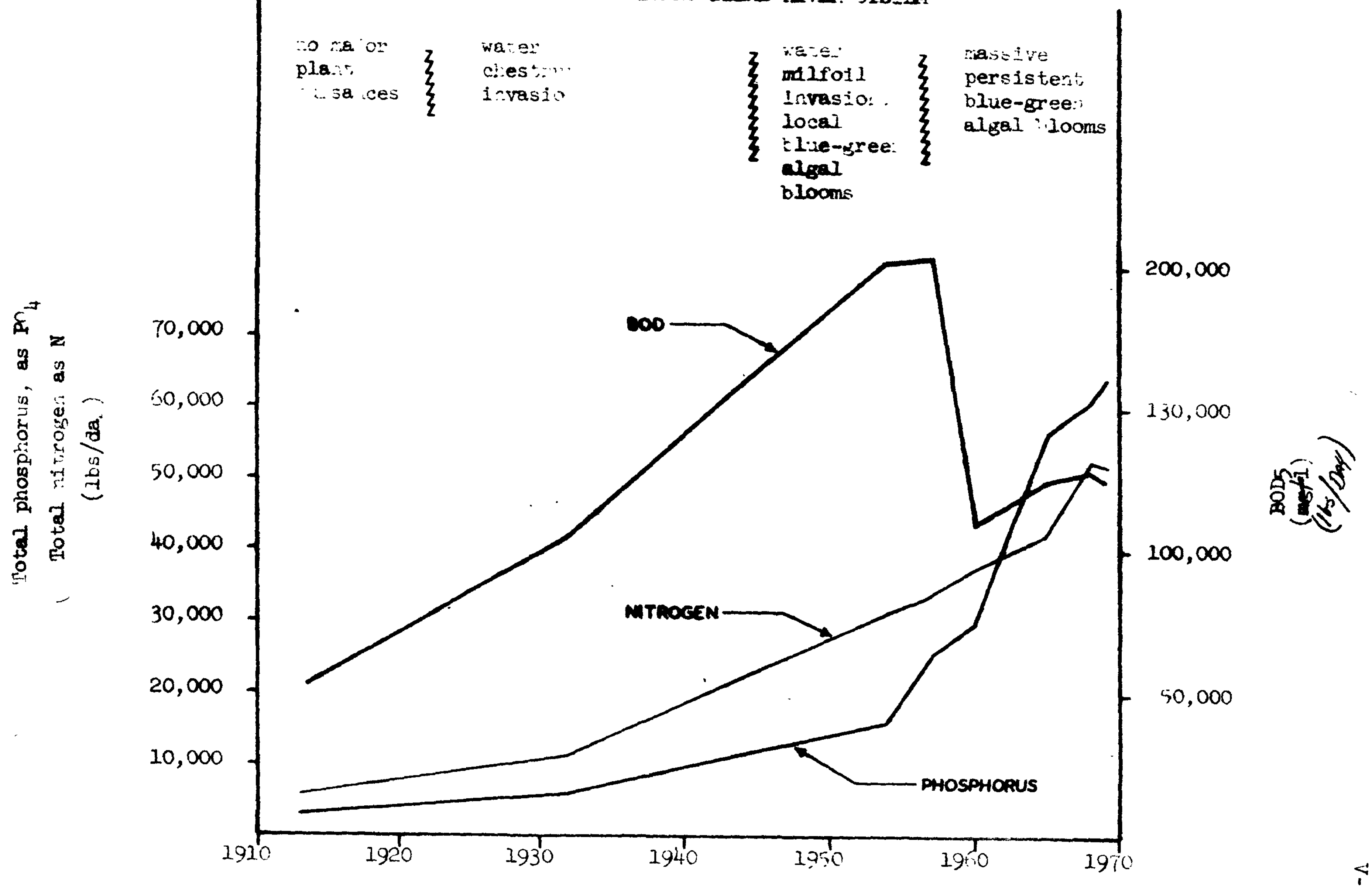


FIGURE - III

in the area was virtually nonexistent. No dense phytoplankton blooms were reported, although the study did not include the areas downstream where they were subsequently found.

In August and September of 1959, a survey of the area was made by Stotts and Longwell [7]. Blooms of the nuisance blue-green alga Anacystis were reported in the Anacostia and Potomac Rivers near Washington, D. C.

In 1958, nuisance conditions of the rooted aquatic plant water milfoil developed in the Potomac estuary. The growth increased to major proportions by 1963, especially in the embayments from Indian Head downstream [8].

These dense stands of rooted aquatic plants which rapidly invaded the system also dramatically disappeared in 1965 and 1966. The decrease was presumably due to a natural virus [9].

Subsequent and continuing observations by the CTSL have confirmed persistent massive summer blooms of the blue-green alga Anacystis at nuisance concentrations from the metropolitan area downstream at least as far as Maryland Point [10].

Data as presented below for comparable flow and temperature conditions for September-October 1965 and October 1969 indicate that algal populations have not only increased in density but have become more widespread.

Potomac Estuary Location	River Miles from Chain Bridge	Chlorophyll a - µg/l		
		Sept. 15, 1965	Oct. 19, 1965*	Oct. 14-16, 1969**
Piscataway	18.35	49	90	74
Indian Head	30.60	36	75	120
Smith Point	45.80	61	56	70

* Single sample

** Average of a minimum of 5 samples

While data are limited for 1965, based upon these data and field observations the increase in nuisance algae appears to be significant. Sampling difficulty makes it impossible to quantify the increase at the present time.

These biological observations can be interpreted as an ecological succession. The initial response to a relatively light over-enrichment was the growth of water chestnut, which when removed allowed the increasing nutrient load to be incorporated into the rooted aquatic plant water milfoil (*Myriophyllum spicatum*). The water milfoil dieoff allowed the nutrients to be competitively selected by the blue-green alga *Anacystis*. Since *Anacystis* is apparently not utilized in the normal food chain, huge mats and masses accumulate and decay.

From these considerations it would appear that nuisance conditions did not increase directly with an increase in nutrients as indicated by the concentrations of phosphorus and nitrogen. Instead, the nutrient increase encouraged a given species to dominate the plant life in the aquatic environment. With a further increase in nutrients this species was rather rapidly replaced in turn by another dominating nuisance form. This is indicated in Figure III where the massive persistent blue-green algal blooms were associated with large increases in phosphorus and nitrogen enrichment in the upper reaches of the Potomac River tidal system. The persistent massive algal blooms have been occurring since the early 1960's even though the amount of carbon (BOD) has been reduced by almost 50 percent.

Laboratory and controlled field pond studies by Mulligan [11] have indicated similar results. Ponds receiving low nutrient additions (phosphorus and nitrogen) had submerged aquatic weeds. Continuous blooms of algae occurred in the ponds having high nitrogen and phosphorus concentrations. An important aspect of Mulligan's studies is that when the aquatic resources were returned to their natural state, the eco-system returned to its natural state. This is also supported by studies of Edmondson [12] on Lake Washington and Hasler on the Madison, Wisconsin lakes [14].

C. NUTRIENT TRANSPORT

A one-year cooperative sampling program with Steuart Petroleum Company has been completed. The survey was designed to determine the nutrient movement throughout the entire tidal system. Since 1969 was a nontypical stream flow year, the study was extended into 1970.

Nutrient data from 1969 taken at Great Falls, Maryland, indicated that large quantities of nutrients enter the tidal system during periods of high stream flow. A study of a high runoff period in 1967 revealed a significant phenomenon. Figure IV shows that the total phosphorus concentration on the early days of March was about 0.150 mg/l at Chain Bridge increasing to over 1.0 mg/l at Woodrow Wilson Bridge as result of wastewater discharges. At the same time the concentrations at Piscataway and Indian Head were 1.4 and 1.0 mg/l, respectively.

On March 7 and 8, the river discharge increased rapidly to about 139,000 cfs (Table VI). This resulted in a discharge on March 8 of over 1,208,000 lbs/day of phosphorus into the tidal system.

However, when the concentrations in the entire upper tidal system are compared to early March, a general overall decrease in phosphorus can be observed. Phosphorus concentrations during high flows are accompanied by high sediment loads and when they enter the slow moving tidal system, much of phosphorus was adsorbed onto the sediment particles and was removed from water as the sediment settled. CTSL conducted laboratory studies using Potomac River samples to confirm this removal of phosphorus by adsorption.

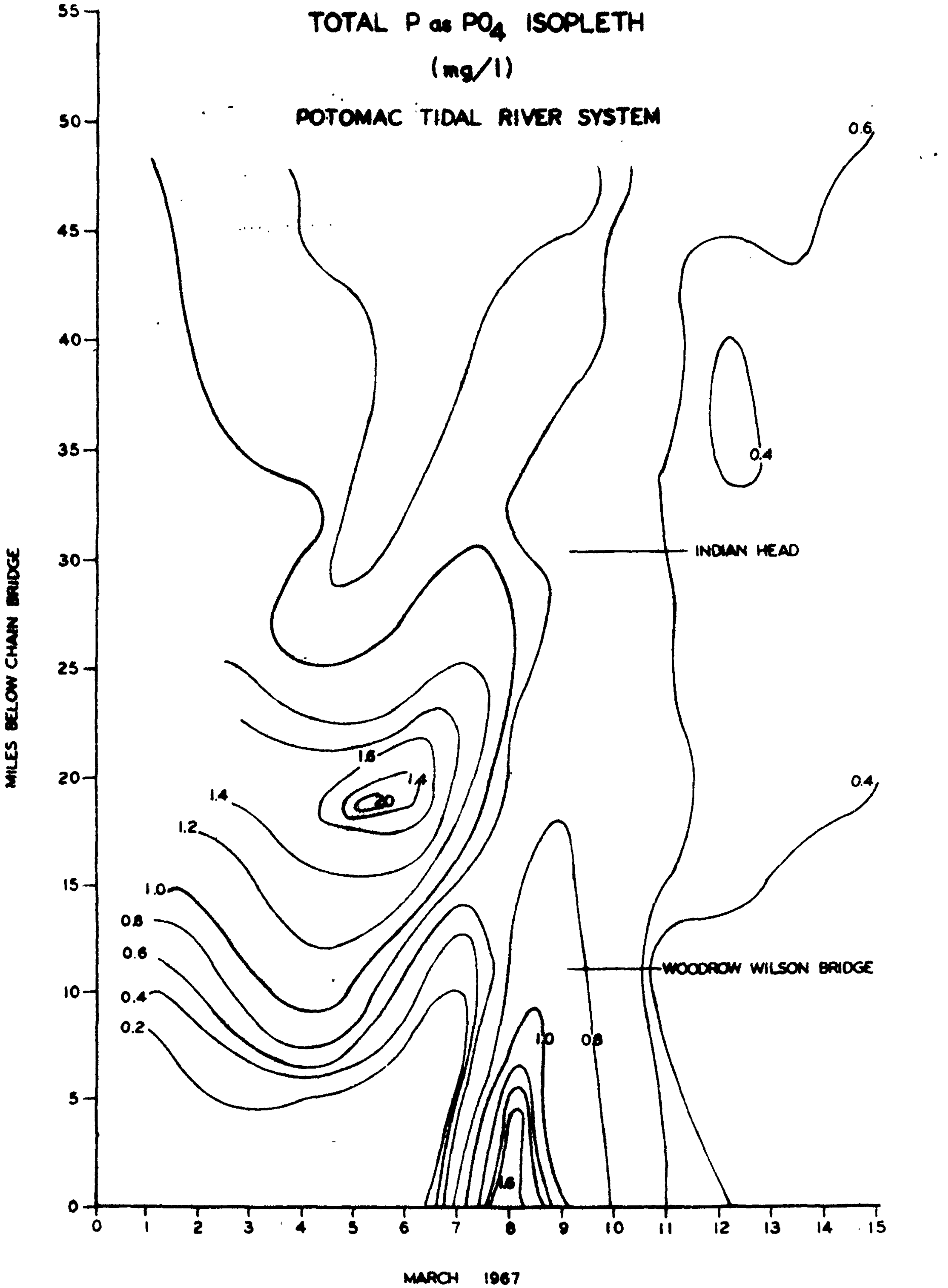

TOTAL P as PO_4 ISOPLETH
(mg/l)
POTOMAC TIDAL RIVER SYSTEM
MILES BELOW CHAIN BRIDGE
MARCH 1967
INDIAN HEAD
WOODROW WILSON BRIDGE
0.6
0.4
0.4
1.6
1.4
2.0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.0
0.8
1.6

FIGURE - II

TABLE VI

RIVER DISCHARGE AND PHOSPHORUS LOADING

Potomac River at Washington, D. C.
March 1 to 14, 1967

Date	River discharge (cfs)	T. Phosphorus as PO_4 (mg/l)	T. Phosphorus as PO_4 (lbs/day)
3- 1	7,690	0.153	6,280
3- 2	7,010	--	--
3- 3	7,230	0.155	5,990
3- 4	7,270	0.132	5,130
3- 5	7,620	0.225	9,150
3- 6	8,590	0.177	8,120
3- 7	63,100	1.316	44,800
3- 8	133,000	1.701	1,208,000
3- 9	139,000	0.936	694,800
3-10	76,400	0.717	292,500
3-11	46,700	0.578	144,200
3-12	36,500	0.355	69,200
3-13	29,500	0.264	41,588
3-14	25,100	--	--

A more sophisticated mathematical model has been recently adapted to the Potomac Estuary to increase sensitivity in simulating the movement of nutrients and other pollutants. Once this capability has been developed and verified, technical areas to be investigated will include:

1. Sensitivity of nutrient concentrations in the upper, middle, and lower reaches to loadings in the upper reach, including contributions from land runoff,

2. The flow probability to be used in determining maximum permissible nutrient levels, including transport, such as seven-day-ten-year flow or the mean monthly flow,

3. Ecological, nutrient transport and nutrient response studies will be necessary to determine whether or not the same nitrogen, phosphorus and carbon removal levels are required during twelve months of the year in order to enhance the water quality in the upper, middle, and lower reaches.

4. Effects of withdrawal of water from the upper portion of Zone I as a supplemental water supply for the Washington metropolitan area on the allowable nitrogen, phosphorus, and carbon loadings from wastewater discharges, and

5. Development of seasonal nutrient loadings for Zones II and III of the upper reach and for the middle and lower reaches of the tidal system.

D. DISSOLVED OXYGEN BUDGET

Investigations of the oxygen budget are in three areas: (1) carbonaceous and nitrogenous oxygen demand from wastewater discharges, (2) oxygen production by phytoplankton, and (3) increased organic carbon and nitrogen loadings from phytoplankton, primarily in the middle and lower reaches. During 1969, preliminary CTSL studies were in the first two areas.

Preliminary analyses of nitrogen data from the past five years indicate that nitrification (the oxidation of NH_3 to NO_3) becomes a minor factor in the oxygen budget at water temperatures below 10°C. This observation would suggest that nitrogen removal from wastewater for the maintenance of oxygen standards would not be required at temperatures below 10°C. The need for nitrogen removal for the control of eutrophication is still being investigated as previously reported.

Effects of organic loadings on the dissolved oxygen budget in the middle and lower reaches is being intensively studied during 1970. During the summer months, dissolved oxygen in the lower reach is often depressed at greater depths, attributed partially to the decay of organic matter, mainly phytoplankton. Salinity differences between surface and bottom waters cause stratification resulting in poor mixing and consequently restrict aeration.

E. EMBAYMENT STUDIES

Except for the Blue Plains facility of the District of Columbia, all major wastewater discharges are into embayments of the Potomac River tidal system. As an interim measure to protect the embayments, the conferees at the Potomac Enforcement Conference applied the Zone I removal percentages to wastewater discharges in Zone II.

A study of the wastewater assimilation and transport capacity of the Piscataway embayment was recently completed [13]. One of the findings of the study was that this embayment has little capacity to assimilate and transport treated wastewater. The study further indicated if the same nutrient levels were to be maintained in the embayments as in the Potomac, only a limited poundage of the waste constituents could be discharged into the embayment if low nutrient levels are to be maintained. Moreover, if the plant were to be expanded to 30 mgd, a higher degree of removal than that currently agreed upon (96% for BOD_5, 91% for phosphorus, and 85% for nitrogen) would be required if the lower nutrient levels are to be maintained.

Preliminary analysis of the Anacostia River tidal system also indicates a limited assimilation and transport capability [3]. In this embayment, complete renovation or ultimate wastewater treatment (UWT) will be required if there are to be any large discharges in the upper portion of the Anacostia tidal system.

Based on the Piscataway and Anacostia studies, a re-examination of the removal requirements for embayment discharges is required. The "real time" mathematical model previously mentioned includes all the major embayments. To complete the analysis, a dye release in each embayment will be required to verify predictive coefficients.

Nutrient response characteristics of the waters of the various embayments are currently being investigated by CTSL. Limited data attained in 1968 and 1969 indicate greater standing crops of algal populations in the embayment for given nutrient levels than in the main stem of the tidal river. The sampling program for the embayments, especially Piscataway, Dogue, Gunston Cove, Occoquan-Belmont, and Mattawoman was initiated in February 1970 to further explore these observations.

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Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Quality Administration
U. S. Department of the Interior

PHYSICAL DATA POTOMAC RIVER TIDAL SYSTEM INCLUDING MATHEMATICAL MODEL SEGMENTATION

Technical Report No. 43

Norbert A. Jaworski
Leo J. Clark

INTRODUCTION

In its continuing water quality studies of the Potomac, the Chesapeake Technical Support Laboratory (CTSL) found it necessary to systematically and accurately define the physical characteristics of the estuary. Factors of major importance are: surface and cross-sectional areas, volumes, and distances between bridges, buoys, prominant landmarks and other reference points. This type of data is not only essential for mathematical modeling studies but also to interpret field survey information.

River mileages were measured along the main channel using a set of dividers on U.S. Geological Survey 7.5 minute quadrangle maps. For convenience, all distances were measured from Chain Bridge rather than from a reference point at the mouth of the Potomac. A reference point at the confluence of the Potomac with the Chesapeake Bay was established (See Figure II). Uniform river mile locations using statute miles were determined for the primary sampling stations, landmarks, navigation buoys, etc., and are presented in this report.

Cross-sections were plotted at intervals from 0.5 to 3.0 miles from soundings shown on U.S. Coast and Geodetic Survey charts and the plots planimetered to determine cross-section areas. Surface areas were also planimetered directly from USC&GS charts. Segment volumes were obtained by multiplying the average cross-sectional areas by the length.

Although much of the data presented in this report applies to a predetermined segmentation for mathematical model studies, it is general in nature and thus adaptable to other needs. Hopefully, these basic data will be used by other agencies involved with the Potomac Estuary to eliminate duplication of effort.

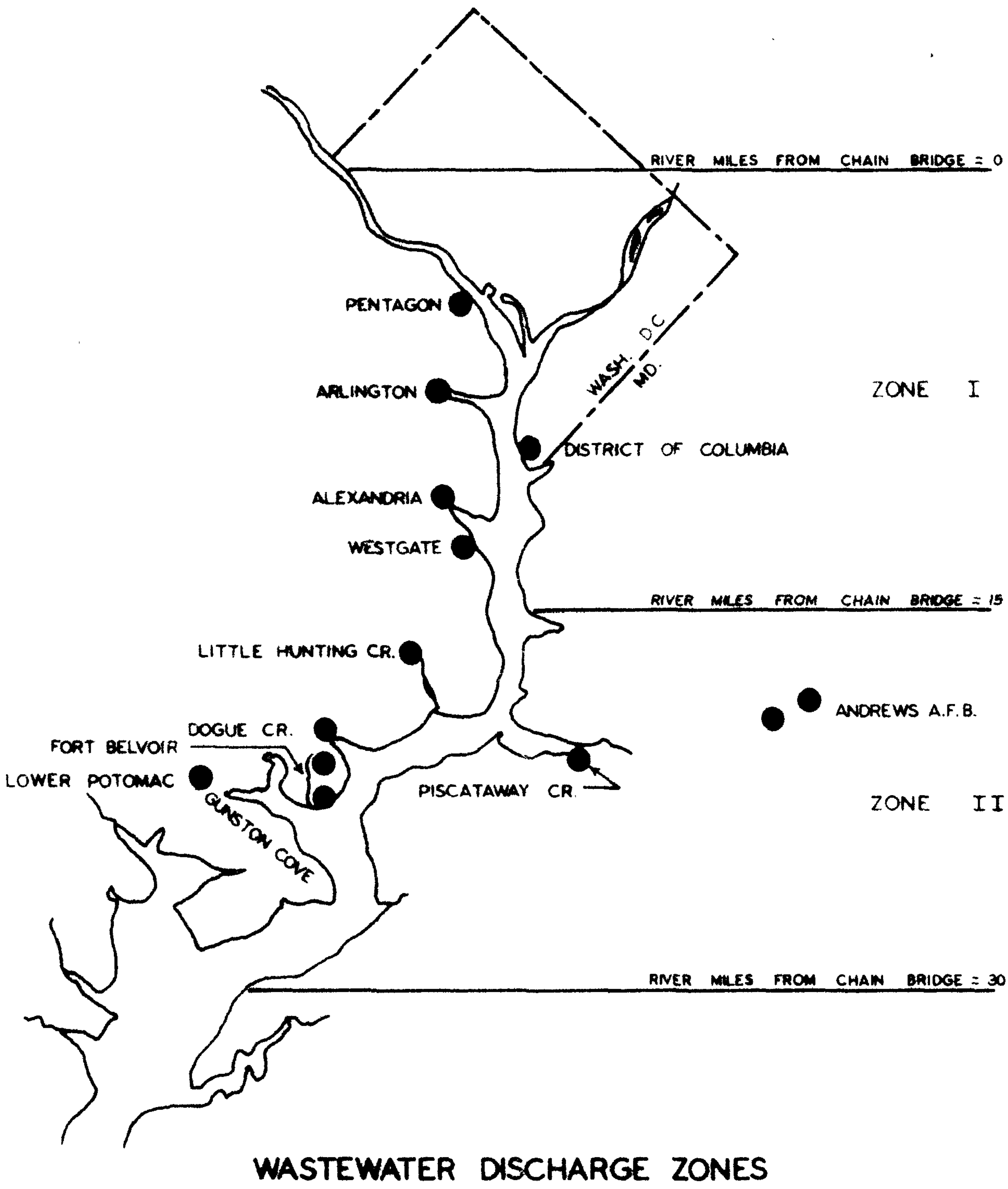
GENERAL DESCRIPTION OF THE POTOMAC RIVER TIDAL SYSTEM

The Potomac River basin is the second largest watershed in the Middle Atlantic States. Its tidal portion begins at Little Falls in the Washington metropolitan area and extends 114 miles southeastward to the Chesapeake Bay.

The tidal portion is several hundred feet in width at its head at Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained upstream to Washington. Except for this channel and a few short reaches where depths up to 100 feet can be found, the tidal portion is relatively shallow with an average depth of about 18 feet.

The mean tidal range is about 2.9 feet in the upper portion near Washington and about 1.4 feet near the Chesapeake Bay. The lag time for the tidal phase between Washington and the Chesapeake Bay is about 6.5 hours.

Effluents from twelve major wastewater treatment plants, with a thirteenth under construction, serving a population of about 2,500,000, are discharged into the upper tidal system. The locations of the discharges from these treatment facilities are shown in Figure I and presented in Table I.



WASTEWATER DISCHARGE ZONES

UPPER POTOMAC TIDAL RIVER SYSTEM

FIGURE I

TABLE I

Major Wastewater Discharge Locations
Upper Potomac Estuary

Facility	Receiving Stream	Distance from Chain Bridge	Expanded Thomann Model Segment	FWQA Model Segment
Combined D.C. system sewer overflow	Potomac Estuary	4.0	4	5
Pentagon	Potomac Estuary	5.8	6	7
Arlington	Four Mile Run		12	78
District of Columbia	Potomac Estuary	10.4	13	129
Alexandria	Hunting Creek	12.4	15	81
Fairfax-West Gate	Hunting Creek Embayment	12.8	16	16
Piscataway	Piscataway Embayment	18.3	22	118
Andrews AFB No. 1	Piscataway Creek	18.3	22	118
Andrews AFB No. 2	Piscataway Creek	18.3	22	118
Fairfax Hunting Cr.	Little Hunting Creek	20.0	24	25
Fairfax Dogue Creek	Dogue Creek	22.5	27	84
Fairfax Lower Potomac	Pohick	24.5	28	128
Ft. Belvoir No. 1	Gunston Cove	24.5	28	85
Ft. Belvoir No. 2	Gunston Cove	24.5	28	85

* If discharge is into an embayment distance is to midpoint of embayment
All distances in statute miles

A. Reaches of Potomac River Tidal System

For discussion and investigative purposes, the tidal portion of the Potomac River was divided into three reaches as shown in Figure II and described below:

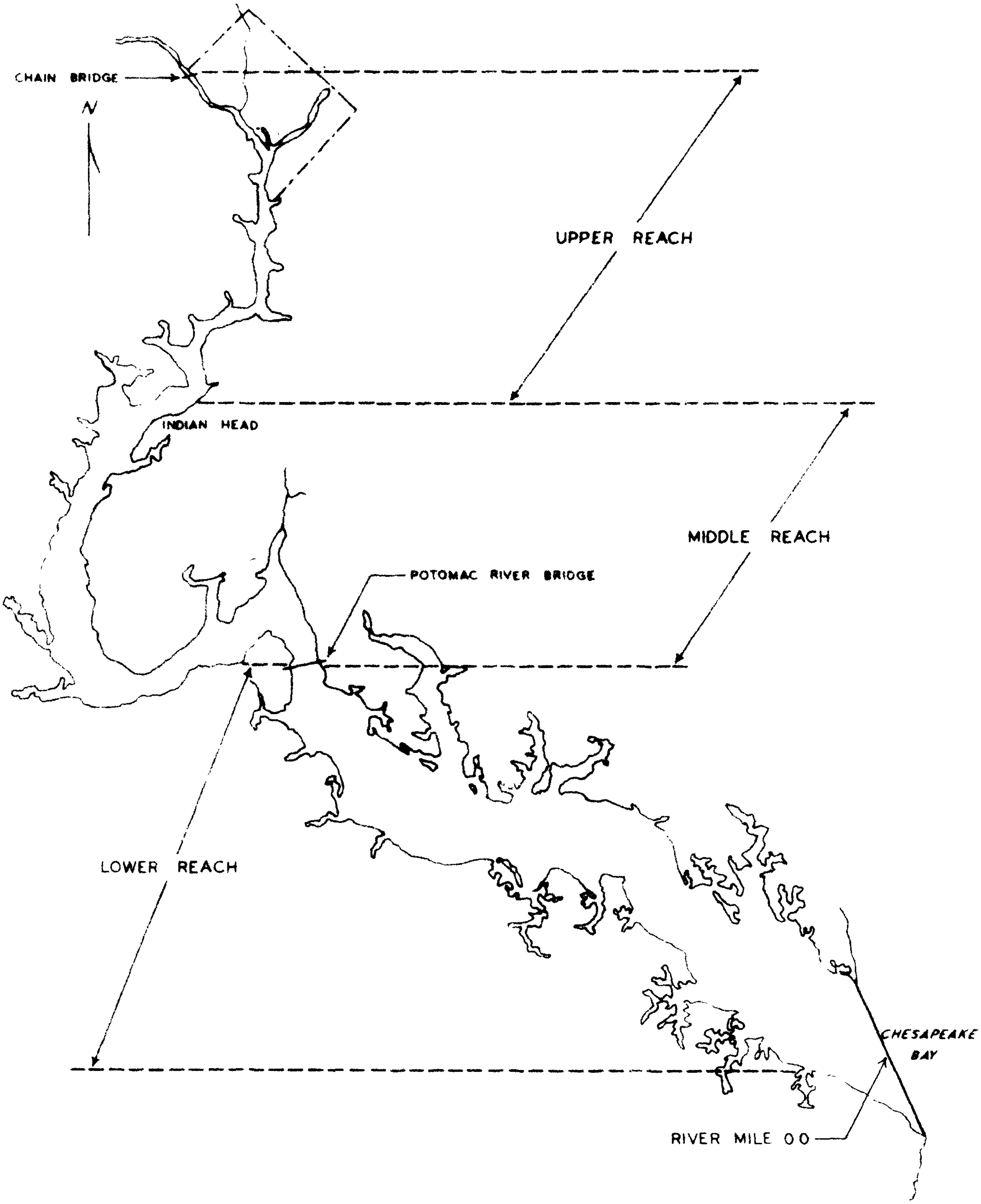
Reach	Description	River Miles	Volume cu.ft.x10^8
Upper	From Chain Bridge to Indian Head	114.4 to 73.8	93.50
Middle	From Indian Head to Rt. 301 Bridge	73.8 to 47.0	362.28
Lower	From Rt. 301 Bridge to Chesapeake Bay	47.0 to 00.0	1754.74

The upper reach, although tidal, contains fresh water. The middle reach is normally the transition zone from fresh to brackish water. In the lower reach, chloride concentrations near the Chesapeake Bay range from about 7,000 to 11,000 mg/l.

B. Zones of Upper Potomac Tidal System

To facilitate determination of water quality control requirements, the upper estuary was segmented by the CTSL into 15 mile zones beginning at Chain Bridge. Establishment of zones similar in physical characteristics allows flexibility in developing control needs. This zone concept was adopted by the conferees of the Potomac Enforcement Conference on May 8, 1969.

River mile distances from both the Chesapeake Bay and Chain Bridge for the upper three zones are given in Table II as well as in Figure II.



POTOMAC RIVER TIDAL SYSTEM

FIGURE - II

TABLE II

ZONES OF UPPER POTOMAC ESTUARY

Zone and Description	River Mile of Upper End of Zone		River Mile of Lower End of Zone	
	from Chain Bridge	from Chesapeake Bay	from Chain Bridge	from Chesapeake Bay
I				
Chain Bridge to Broad Creek	0.0	114.4	15.0	99.4
II				
Broad Creek to Indian Head	15.0	99.4	30.0	84.4
III				
Indian Head to Maryland Point	30.0	84.4	45.0	69.4

MATHEMATICAL MODEL INVESTIGATIONS

Two approaches have been adopted to simulate water quality conditions in the Potomac Estuary. The first was the "average" tidal model developed by Dr. Robert Thomann at New York University. The second and the more recent approach is the FWQA Dynamic Estuary or "real time" tidal model originally developed by Water Resources Engineers of Walnut Creek, California under contract to U.S. Public Health Service, FWQA, and the State of California.

Details of both approaches have been adequately documented and are available from the authors or FWQA. A report comparing the two approaches in simulating the movement of pollutants in the Potomac Estuary is currently being prepared by CTSL.

Originally, the Potomac Estuary was divided into 28 segments for the Thomann Model. To add greater sensitivity in analyzing field data and reaction rates, the estuary divisions were further increased to 73 segments.

For the FWQA Model, three networks have been developed, one corresponding to the 73-segment FWQA Model with embayment segmentation added to give a total of 141 segments, and a detailed network of 766 segments.

In this report, segmentation data for both versions of the Thomann and the main stem of 73 node FWQA models were presented.

Detailed data on the other system are available from CTSL upon request. For the main Potomac, nodes for the FWQA Model were placed at the interfaces of the Thomann Model segments.

In Figures VII and VIII are exhibited the segmentation for the Thomann approach for the Anacostia and Potomac Tidal River Systems with Figure IX presenting a schematic of the FWQA Potomac Estuary Model. The lower 11 segments of the FWQA Model are not incorporated into the current working system.

DATA FORMAT

The remainder of this report presents the following:

A. Sampling Stations and Landmark Locations

B. Mathematical Model and Physical Data

TABLE III

CTSL SAMPLING STATIONS

Station Number	Location	Buoy Reference	Miles below Chain Bridge
1	Key Bridge		3.35
1A	Memorial Bridge		4.85
2	14th Street Bridge		5.90
2A	Potomac Park	N "6"	6.70
3	Hains Point	C "1" - N "4"	7.60
3A	Hunters Point	C "11" - C "9"	8.70
4	Bellevue	FLR - 23' Bell	10.00
4A	Goose Island	R "8" - N "6"	11.05
5	Woodrow Wilson Bridge		12.10
5A	Rosier Bluff	C "87"	13.55
6	Broad Creek	N "86"	15.20
7	Piscataway Creek	FL "77"	18.35
8	Dogue Creek	FL "67"	22.30
8A	Gunston Cove	R "64"	24.30
9	Hallowing Point	FL "59"	26.90
10	Indian Head	N "54"	30.60
10A	Occuquon Bay	N "52"	32.15
11	Possum Point	R "44"	38.00
12	Sandy Point	N "40"	42.50
13	Smith Point	N "30"	46.80
14	Maryland Point	G "21"	52.40

CTSL SAMPLING STATIONS

Station Number	Location	Buoy Reference	Miles below Chain Bridge
15	Nanjemoy Creek	N "10"	58.55
15A	Port Tobacco	C "3"	63.75
16	301 Bridge		67.40
17	Bluff Point or Stony Pt.	BW - MO(A) "H"	73.45
18	Colonial Beach/Kettle Bottom Shoals	FL "25"	76.60
19	Wicomico River	C "15"	82.00
20	Kingcopsico	BWN "52" B	90.25
21	Ragged Point	BW "51" B	95.42
22	Piney Point	FR "O" FR A	99.20
23	Point Lookout	FL "4" Bell	107.41
24	Smith Point	BWN "43" B	118.00
25	Point Lookout	BWN "57" B	114.85

TABLE IV

D. C. WATER POLLUTION CONTROL DIVISION
SAMPLING STATIONS

Station Number	Location	Buoy Reference	Miles below Chain Bridge
1	Chain Bridge		0.00
2	Fletcher's Boat House		1.40
3	Three Sisters Island	Sewer outlet	2.75
4	Roosevelt Island		4.25
5	Memorial Bridge		4.85
6	Highway Bridge		5.90
7	Potomac Park	N "6"	6.70
8	Hains Point	N "4" N "3"	7.20
9	Giesboro Park	N "11"	8.20
10	Above WPCP (Blue Plains)	FLR 4 sec "23"	10.20
11	Opposite WPCP " "	Sewer outlet	10.40
12	Below WPCP " "	N "8"	10.70
13	Woodrow Wilson Bridge		12.10
14	Ft. Foote	N "86" N "87"	14.45
15	Ft. Washington	C "79"	17.95
16	Marshall Hall	N "69"	21.80
17	Hallowing Point	FL "59"	26.90
18	Indian Head	N "54"	30.60
19	St. Neck	N "46"	35.20
20	Sandy Point	N "41"	42.50
21	Smith Point	N "30"	45.80
22	Maryland Point	G "21"	52.40

TABLE V

BRIDGES

Location or Name	Miles below Chain Bridge
Chain Bridge	0
Key Bridge	3.35
Theodore Roosevelt Bridge	4.45
Memorial Bridge	4.85
14th Street Bridges	
a. George Mason	5.90
b. Rochambeau	6.05
Woodrow Wilson Bridge	12.10
301 Bridge	67.40

TABLE VI

POTOMAC ESTUARY BUOYS USED
TO REFERENCE WATER QUALITY SAMPLING

Buoy	River Miles from Chain Bridge
N "12"	5.15
RN "10"	5.75
N "6"	6.70
C "1"	7.87
N "4"	7.20
C "3"	7.20
N "2"	7.72
C "11"	8.50
C "9"	8.95
C "1"	9.15
N "2"	9.25
23' Bell	10.01
R "8"	10.75
N "6"	11.30
N "4"	11.70
R "2"	13.05
C "87"	13.95
N "86"	14.95
R "84"	15.95
C "83"	17.13

POTOMAC ESTUARY BUOYS USED

TO REFERENCE WATER QUALITY SAMPLING (Cont.)

Buoy	River Miles from Chain Bridge
C "81"	17.40
C "79	17.95
FL "77"	18.50
C "75"	19.00
C "73"	19.90
FL "71"	20.90
C "69"	21.55
FL "67"	22.30
N "66"	23.05
R "64"	24.25
R "62"	24.90
C "61"	26.40
FL "59"	26.90
R "60"	27.00
C "57"	27.70
N "54"	30.60
N "52"	32.15
R "44"	37.90
N "40"	42.50
N "30"	45.80

POTOMAC ESTUARY BUOYS USED

TO REFERENCE WATER QUALITY SAMPLING (Cont.)

Buoy	River Miles from Chain Bridge
N "24"	50.20
G "21"	52.40
N "16"	55.00
N "10"	58.55
C "3"	63.75
FL "29"	70.65
BW MO(A) "H"	73.45
FL "25"	76.60
C "15"	82.00
BWN "52" B	90.25
BW SI B	95.42
FR "D" FR A	99.20
FL "4" Bell	107.41
BWN "57" B	114.85
BWN "43" B	118.00

TABLE VII

MILEAGE LOCATION OF PROMINENT REFERENCE POINTS
ALONG THE POTOMAC ESTUARY
(excluding those used as sampling stations)

Landmark Points	Miles below Chain Bridge
Marbury Point	10.55
Fox Ferry Point	7.50
Jones Point	12.34
Indian Queen Point	14.90
Hatton Point	17.30
Sheridon Point	18.65
Mockley Point	18.60
Bryan Point	19.80
Ferry Point	21.90
Whitestone Point	24.10
Pomonkey Point	26.40
Sycamore Point	29.80
High Point	31.30
Deep Point	34.00
Cockpit Point	35.90
Douglas Point	43.90
Simms Point	46.80
Marlboro Point	49.35
Blossom Point	59.10
Upper Cedar Point	60.10

MILEAGE LOCATION OF PROMINENT REFERENCE POINTS
ALONG THE POTOMAC ESTUARY
(excluding those used as sampling stations)

Landmark Points	Miles below Chain Bridge
Mathias Point	62.70
Persimmon Point	66.20
Lower Cedar Point	68.80
Stony Point	72.70
Swan Point	74.20
White Point	75.00
Gum Bar Point	76.00
Church Point	77.00
Cobb Point	80.25
Waterloo Point	84.30
Crunch Point	88.10
Ragged Point	95.40
Deep Point	102.80
Kitts Point	105.20
Lawson Point	106.60

Table VIII
THOMANN MODEL
SEGMENT GEOMETRY POTOMAC ESTUARY
MEAN LOW WATER DATA
(Excluding Embayments)

Segment Number	Interface Areas Upper ft^2	Interface Areas Lower ft^2	Length ft	Volume $ft^3 \times 10^6$	Accumulative Volume $ft^3 \times 10^6$	Surface Area $ft^2 \times 10^6$	Average Width ft	Average Depth ft
1	1,000	41, 00	14,890	1.94	1.94	8.332	559	23.3
2	41,700	22,500	10,665	2.58	4.52	13.886	1,302	18.6
3	22,500	20,200	9,187	1.31	[illegible].33	19.218	2,092	9.4
4	20,200	30,900	[illegible],504	2.30	8.[illegible]3	25.439	2,677	9.0
5	30,900	35,700	8,396	2.88	11.51	24.440	2,911	11.8
6	35,700	32,400	11,404	3.63	15.14	30.883	2,708	11.8
7	32,400	43,350	13,992	5.69	20.83	52.323	3,739	10.9
8	43,350	49,500	11,300	5.70	26.53	47.768	4,227	11.9
9	49,500	60.300	13,516	8.60	35.13	45.769	3,386	18.8
10	60,300	60.150	10,085	6.94	42.07	57.433	5,695	12.1
11	60,150	86,250	13,570	9.80	51.87	55.878	4,118	17.5
12	86.250	99,600	24,129	23.57	75.44	146.860	6,086	16.0
13	99,600	123.150	15,312	18.06	93.50	123.309	8,053	14.6
14	123,150	179,700	14,732	20.57	114.07	182.186	12,367	11.3
15	179,700	160,350	22,387	38.58	152.65	195.516	8,734	19.7
16	160.350	208,500	21,859	40.60	193.25	236.064	10,800	17.2
17	208,500	212,400	22,123	49.11	242.36	274.925	16,947	13.1
18	121,400	216,600	25,291	53.34	295.70	391.366	15,475	13.6
19	216,600	161,400	28,354	49.68	345.38	251.061	8,854	19.8
20	161,400	198,900	24,816	48.26	393.64	327.268	13,188	14.75
21	198,900	242,000	27,614	62.14	455.78	286.387	10,371	21.7

SEGMENT GEOMETRY POTOMAC ESTUARY (Cont.)
MEAN LOW WATER DATA
(Excluding Embayments)

Segment Number	Interface Areas Upper ft^2	Interface Areas Lower ft^2	Length ft	Volume ft^3 X 10^8	Accumulative Volume ft^3 X 10^8	Surface Area ft^2 X 10^6	Average Width ft	Average Depth ft
22	242,000	463,320	32,103	110.90	506.68	558.777	17,406	19.90
23	463,320	547,800	33,739	149.38	716.06	835.277	24,757	17.90
24	547,800	488,400	31,152	182.80	898.86	946.922	30,397	19.30
25	488,400	580,800	28,934	155.46	1054.32	892.044	30,830	17.40
26	580,800	731,280	42,135	275.58	1329.90	1139.439	27,043	24.20
27	731,280	1,128,600	31,416	272.02	1601.92	843.387	26,846	32.30
28	1,128,600	1,689,600	51,163	608.60	2210.52	2268.657	44,342	26.80

Table IX
THOMANN MODEL
SEGMENT GEOMETRY POTOMAC ESTUARY
MEAN WATER DATA
(Excluding Embayments)

Segment Number	Interface Areas Upper ft^2	Interface Areas Lower ft^2	Length ft	Volume ft^3 X 10^8	Accumulative Volume ft^3 X 10^8	Surface Area ft^2 X 10^6	Average Width ft	Average Depth ft
1	1,078	42,960	14,890	2.06	2.06	8.332	559	24.7
2	42,960	25,062	10,665	2.77	4.83	13.886	1,302	20.0
3	25,062	24,153	9,187	2.08	6.91	19.218	2,092	10.8
4	24,153	34,815	9,504	2.67	9.58	25.439	2,677	10.5
5	34,815	40,740	8,396	3.23	12.31	24.440	2,911	13.2
6	40,740	37,860	11,404	4.08	16.87	30.883	2,708	13.2
7	37,860	50,760	13,992	6.40	23.27	52.323	3,739	12.2
8	50,760	53,588	11,300	6.31	29.58	47.768	4,227	13.2
9	53,588	66,372	13,516	9.15	38.73	45.769	3,386	20.0
10	66,372	64,654	10,085	7.57	46.30	57.433	5,695	13.2
11	64,654	92,850	13,570	10.37	56.67	55.878	4,118	18.5
12	92,850	108,537	24,129	25.00	81.67	146.860	6,086	17.0
13	108,537	130,350	15,312	19.11	100.78	123.309	8,053	15.5
14	130,350	191,700	14,732	22.03	122.81	182.186	12,368	12.1
15	191,700	165,915	22,387	40.05	162.86	195.516	8,732	20.5
16	165,915	218,250	21,859	42.19	205.05	236.064	10,799	17.9
17	218,250	221,328	22,123	51.36	256.41	374.925	16,950	13.7
18	221,328	224,190	25,291	55.61	312.02	391.366	15,475	14.2
19	224,190	165,060	28,354	51.04	363.06	251.061	8,856	20.3
20	165,060	205,614	24,816	50.06	413.12	327.268	13,186	15.3
21	205,614	248,468	27,614	63.97	477.09	286.387	10,371	22.3

SEGMENT GEOMETRY POTOMAC ESTUARY (Cont.)
MEAN WATER DATA
(Excluding Embayments)

Segment Number	Interface Areas Upper ft^2	Interface Areas Lower ft^2	Length ft	Volume $ft^3 \times 10^8$	Accumulative Volume $ft^3 \times 10^8$	Surface Area $ft^2 \times 10^6$	Average Width ft	Average Depth ft
22	248,468	483,595	32,103	115.50	592.59	558.777	17,406	20.7
23	483,595	574,886	33,739	157.20	[illegible]49.79	835.277	24,757	18.8
24	574,886	508,966	31,152	192.00	941.79	946.922	30,397	20.2
25	508,966	607,517	28,934	163.70	1105.49	892.044	20,830	18.35
26	607,517	746,890	42,135	285.30	1390.79	1139.439	27,043	25.0
27	746,890	1,156,690	31,416	278.10	1668.89	843.387	26,846	33.0
28	1,156,690	1,724,765	51,163	622.10	2291.00	2268.657	44,342	27.4

Table X
THOMANN MODEL
SEGMENT VOLUMES
(Including Embayments)

Segment Number	Total Volume at Low Water (ft^3 X 10^8)	Total Volume at Mean Water (ft^3 X 10^8)	Accumulative Volume at Low Water (ft^3 X 10^8)	Accumulative Volume at Mean Water (ft^3 X 10^8)
1	1.94	2.06	1.94	2.06
2	2.58	2.77	4.52	4.83
3	2.34	2.70	6.86	7.53
4	9.20	10.21	16.06	17.74
5	3.58	4.02	19.64	21.76
6	4.72	5.34	24.36	27.10
7	7.58	8.82	31.94	35.92
8	6.19	7.01	38.13	42.93
9	9.69	10.68	47.82	53.61
10	7.03	7.71	54.85	61.32
11	10.34	11.09	65.19	72.41
12	26.45	28.62	91.64	101.03
13	18.06	19.11	109.70	120.14
14	30.79	33.99	140.49	154.13
15	46.19	48.78	186.68	202.91
16	41.05	42.76	227.73	245.67
17	49.11	51.36	276.84	297.03
18	59.69	63.02	336.53	360.05
19	49.68	51.04	386.21	411.09
20	52.01	54.50	438.22	465.59
21	71.97	75.03	510.19	540.62

SEGMENT VOLUMES (Cont.)
(Including Embayments

Segment Number	Total Volume at Low Water ($ft^3 \times 10^8$)	Total Volume at Mean Water ($ft^3 \times 10^8$)	Accumulative Volume at Low Water ($ft^3 \times 10^8$)	Accumulative Volume at Mean Water ($ft^3 \times 10^8$)
22	114.92	120.21	625.11	660.82
23	153.49	162.20	778.60	823.03
24	227.98	241.78	1006.58	1064.81
25	189.07	200.92	1195.65	1265.73
26	282.79	293.45	1478.44	1559.18
27	315.76	325.45	1794.20	1884.63
28	619.24	633.84	2413.44	2518.47

Table XI
THOMANN MODEL
REVISED POTOMAC ESTUARY GEOMETRY FOR EXPANDED SEGMENTED SYSTEM
MEAN WATER DATA
(Excluding Embayments)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
1	1078	6630	7814	0.30	3.222	412	9.3
2	6630	42960	7076	1.75	5.110	722	34.2
3	42960	22282	2851	0.93	3.110	1091	29.9
4	22282	23406	4065	0.93	4.560	1122	20.4
5	23406	25062	3749	0.91	6.110	1630	14.9
6	25062	21789	5597	1.31	10.766	1925	12.2
7	21789	24153	3590	0.82	8.443	2352	9.7
8	24153	28676	5439	1.44	15.108	2778	9.5
9	28676	34815	4065	1.29	10.331	2541	12.5
10	34815	43352	1690	0.66	5.110	3024	12.9
11	43352	36996	3696	1.48	10.331	2795	14.3
12	36996	40740	3010	1.17	8.998	2989	13.0
13	40740	32160	6124	2.23	16.663	2721	13.4
14	32160	37860	5280	1.85	14.219	2693	13.0
15	37860	33255	3960	1.41	11.331	2861	12.4
16	33255	57396	3855	1.75	13.775	3573	12.7
17	57396	50760	6177	3.34	25.106	4064	13.3
18	50760	56172	2640	1.41	13.886	5260	10.2
19	56172	58875	5386	3.10	23.106	4290	13.4
20	58875	53588	3274	1.84	10.776	3291	17.1
21	53588	58992	5280	2.97	14.997	2840	19.8

REVISED POTOMAC ESTUARY GEOMETRY FOR EXPANDED SEGMENTED SYSTEM
MEAN WATER DATA (Cont.)
(Excluding Embayments)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
22	58992	87642	3009	2.21	9.220	3064	24.0
23	87642	66372	5227	4.03	21.551	4123	18.7
24	66372	84210	5069	3.82	29.439	5808	13.0
25	84210	64654	5016	3.73	27.994	5581	13.3
26	64654	72693	4805	3.30	19.996	4162	16.5
27	72693	92850	8765	7.25	35.882	4094	20.2
28	92850	97380	9081	8.64	53.656	5909	16.1
29	97380	116509	6706	7.17	42.436	6328	16.9
30	116509	108537	8342	9.39	50.768	6086	18.5
31	108537	129910	5597	6.67	53.767	9606	12.4
32	129910	128000	5650	7.29	38.659	6842	18.9
33	128000	130350	4065	5.25	30.883	7597	12.0
34	130350	136980	6706	8.96	76.429	11397	11.7
35	136980	191700	8026	13.19	105.757	13177	12.5
36	191700	181894	10507	19.63	100.535	9569	19.5
37	181894	165915	13464	23.41	94.981	7054	24.6
38	165915	191334	9715	17.35	88.643	9125	19.5
39	191334	218250	12144	24.87	147.414	12139	16.8
40	218250	246360	10876	25.27	190.184	17486	13.3
41	246360	221328	11246	26.30	187.740	16427	14.2
42	221328	216642	12460	27.29	178.630	14336	15.3

REVISED POTOMAC ESTUARY GEOMETRY FOR EXPANDED SEGMENTED SYSTEM
MEAN WATER DATA (Cont.)
(Excluding Embayments)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
43	216642	224190	12830	28.28	212.735	16581	13.3
44	224190	172892	10824	21.50	126.308	11669	17.0
45	172892	165060	17529	29.60	124.752	7117	23.7
46	165060	214518	10560	20.04	130.196	12330	15.4
47	214518	205614	14256	29.95	197.071	13824	15.2
48	205614	236645	12936	28.61	164.189	12685	17.4
49	236645	248468	12038	29.20	122.197	10151	23.9
50	248468	258192	9820	24.88	107.200	10916	23.2
51	258192	444206	6441	22.62	190.184	29526	11.9
52	444206	483595	10560	48.99	261.392	24753	18.7
53	483595	328522	9451	38.38	164.411	17396	23.3
54	328522	548750	6811	29.88	337.154	49501	8.9
55	548750	574886	10665	59.92	333.711	31290	18.0
56	574886	690598	10137	64.14	316.381	31210	20.3
57	690598	640497	8712	57.98	256.948	29494	22.6
58	640497	508966	12302	70.70	373.591	30368	18.9
59	508966	550744	10612	56.23	264.947	24967	21.2
60	550744	608974	11616	67.36	314.937	27113	21.4
61	608974	607517	6705	40.78	312.159	46556	13.1
62	607517	616704	8712	53.33	233.953	26854	22.8
63	616704	644292	8659	54.59	288.831	33356	18.9

REVISED POTOMAC ESTUARY GEOMETRY FOR EXPANDED SEGMENTED SYSTEM
MEAN WATER DATA (Cont.)
(Excluding Embayments)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume (ft^3 X 10^8)	Surface Area (ft^2 X 10^6)	Width (ft)	Depth (ft)
64	644292	724601	8659	59.27	270.834	31277	21.9
65	724601	746890	16104	118.48	345.819	21474	34.3
66	746890	858496	10560	84.66	262.058	24816	32.3
67	858496	857947	10348	88.81	257.615	24896	34.5
68	857947	1156690	10507	105.84	323.733	30809	32.7
69	1156690	1144810	11352	130.63	421.026	37087	31.0
70	1144810	1182700	10560	122.89	403.030	36166	30.5
71	1182720	1162709	11140	130.64	367.704	32992	35.5
72	1162709	1198613	8448	99.74	310.604	36766	32.1
73	1198613	1724765	9662	141.23	766.291	79309	18.4

Table XII

MATHEMATICAL MODEL SEGMENTATION
Anacostia Tidal River System
Mean Water Data*

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Interface Widths Upper (ft)	Interface Widths Lower (ft)	Length (ft)	Volume ($ft^3 x 10^6$)	Surface Area ($ft^2 x 10^6$)	Depth (ft)
1	31,290	58,000	1500	3200	2900	129.55	4.96	26.11
2	27,100	31,290	1250	1500	2380	69.48	3.24	21.44
3	27,100	27,100	1250	1250	2380	64.49	2.68	24.06
4	24,710	27,100	1150	1250	2640	68.38	3.20	21.36
5	14,450	24,710	750	1150	2640	51.69	2.36	21.90
6	8,580	14,450	750	750	3430	39.84	2.80	14.22
7	8,645	8,580	750	750	3430	29.53	2.44	12.10
8	3,095	8,645	550	750	3170	18.60	1.76	10.56
9	4,805	3,095	400	550	2900	11.45	1.36	8.41
10	2,840	4,805	350	400	3960	15.13	1.32	11.46
11	3,195	2,840	300	350	3170	9.56	1.00	9.56
12	3,000	3,195	300	300	3430	10.62	1.04	10.21
13	3,030	3,000	250	300	2900	8.74	0.80	10.92
14	1,775	3,030	250	250	2640	6.34	0.60	10.57
15	775	1,775	200	250	2640	5.20**	1.00	5.20

* Data based on soundings made April 1970

** Volume of Marina = 1500 ft x 2710 ft^2 = 4.06 x 10^6 ft^3

Table XIII
FWQA NETWORK DATA
POTOMAC ESTUARY
(Excluding Embayments)

	Node	Cross-sectional Area at Node (ft)	Average Depth at Node (ft)	Surface Area (ft^2)	Channel		Length (ft)	Average Cross-sectional Area (ft^2)	Average Depth (ft)
Chain Br.	114	1000	17.8	888711	01	66-02	7814	3500	15.6
	02	6000	13.3	4332467	02	02-03	7076	23850	29.8
	03	41700	46.3	4665733	03	03-04	2851	31230	32.7
	04	20760	19.1	4443556	04	04-05	4065	21180	17.9
	05	21600	16.7	4665733	05	05-06	3749	22050	14.5
	06	22500	12.3	8442756	06	06-07	5597	20622	10.6
	07	18744	9.0	8887111	07	07-08	3590	19502	8.3
	08	20260	7.6	12886311	08	08-09	5439	22130	7.6
	09	24000	7.5	13219578	09	09-10	4065	27450	9.4
	10	30900	11.4	8664933	10	10-11	1690	34840	11.8
	11	38780	12.3	7109689	11	11-12	3696	35515	10.9
	12	32250	9.5	9442556	12	12-13	3010	33975	9.7
	13	35700	9.9	15552445	13	13-14	6124	32670	13.2
	14	29640	16.5	12886311	14	14-15	5280	31020	12.4
	15	42400	8.3	13775022	15	15-16	3960	30600	8.5
	16	28800	8.7	12664133	16	16-17	3855	40365	10.8
	17	51930	12.8	19773822	17	17-18	6177	47640	10.2
	18	43350	7.6	22884311	18	18-19	2640	46250	8.4
	19	49150	9.1	19329467	19	19-20	5386	51875	12.6
	20	54600	16.0	15552445	20	20-21	3274	52050	15.6
	21	49500	15.1	13108489	21	21-22	5280	52500	17.2

FWQA NETWORK DATA
POTOMAC ESTUARY (Cont.)
(Excluding Embayments)

Node	Cross-sectional Area at Node (ft)	Average Depth at Node (ft)	Surface Area (ft^2)	Channel		Length (ft)	Average Cross-sectional Area (ft^2)	Average Depth (ft)
22	55500	19.2	10775622	22	22-23	3009	69365	20.9
23	83230	22.6	14441556	23	23-24	5227	71765	17.0
24	60300	11.4	26772422	24	24-25	5069	68625	11.5
25	76950	11.6	29216378	25	25-26	5016	68550	12.8
26	60150	14.0	23661934	26	26-27	4805	64060	14.6
27	67970	15.1	29327467	27	27-28	8765	77110	14.1
28	86250	13.1	42769223	28	28-29	9081	88500	13.4
29	90750	13.7	53878112	29	29-30	6706	100815	16.2
30	110880	18.7	47990400	30	30-31	8342	105240	14.4
31	99600	10.0	49323467	31	31-32	5597	111300	12.6
32	123000	15.1	53544845	32	32-33	5650	122500	16.2
33	122000	17.3	43324667	33	33-34	4065	122575	15.5
34	123150	13.7	59099289	34	34-35	6706	125325	12.2
35	127500	10.8	81094890	35	35-36	8026	153600	11.4
36	179700	12.0	120531446	36	36-37	10507	177900	17.4
37	176100	22.8	92648134	37	37-38	13464	168225	21.5
38	160350	20.2	83983201	38	38-39	9715	172425	19.3
39	184500	18.4	119976001	39	39-40	12144	196500	16.2
40	208500	13.9	174965002	40	40-41	10876	221850	13.2
41	235200	12.6	190184180	41	41-42	11246	223800	13.4
42	212400	14.3	184963002	42	42-43	12460	210450	14.7

FWQA NETWORK DATA
POTOMAC ESTUARY (Cont.)
(Excluding Embayments)

Node	Cross-sectional Area at Node (ft)	Average Depth at Node (ft)	Surface Area (ft^2)	Channel		Length (ft)	Average Cross-sectional Area (ft^2)	Average Depth (ft)
43	208500	15.1	166300068	43	43-44	12830	212550	15.4
44	216600	15.7	209735824	44	44-45	10824	192300	17.3
45	168000	18.9	121420157	45	45-46	17529	164700	20.4
46	161400	22.0	219956002	46	46-47	10560	183900	18.0
47	206400	14.0	186296069	47	47-48	14256	222650	15.9
48	198900	17.8	172187780	48	48-49	12936	213750	18.0
49	228600	18.1	156524246	49	49-50	12038	235300	22.2
50	242000	26.2	102646134	50	50-51	9820	245740	23.8
51	249480	21.5	168077491	51	51-52	6441	336600	19.0
52	423720	16.5	235286269	52	52-53	10560	443520	17.4
53	463320	18.3	215845713	53	53-54	9451	388740	17.9
54	314160	17.5	193294669	54	54-55	6811	418440	17.3
55	522720	17.1	291719425	55	55-56	10665	535260	17.6
56	547800	18.2	320047092	56	56-57	10137	603900	19.4
57	660000	20.5	349818915	57	57-58	8712	634260	19.2
58	608520	18.0	371925604	58	58-59	12302	548460	20.3
59	488400	22.6	268724025	59	59-60	10612	504900	19.8
60	521400	16.9	325490448	60	60-61	11616	552420	19.0
61	583440	21.2	246839514	61	61-62	6705	582120	20.6
62	580800	20.0	225954802	62	62-63	8712	586740	21.2
63	592680	22.4	241396158	63	63-64	8659	607200	23.6

FWQA NETWORK DATA
POTOMAC ESTUARY (Cont.)
(Excluding Embayments)

	Node	Cross-sectional Area at Node (ft)	Average Depth at Node (ft)	Surface Area (ft^2)	Channel		Length (ft)	Average Cross-sectional Area (ft^2)	Average Depth (ft)
	64	621720	24.8	293052492	64	64-65	8659	663300	27.2
	65	704880	29.6	276944603	65	65-01	16104	718080	31.9
Piney Pt.	66	731280	34.2	336154981	66	01-67	10560	786720	34.6

Table XIV
EMBAYMENT DATA - POTOMAC ESTUARY

Name	Segment	Surface Area ($ft^2 \times 10^6$)	Average Depth at Low Water (ft)	Volume at Low Water ($ft^3 \times 10^8$)	Average Depth at Mean Water (ft)	Volume at Mean Water ($ft^3 \times 10^8$)	Location (Miles below Chain Bridge)
Columbia Island Channel	3	2.555	5.0	0.13	6.40	0.16	4.65 - 5.76
Tidal Basin	3	4.444	9.0	0.40	10.40	0.46	5.81
Washington Channel	4	8.109	23.0	1.86	24.45	1.98	-
Anacostia River	4	35.993	14.0	5.04	15.45	5.56	7.60 - 8.20
Four Mile (Hunter Pt.)	5	6.332	11.0	0.70	12.45	0.79	8.79 - 9.70
Oxon Creek (Upper)	6	13.664	8.0	1.09	9.40	1.28	10.55 - 12.13
Oxon Creek (Lower)	7	18.330	8.0	1.47	9.35	1.71	12.13 - 13.57
Hunting Creek	7	21.218	2.0	0.42	3.35	0.71	12.13 - 13.50
Broad Creek	8	16.219	3.0	0.49	4.30	0.70	14.90 - 15.92
Piscataway Creek	9	36.437	3.0	1.09	4.20	1.53	18.11 - 18.63
Little Hunting Creek	10	4.444	2.0	0.09	3.10	0.14	19.90 - 20.33
Dogue Creek	11	17.885	3.0	0.54	4.05	0.72	21.85 - 22.80
Gunston Cove	12	65.431	4.0	2.62	5.00	3.27	24.02 - 25.42
Pomonkey Creek	12	8.776	3.0	0.26	3.95	0.35	26.73 - 27.10
Belmont Bay	14	69.431	4.0	2.78	4.80	3.33	-
Occoquan Bay	14	148.859	5.0	7.44	5.80	8.63	31.45 - 34.09
Powells Creek	15	19.218	2.0	0.38	2.80	0.54	34.79 - 35.92
Mattawoman Creek	15	74.541	8.0	5.96	8.80	6.56	34.13 - 35.60
Quantico Creek	15	29.327	2.0	0.59	2.70	0.79	38.10 - 38.55
Chicamuxen Creek	15	22.773	3.0	0.68	3.70	0.84	36.91 - 37.75
Chopawamsic Creek	16	13.553	2.0	0.27	2.67	0.36	40.75

EMBAYMENT DATA - POTOMAC ESTUARY (Cont.)

Name	Segment	Surface Area (ft^2 X 10^6)	Average Depth at Low Water (ft)	Volume at Low Water (ft^3 X 10^8)	Average Depth at Mean Water (ft)	Volume at Mean Water (ft^3 X 10^8)	Location (Miles below Chain Bridge)
Mallows Bay	16	4.444	4.0	0.18	4.65	0.21	41.04 - 42.44
Aquia Creek	18	101.091	4.0	4.04	4.60	4.65	46.89 - 48.40
Potomac Creek	18	76.985	3.0	2.31	3.58	2.76	49.20 - 49.70
Nanjemoy Creek	20	124.975	3.0	3.75	3.55	4.44	58.18 - 59.20
Port Tobacco River	21	163.856	6.0	9.83	6.75	11.06	62.00 - 63.80
Upper Machodoc Creek	22	71.736	5.0	3.59	5.80	4.16	69.45 - 71.32
Rosier Creek	22	14.442	3.0	0.43	3.80	0.55	72.10 - 73.27
Cuckold Creek	23	16.663	2.0	0.33	2.80	0.47	72.00 - 72.21
Monroe Creek	23	18.552	3.0	0.56	3.80	0.70	-
Mattox Creek	23	61.988	5.0	3.10	5.80	3.60	75.98 - 77.32
Popes Creek	23	12.442	1.0	0.12	1.85	0.23	79.15
Wicomico River	24	389.367	9.0	35.04	9.92	38.62	80.52 - 82.85
St. Clement Bay	25	154.080	9.0	13.87	9.90	15.25	86.05 - 88.35
Breton Bay	25	135.306	9.0	12.18	9.90	13.40	89.36 - 90.20
Nomini Bay	25	126.086	6.0	7.56	6.80	8.57	87.26 - 89.48
Lower Machodoc Creek	26	92.648	7.0	6.48	7.85	7.27	91.15 - 93.38
Herring Creek	26	18.330	4.0	0.73	4.80	0.88	96.10
St. Georges Creek	27	77.318	5.0	3.87	5.75	4.45	-
St. Mary's River	27	285.165	11.0	31.37	11.75	33.51	102.96 -104.35
Yeocomico River	27	141.638	6.0	8.50	6.63	9.39	103.80 -104.65
Smith Creek	28	48.657	7.0	3.40	7.75	3.77	105.15 -106.65
Coan River	28	100.424	6.0	6.02	6.60	6.63	107.20 -109.00
Hull Creek	28	20.329	6.0	1.22	6.00	1.34	113.00

TABLE XV

MATHEMATICAL MODEL PLOTTING POSITIONS FOR
MAIN STEM OF POTOMAC ESTUARY

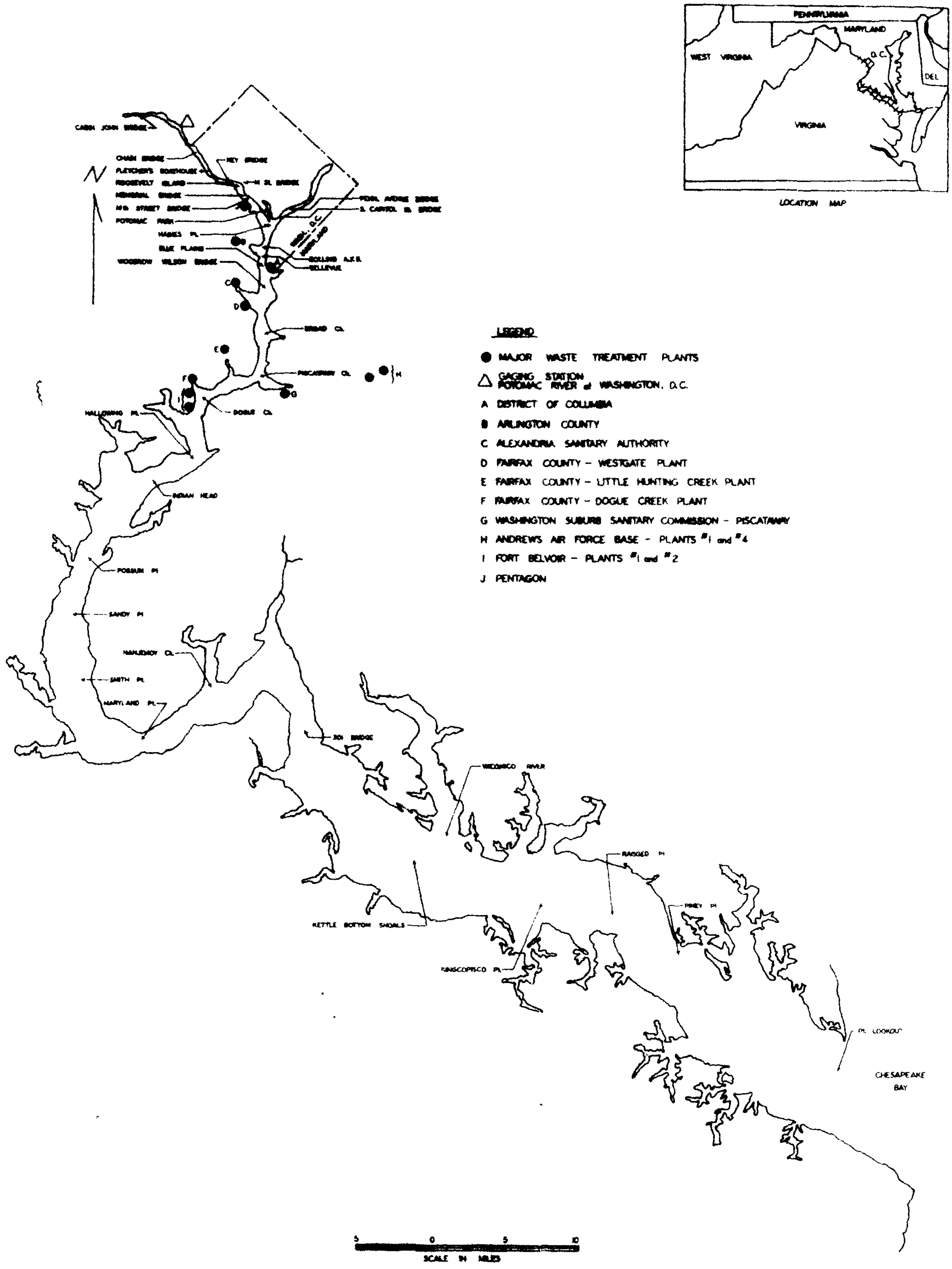
Segment Number	Thomann Model (miles)	FWQA Model (miles)
1	0.74	0*
2	2.15	1.48
3	3.09	2.82
4	3.74	3.30
5	4.48	4.13
6	5.37	4.83
7	6.24	5.90
8	7.10	6.57
9	8.00	7.61
10	8.54	8.37
11	9.05	8.70
12	9.68	9.40
13	10.55	9.97
14	11.63	11.12
15	12.50	12.12
16	13.24	12.87
17	14.20	13.61
18	15.03	14.77

* Junction 114

Segment Number	Thomann Model (miles)	FWQA Model (miles)
19	15.79	15.27
20	16.61	16.30
21	17.42	16.92
22	18.20	17.92
23	18.98	18.48
24	19.96	19.47
25	20.92	20.44
26	21.84	21.39
27	28.13	22.30
28	24.82	23.96
29	26.32	25.67
30	27.74	26.95
31	29.06	28.52
32	30.12	29.58
33	31.04	30.66
34	32.06	31.42
35	33.46	32.70
36	35.26	34.22
37	37.34	36.21
38	39.38	38.76
39	41.45	40.60
40	43.63	42.90

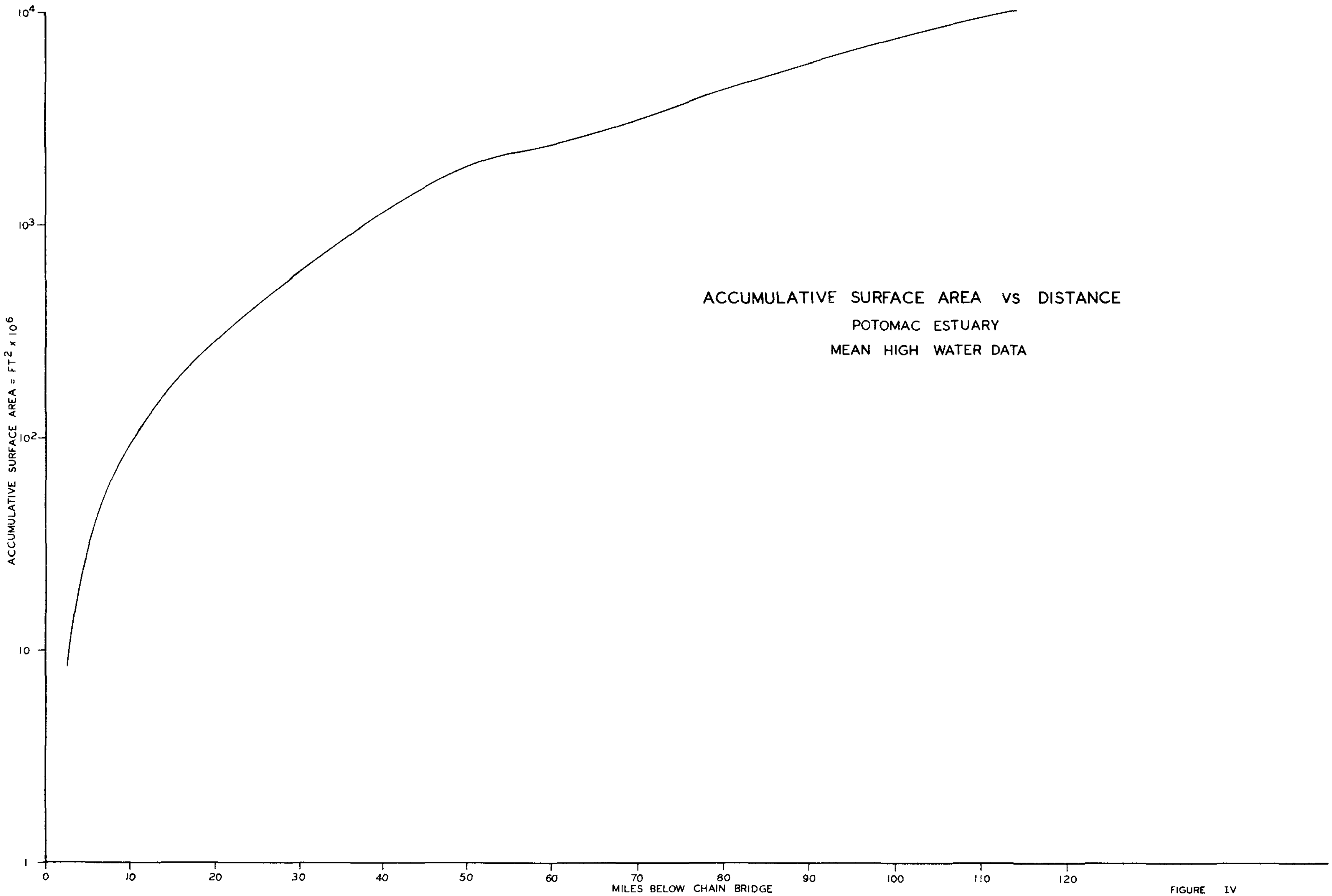
Segment Number	Thomann Model (miles)	FWQA Model (miles)
41	45.73	44.95
42	47.97	47.08
43	50.37	49.44
44	52.11	51.87
45	55.29	53.92
46	57.95	57.24
47	60.30	59.24
48	62.88	61.94
49	66.24	64.39
50	67.82	66.67
51	69.35	68.53
52	71.96	69.75
53	73.85	71.75
54	76.04	73.54
55	78.34	74.83
56	80.31	76.85
57	82.13	78.77
58	84.09	80.42
59	86.26	82.75
60	88.36	84.76

Segment Number	Thomann Model (miles)	FWQA Model (miles)
61	90.10	86.96
62	91.56	88.23
63	93.20	89.88
64	96.48	91.52
65	97.19	93.16
66	99.71	96.21
67	101.89	98.21
68	103.67	100.17
69	105.83	102.16
70	107.81	104.31
71	109.87	106.31
72	111.72	108.42
73	113.84	110.02



POTOMAC ESTUARY
SAMPLING STATIONS

FIGURE III



ACCUMULATIVE SURFACE AREA VS DISTANCE
POTOMAC ESTUARY
MEAN HIGH WATER DATA
ACCUMULATIVE SURFACE AREA = FT^2 x 10^6
10^4
10^3
10^2
10
1
0
10
20
30
40
50
60
70
80
90
100
110
120
MILES BELOW CHAIN BRIDGE

FIGURE IV

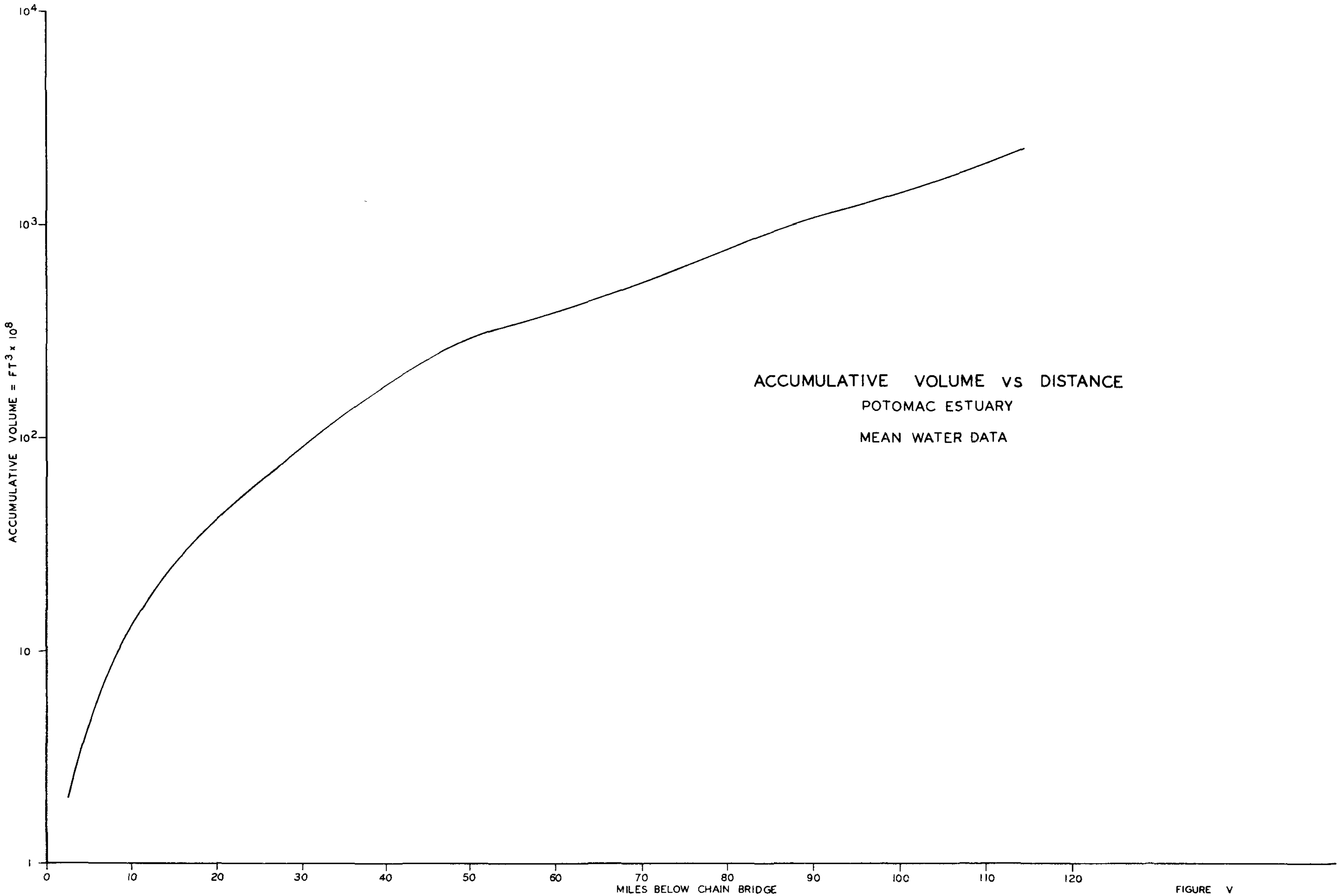

ACCUMULATIVE VOLUME vs DISTANCE
POTOMAC ESTUARY
MEAN WATER DATA
ACCUMULATIVE VOLUME = FT3 x 108
1
10
102
103
104
0
10
20
30
40
50
60
70
80
90
100
110
120
MILES BELOW CHAIN BRIDGE

FIGURE V

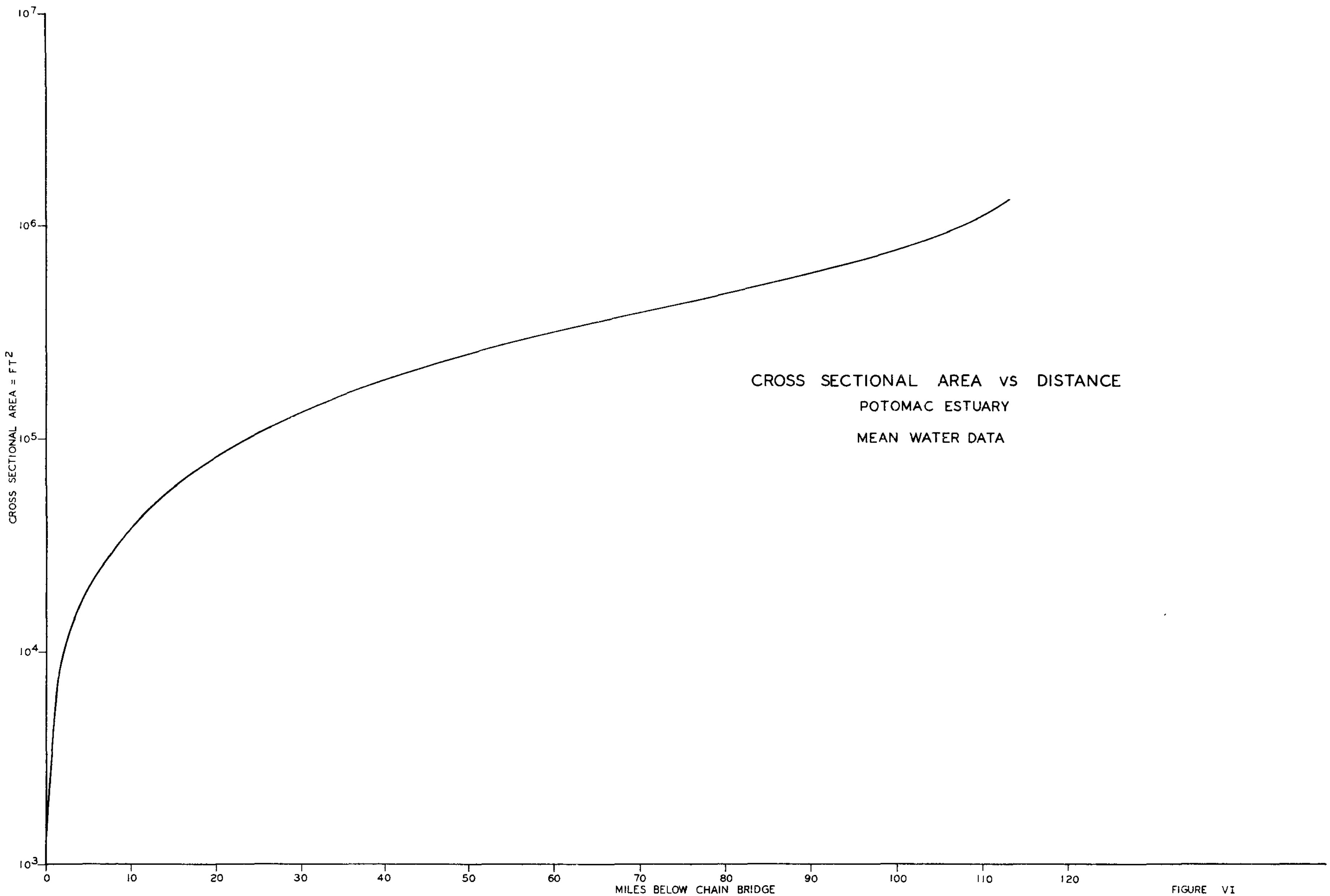
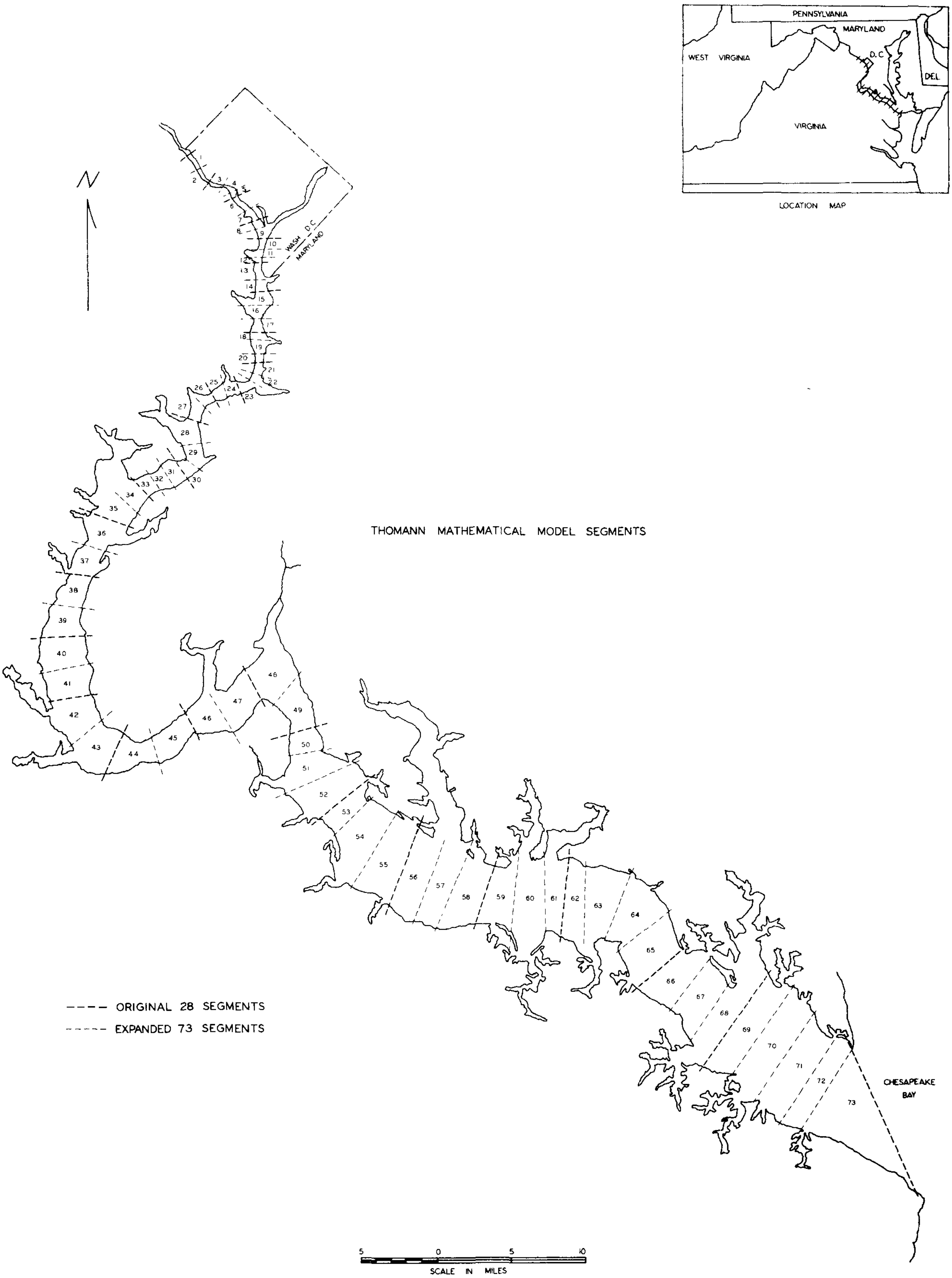
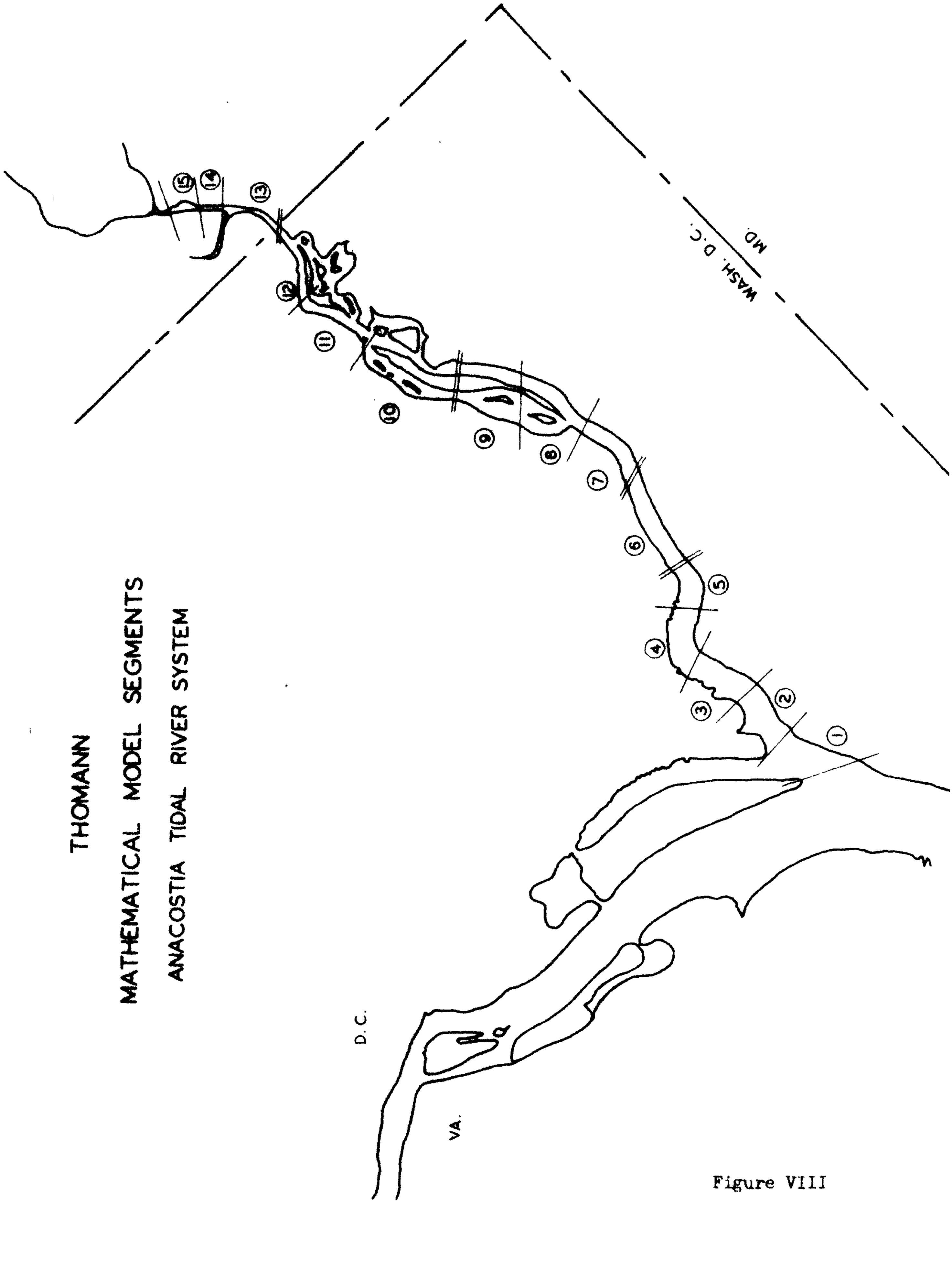

CROSS SECTIONAL AREA VS DISTANCE
POTOMAC ESTUARY
MEAN WATER DATA
CROSS SECTIONAL AREA = FT2
10^7
10^6
10^5
10^4
10^3
0
10
20
30
40
50
60
70
80
90
100
110
120
MILES BELOW CHAIN BRIDGE

FIGURE VI



POTOMAC ESTUARY

FIGURE VII


THOMANN
MATHEMATICAL MODEL SEGMENTS
ANACOSTIA TIDAL RIVER SYSTEM
WASH. D.C.
MD.
D.C.
VA.
1
2
3
4
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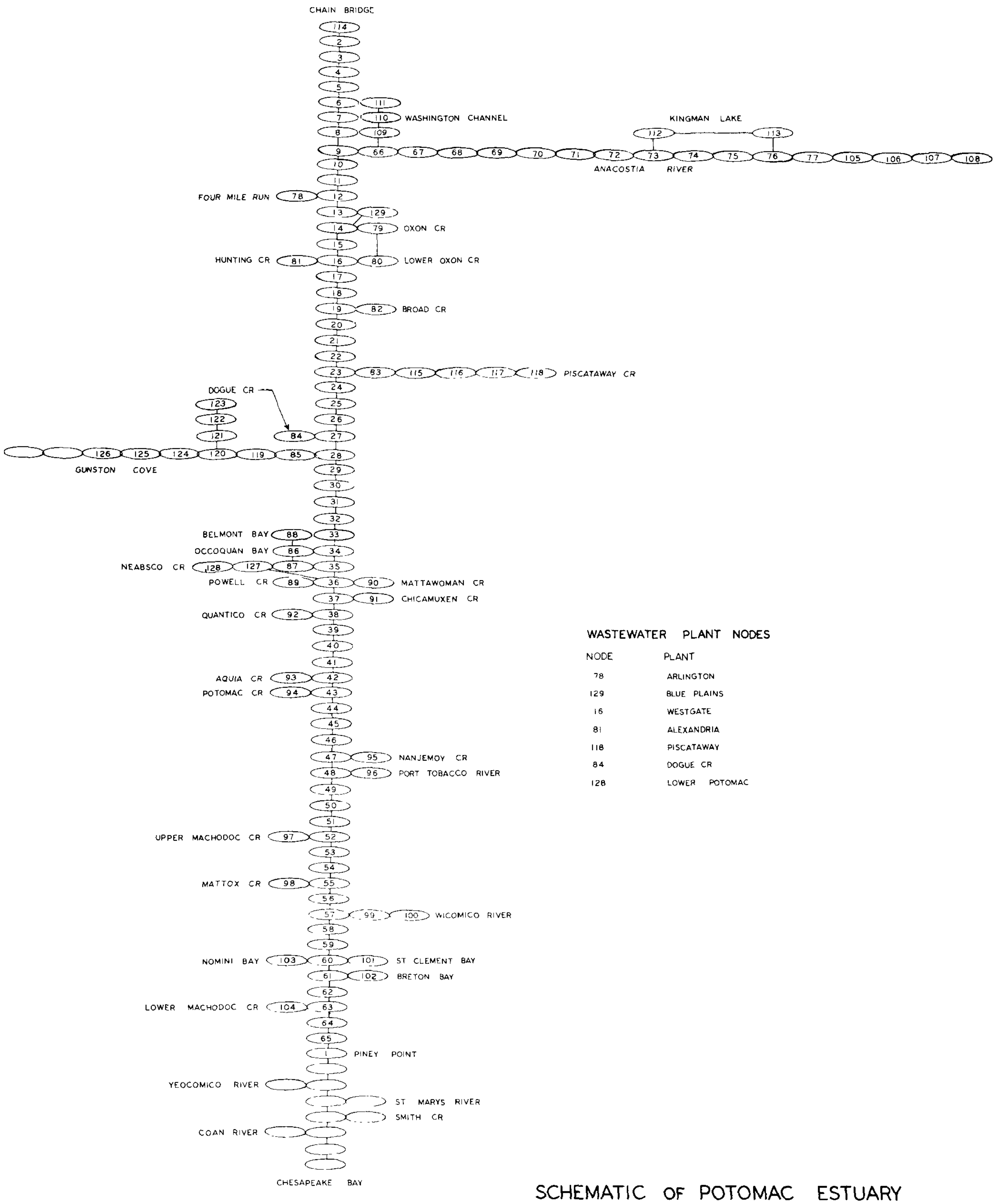
14
15

Figure VIII



WASTEWATER PLANT NODES

NODE	PLANT
78	ARLINGTON
129	BLUE PLAINS
16	WESTGATE
81	ALEXANDRIA
118	PISCATAWAY
84	DOGUE CR
128	LOWER POTOMAC

SCHEMATIC OF POTOMAC ESTUARY
FOR FWQA DYNAMIC MODEL

FIGURE IX

Chesapeake Technical Support Laboratory
Middle Atlantic Region
Water Quality Office
Environmental Protection Agency

NUTRIENT MANAGEMENT IN THE POTOMAC ESTUARY

Technical Report 45

January 1971

Norbert A. Jaworski

Donald W. Lear, Jr.

Orterio Villa, Jr.

To be presented at the American Society of Limnology and Oceanography Symposium on Nutrients and Eutrophication: "The Limiting Nutrient Controversy," February 11-13, 1971, Michigan State University, East Lansing,Michigan

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INTRODUCTION

Historically, since the first sanitary survey was made in 1913 [30], the water quality of the upper Potomac Estuary has been degraded as a result of the discharge of either untreated or partially treated municipal wastewater from the Washington Metropolitan Area. Early surveys indicated that high coliform densities and low dissolved oxygen content were the two major water quality problems of the upper estuary. In the past decade, large nuisance populations of blue-green algae have also added to the water quality management problems of the upper and middle reaches of the estuary.

Initially, as part of the Chesapeake Bay-Susquehanna River Basins Comprehensive Planning Project* and now as an integral part of the Potomac Enforcement Conference, field water quality studies were undertaken, beginning in 1965, to define wastewater treatment requirements. The studies and concepts used to formulate a nutrient management program for the Potomac Estuary are presented in this paper.

Brief Description of the Study Area

The Potomac River Basin, with a drainage area of 14,670 square miles, is the second largest watershed in the Middle Atlantic States. From its headwaters on the eastern slope of the Appalachian Mountains,

* The Chesapeake Bay-Susquehanna River Basin Comprehensive Project was initiated by the Division of Water Supply and Pollution Control of the Public Health Service, U. S. Department of Health, Education, and Welfare.

the Potomac flows first northeasterly then generally southeasterly in direction some 400 miles to the Chesapeake Bay.

Upstream from Washington, D. C., the Potomac traverses the Piedmont Plateau to the Coastal Plain at the Fall Line. Below the Fall Line, the Potomac is tidal extending 114 miles southeastward and discharges into the Chesapeake Bay.

The tidal portion is several hundred feet in width at its uppermost reach near Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained upstream to Washington. Except for this channel and a few short reaches where depths up to 100 feet can be found, the tidal portion is relatively shallow with an average depth of approximately 18 feet.

Of the 3.3 million people living in the entire basin, approximately 2.8 million reside in the upper portion of the Potomac Estuary within the Washington Metropolitan Area. The lower areas of the tidal portion, which drains 3,216 square miles, are sparsely populated.

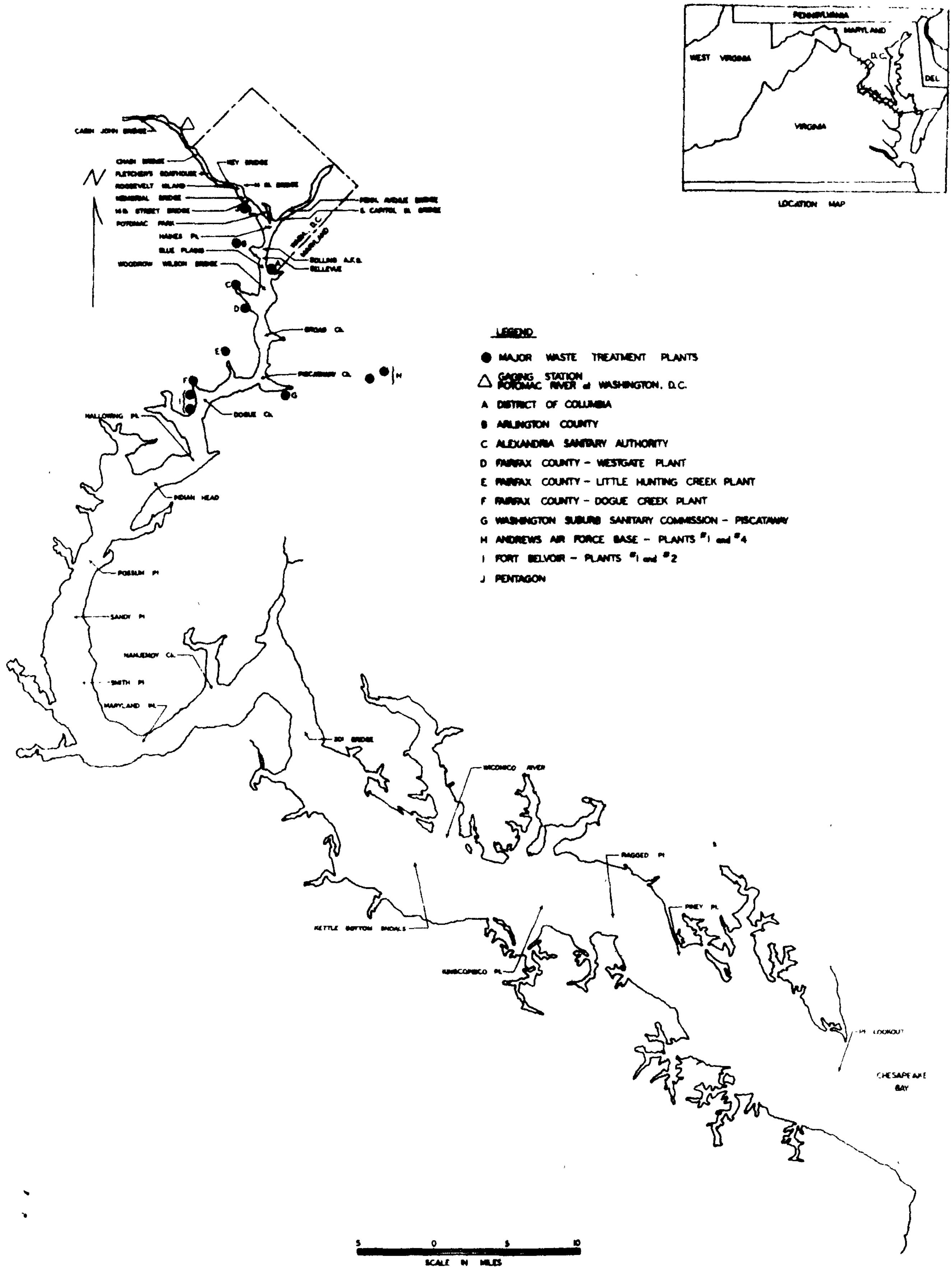
For purposes of discussion and investigation, the tidal portion of the Potomac River (Figure 1) has been divided into the three reaches described below:

Reach	Description	River Mile* (mi. below Chain Br.)	Volume (cu.ft.x10^8)
Upper	From Chain Bridge to Indian Head	0.0 to 30.0	93.50
Middle	From Indian Head to Rte. 301 Bridge	30.0 to 67.0	362.28
Lower	From Rte. 301 Bridge to Chesapeake Bay	67.0 to 114.4	1754.74

* All river miles are referenced to Chain Bridge which is located at the upper end of the tidal portion of the Potomac River.

The upper reach, although tidal, is essentially fresh water. The middle reach is normally the transition zone from fresh to brackish water. The lower reach is mesohaline with chloride concentrations near the Chesapeake Bay ranging from approximately 7,000 to 11,000 mg/l.

The average freshwater flow of the Potomac River near Washington before diversions for municipal water supply is 10,800 cubic feet per second (cfs) with a median flow of 6,500 cfs. The flow of the Potomac is characterized by flash floods and extremely low flows.



POTOMAC ESTUARY

Figure 1

CURRENT WATER QUALITY CONDITIONS

In the upper reach, approximately 325 million gallons per day (mgd) of wastewater is discharged mainly from municipal treatment facilities currently serving approximately 2.5 million people in the Washington Metropolitan Area. The largest wastewater treatment facility is the Blue Plains plant of the District of Columbia which serves approximately 1.8 million people. Wastewater discharged from the 18 facilities currently contributes 450,000, 24,000, and 60,000 lbs/day of ultimate oxygen demand* (UOD), phosphorus** and nitrogen respectively, to the waters of the upper estuary. The quantities of wastewater discharged into the middle and lower reaches is less than 5.0 mgd and thus very insignificant when compared to the upper reach.

Low dissolved oxygen (DO) concentrations, often less than 1.0 mg/l during summer, occur in the upper reach as a result of the oxidation of 200,000 and 240,000 lbs/day of carbonaceous and nitrogenous UOD respectively. Since the summer of 1969, the high fecal coliform densities (over 50,000 MPN/100 ml) previously observed near the wastewater discharges have been significantly reduced (less than 1,000 MPN/100 ml) by effective continuous chlorination.

* Ultimate oxygen demand is basically the sum of 1.45 times the 5-day biochemical oxygen demand and 4.57 times the unoxidized nitrogen.

** Phosphorus concentrations or loadings in this paper are given as phosphorus (P) except when specifically designated as PO_4.

The concentrations or forms of phosphorus and nitrogen in the Potomac Estuary are a function of wastewater loadings, temperature, freshwater inflow, distance from the Chain Bridge, and biological activity. As shown in Figure 2, the inorganic phosphorus varied considerably for the six stations presented from March 1969 through September 1970. The concentration at Hains Point, which is located at the upper end of the tidal excursion of the major wastewater discharges, was fairly uniform averaging 0.1 mg/l as P (0.3 mg/l as PO_4). At Woodrow Wilson Bridge, which is located below the Blue Plains wastewater discharge, the inorganic phosphorus increased appreciably with concentrations over 0.8 mg/l (2.5 mg/l as PO_4) occuring during low-flow periods as those in the months of May-July 1969, October-November 1969, and September 1970. The remaining four downstream stations had progressively lower concentrations.

The total phosphorus concentration closely parallels that of inorganic phosphorus. In the upper reach, the ratio of total phosphorus to inorganic phosphorus ranges from 1.1 to 1.5. The ratio is higher in the middle reach normally varying from 1.5 to 2.0 with the lower reach having a range from approximately 2.0 to 2.5.

The concentration of nitrite and nitrate nitrogen at Hains Point and Woodrow Wilson Bridge varies almost inversely with that of phosphorus (Figure 3). The NO_2 + NO_3 concentrations as a result of land runoff were the highest during periods of high river flows as in July

INORGANIC PHOSPHATE CONCENTRATION as PO_4

POTOMAC ESTUARY

1969 - 1970

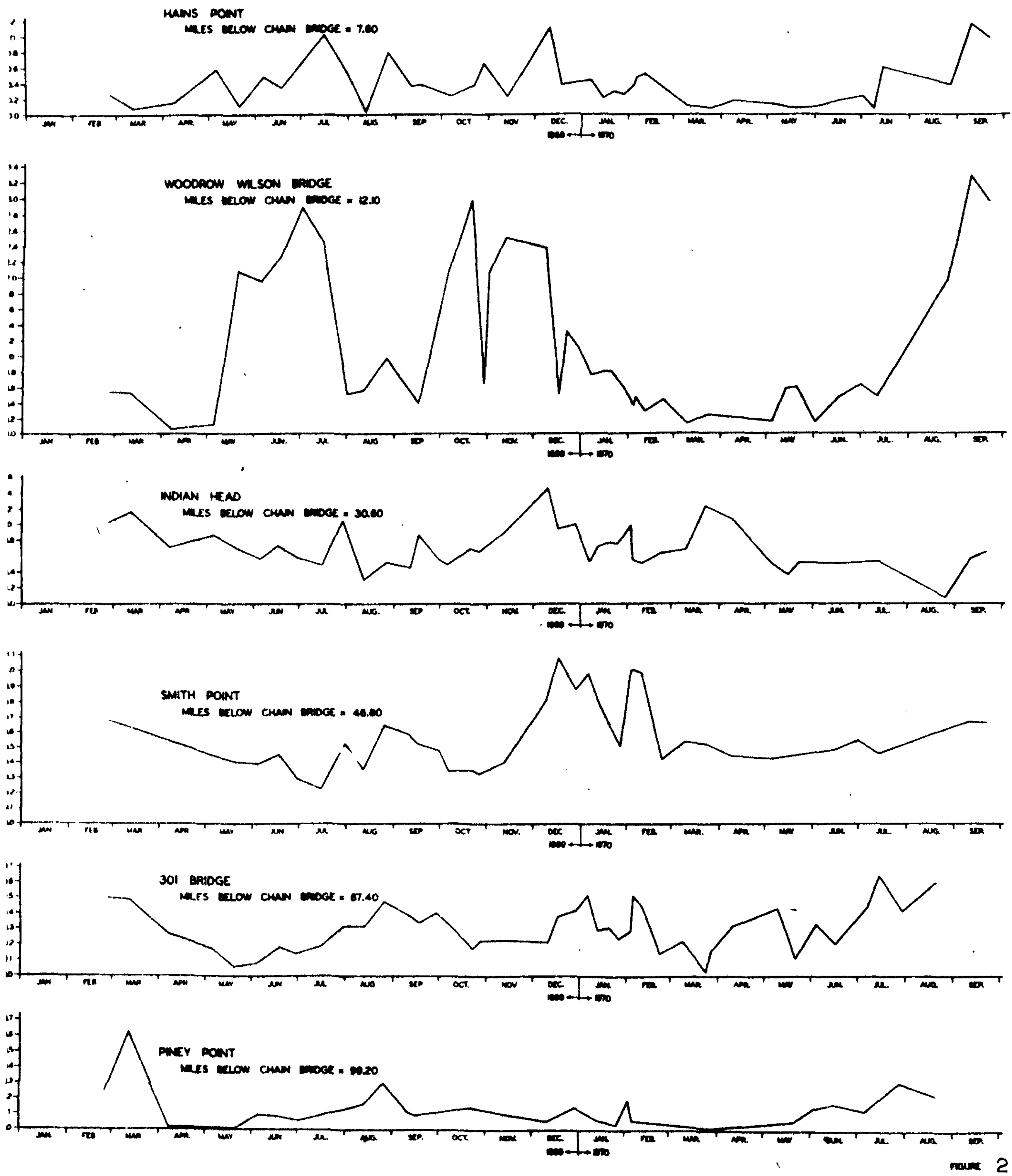


FIGURE 2

NITRATE and NITRITE NITROGEN as N
POTOMAC ESTUARY
1969 - 1970

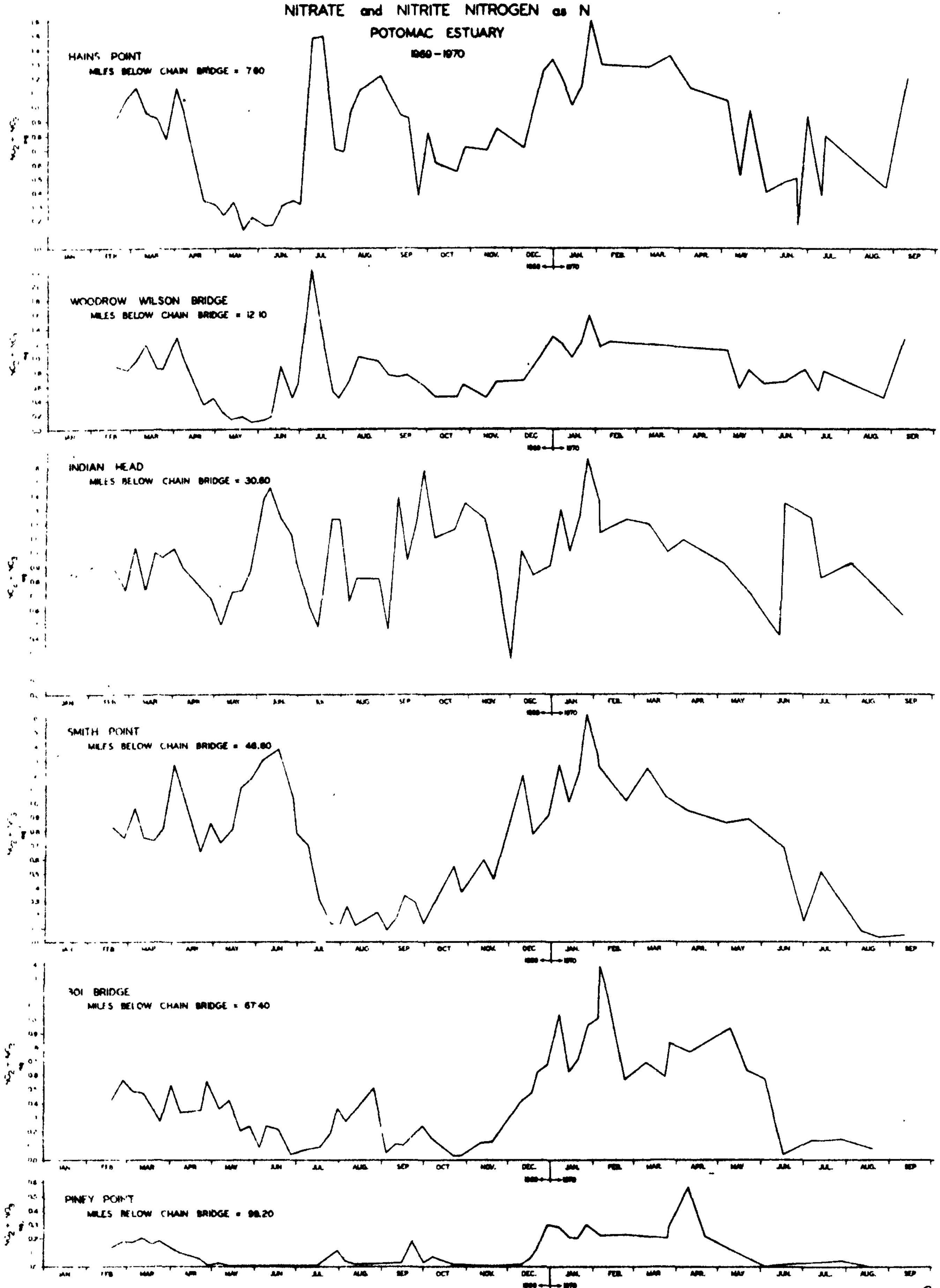


FIGURE 3

and August 1969, and during the late winter and early spring months of 1969 and 1970. During these flow conditions, the inorganic phosphorus concentration was lowest (Figure 2).

The increase of $NO_2 + NO_3$ at Indian Head as compared to Woodrow Wilson Bridge in May-June 1969, September-November 1969, and July 1970 is the result of the conversion of ammonia (from the wastewater treatment plant discharges) to nitrates. The low concentration of $NO_2 + NO_3$ in the summer months at Smith Point is caused by uptake of algal cells as described later in this report. During winter months, algal utilization is much less thus the concentrations of nitrates are high as in the months of January through April 1970. At Piney Point, concentrations of $NO_2 + NO_3$ are usually less than 0.1 mg/l on an annual basis.

As shown in Figure 4, the concentration of ammonia nitrogen is also affected by flow and temperature conditions. Although large quantities of ammonia are discharged from wastewater treatment facilities into the Potomac near Woodrow Wilson Bridge, ammonia concentrations at Indian Head during the summer months are low due to nitrification.

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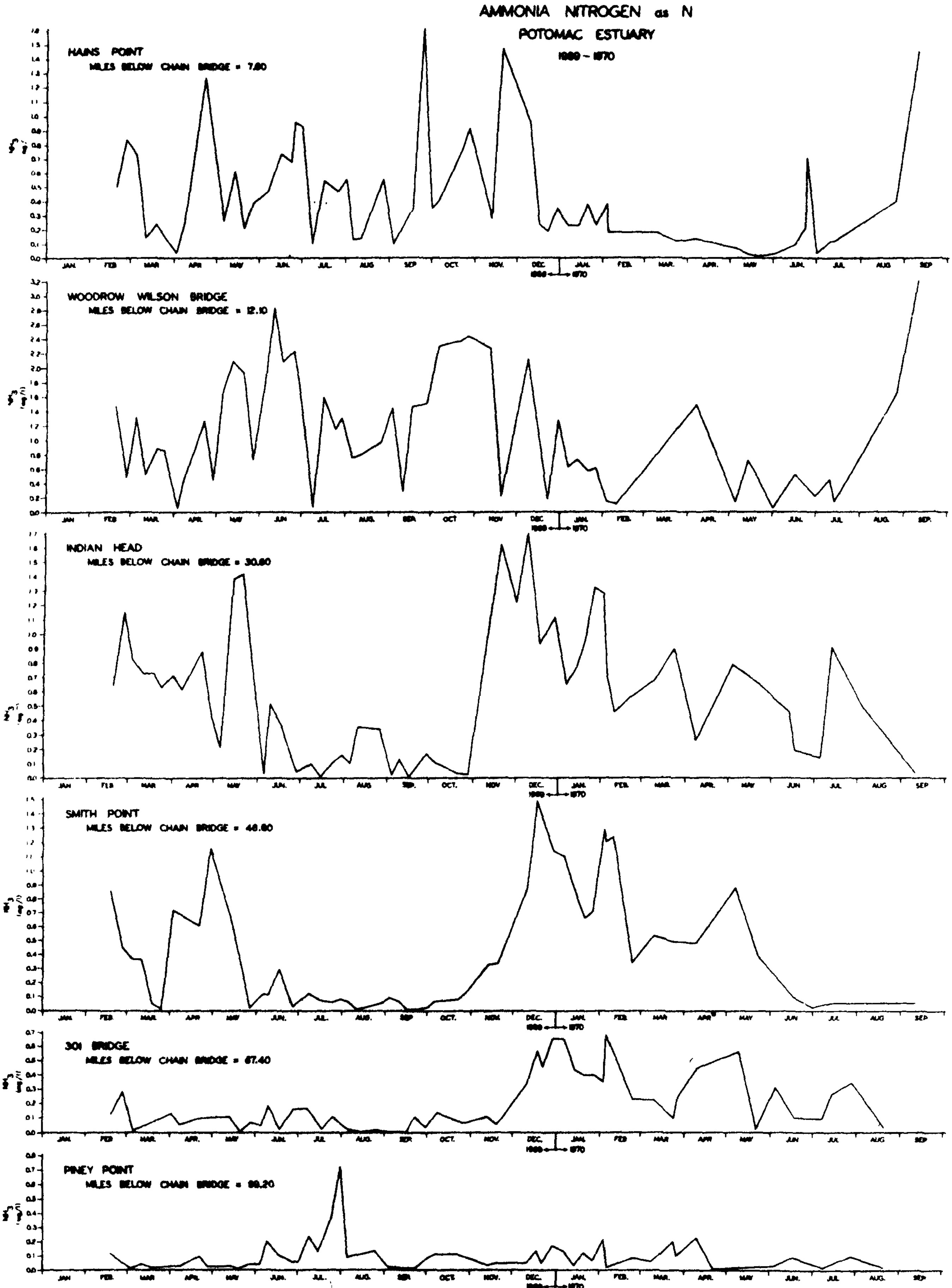

AMMONIA NITROGEN as N
POTOMAC ESTUARY
1969 - 1970
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.80
WOODROW WILSON BRIDGE
MILES BELOW CHAIN BRIDGE = 12.10
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.60
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
PINEY POINT
MILES BELOW CHAIN BRIDGE = 89.20
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP.
1969 ← → 1970

FIGURE 4

During the summer and early fall months, the average ranges of pH, alkalinity, and free dissolved CO_2 (measured by titration) for the five stations in the upper and middle reaches were:

Location	pH (units)	Alkalinity (mg/l as $CaCO_3$)	Free Dissolved CO_2 (mg/l)
Chain Bridge	7.5 - 8.0	80 - 100	2 - 4
W. Wilson Bridge	7.0 - 7.5	90 - 110	8 - 12
Indian Head	7.2 - 8.0	70 - 90	6 - 10
Maryland Point	7.5 - 8.2	60 - 85	2 - 8
Rte. 301 Bridge	7.5 - 8.0	65 - 85	7 - 8

In the vicinity of the Woodrow Wilson Bridge, there is an increase in both alkalinity and CO_2 with a corresponding decrease in pH attributed to wastewater discharges. There is a decrease in both alkalinity and CO_2 with a corresponding increase in pH at the Indian Head and Maryland Point stations which are due to algal growths. In the lower estuary, the alkalinity and CO_2 increases while pH decreases. The algal standing crops are considerably smaller in this reach.

Salinity concentration as well as nutrient enrichment from wastewater discharges has a pronounced effect on the ecology of the estuary. Under summer and fall conditions, large populations of blue-green algae, primarily *Anacystis* sp. (Microcystis), are prevalent from the metropolitan area as far downstream as Maryland Point.

Under warm temperature and low-flow conditions, large standing crops of this alga develop forming "green mats" of cells. Chlorophyll *a* concentrations (a measure of algal standing crop) range from approximately 50 to over 200 ug/l in these areas of dense growth which at times encompass approximately 50 miles of the upper and middle reaches of the estuary. These high chlorophyll levels are 5 to 10 times those reportedly observed in other eutrophic waters [5] [32]. During a dense bloom, the dry weight of cells ranges from 10 to 25 mg/l which is almost twice those reported for the Madison, Wisconsin lakes [22].

Chlorophyll a determinations for the upper reach and for the middle and lower reaches of the Potomac Estuary are presented in Figures 5 and 6, respectively. At Indian Head and Smith Point for 1965-1966 and 1969-1970, the chlorophyll a concentrations indicate that algal populations have not only increased in density in the latter years but have become more persistent over the annual cycle. At both stations, higher values of chlorophyll were measured during the 1969-1970 sampling cruises than during the 1965-1966 cruises even though flow conditions were more stable in 1965-1966. The occurrence of a spring bloom of diatoms was observed in 1969 and 1970 but not during the 1965-1966 cruises.

In the mesohaline portion of the lower reach of the Potomac Estuary, the algal populations are not as dense as in the freshwater portion. Nevertheless at times, large populations of marine phytoplankton (primarily the dinoflagellates *Gymnodinium* sp. and *Amphidinium* sp.) occur producing what are known as "red tides."

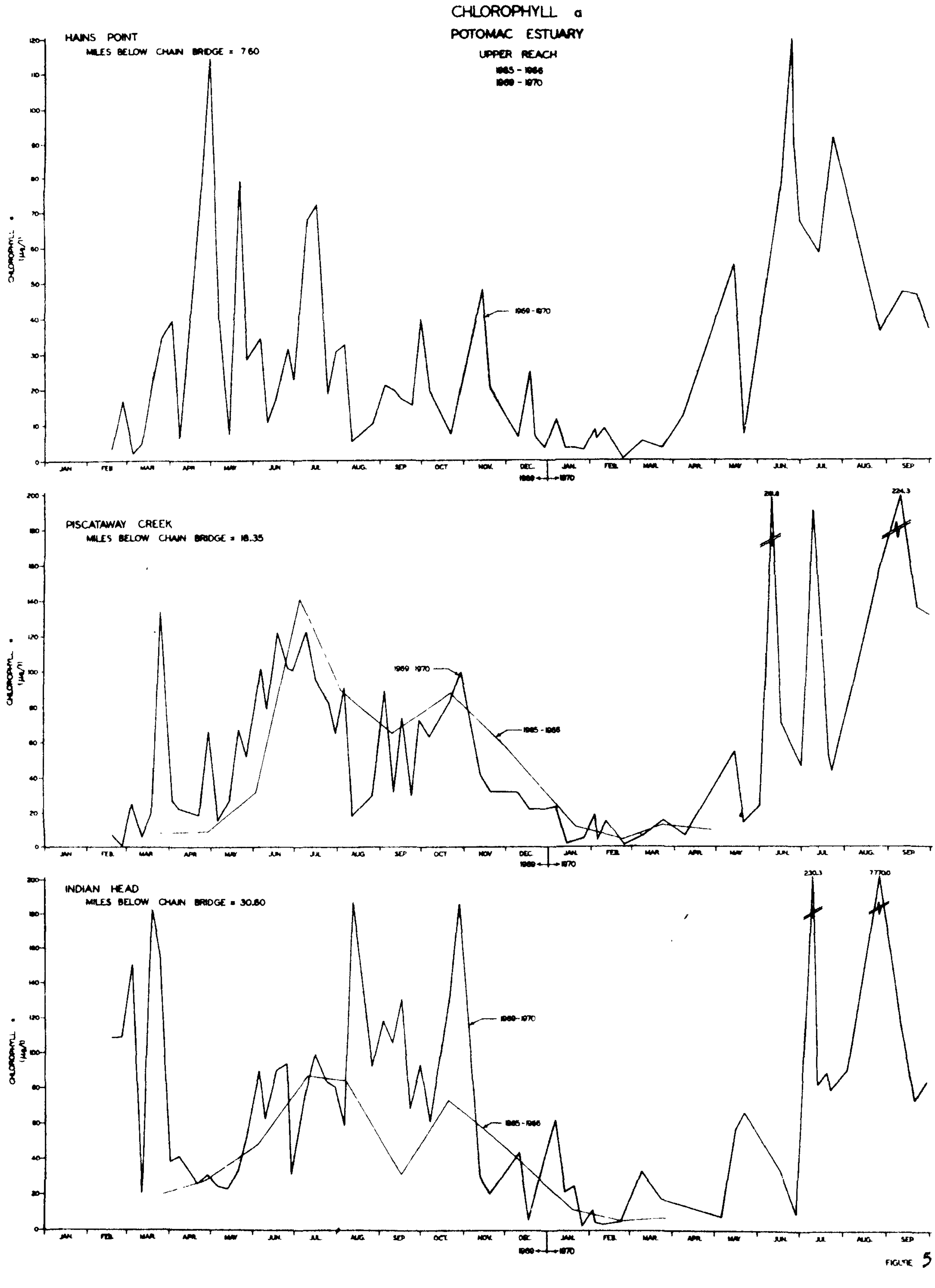

CHLOROPHYLL a
POTOMAC ESTUARY
UPPER REACH
1965 - 1966
1969 - 1970
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
1969 - 1970
PISCATAWAY CREEK
MILES BELOW CHAIN BRIDGE = 18.35
1969 1970
1965 - 1966
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.80
1969-1970
1965-1966
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
1969 ← → 1970

FIGURE 5

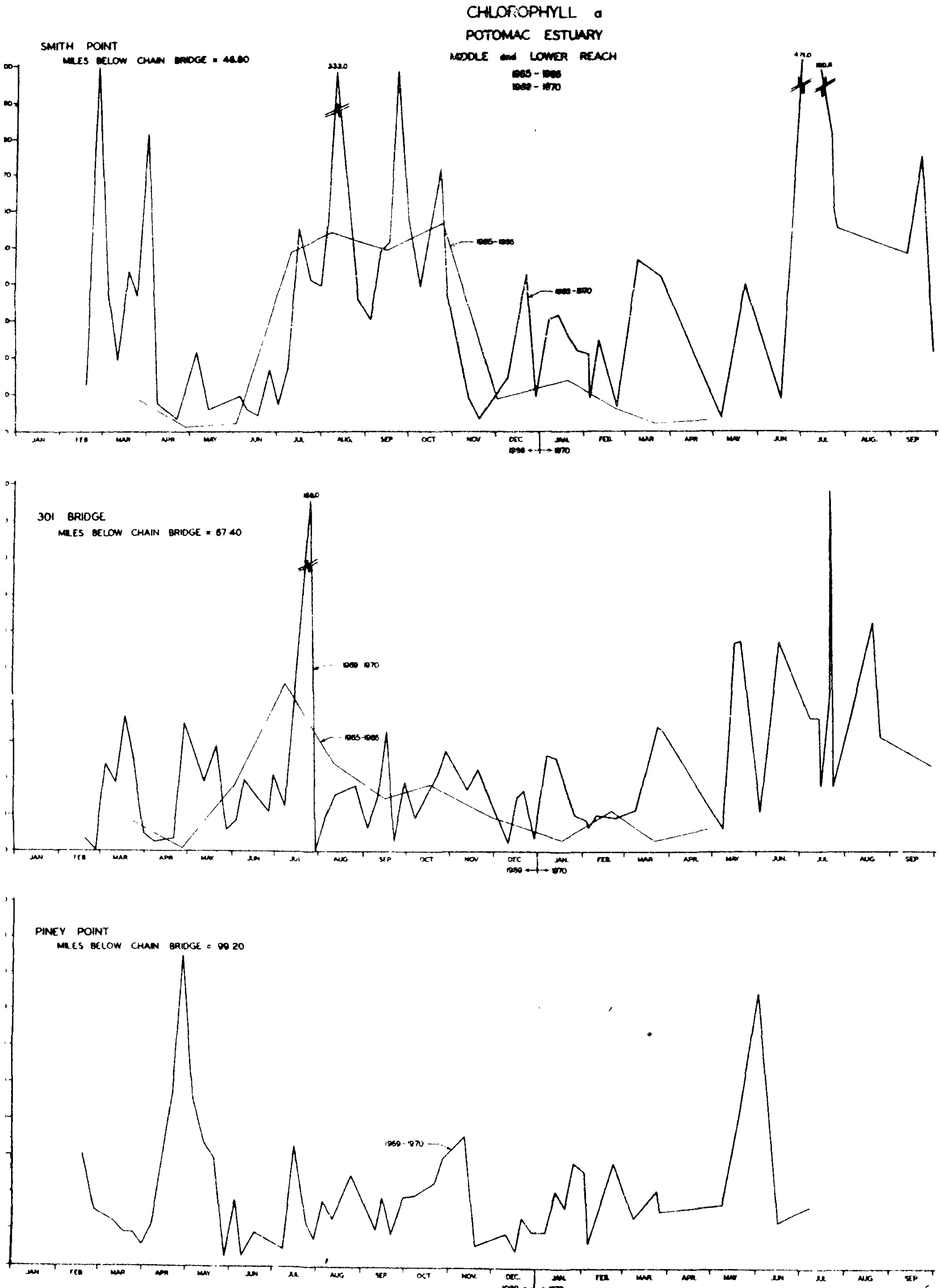

CHLOROPHYLL a
POTOMAC ESTUARY
MIDDLE and LOWER REACH
1965 - 1966
1969 - 1970
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.80
333.0
1965-1966
1969-1970
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1969
1970
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
1969 1970
1965-1966
PINEY POINT
MILES BELOW CHAIN BRIDGE = 99.20
1969-1970

FIGURE 6

ECOLOGICAL TRENDS AS RELATED TO NUTRIENT ENRICHMENT

Since the first observations reported in 1913, the effect of the increased nutrients on the ecology of the upper Potomac Estuary has been dramatic (Figure 7). Historical invasions of nuisance plant growths in the upper Potomac Estuary can be inferred from several studies. Cumming [6] surveyed the estuary in 1913-1914 and noted the absence of plant life near the major waste outfalls with "normal" amounts of rooted aquatic plants on the flats or shoal areas below the urban area. No nuisance levels of rooted aquatic plants or phytoplankton blooms were noted.

In the 1920's, an infestation of water chestnut appeared in the waters of the Chesapeake Bay including the Potomac Estuary. This infestation was controlled by mechanical removal [23].

In September and October 1952, another survey of the reaches near the metropolitan area made by Bartsch [2] revealed that vegetation in the area was virtually nonexistent. While no massive phytoplankton blooms were reported, there was a noticeable increase in blue-green algae and diatoms when compared to the 1913-1914 studies.

In August and September 1959, a survey of the area was made by Stotts and Longwell [28]. Blooms of the nuisance blue-green alga *Anacystis* were reported in the Anacostia and Potomac Rivers near Washington.

In 1958 a rooted aquatic plant, water milfoil, developed in the waters of the Chesapeake Bay including the Potomac Estuary and created

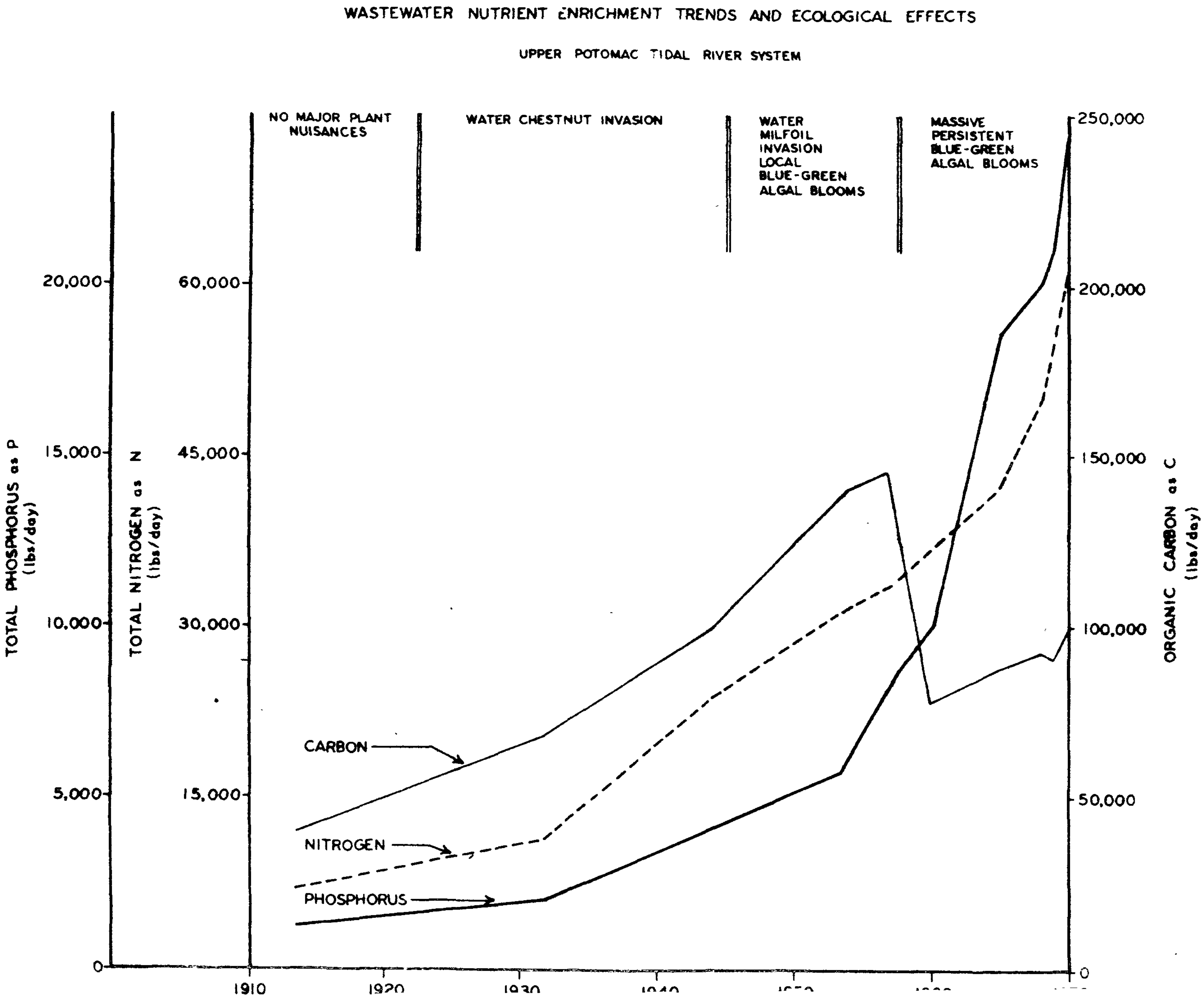

WASTEWATER NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS
UPPER POTOMAC TIDAL RIVER SYSTEM
NO MAJOR PLANT NUISANCES
WATER CHESTNUT INVASION
WATER MILFOIL INVASION LOCAL BLUE-GREEN ALGAL BLOOMS
MASSIVE PERSISTENT BLUE-GREEN ALGAL BLOOMS
TOTAL PHOSPHORUS as P (lbs/day)
TOTAL NITROGEN as N (lbs/day)
ORGANIC CARBON as C (lbs/day)
20,000
15,000
10,000
5,000
0
60,000
45,000
30,000
15,000
250,000
200,000
150,000
100,000
50,000
0
CARBON
NITROGEN
PHOSPHORUS
1910
1920
1930

FIGURE 7

nuisance conditions. The growth increased to major proportions by 1963, especially in the embayments from Indian Head downstream [8] and then dramatically disappeared beginning in late 1965. The decrease was presumably due to a natural virus [3].

Subsequent and continuing observations by the Chesapeake Technical Support Laboratory (CTSL) staff have confirmed persistent massive summer blooms of the blue-green alga *Anacystis*. Nuisance concentrations occur from the Washington Metropolitan Area downstream as far as Maryland Point [16].

From the above considerations, it would appear that nuisance 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 *Anacystis*.

Figure 7 indicates that the massive blue-green algal blooms now occurring every summer since 1960 are associated with large phosphorus and nitrogen loading increases in the upper reaches of the Potomac River tidal system. The blooms have persisted since the early 1960's although the amount of organic carbon from wastewater has been reduced by almost 50 percent of that discharged prior to 1960. Moreover, the organic carbon loadings being discharged now are equal to those that were discharged in the early 1940's when there were no reported nuisance conditions as a result of algal growth. These observations tend to suggest that the ecological changes have been caused by increases in nitrogen and phosphorus and not by organic carbon.

NUTRIENT SOURCES AND CONTROLLABILITY

A complete analysis of the nutrient sources in the upper Potomac Estuary has been made by Jaworski *et al* [17]. A summary of the three major sources is presented in Table 1 for low- and median-flow conditions. For low- and median-flows, the contribution from wastewater discharges of the three nutrients on a percentage basis is presented below:

Percentage from Wastewater Discharges

	Excluding Air-Water Interface Median Flow (%)		Excluding Air-Water Interface Low Flow (%)	Including Air-Water Interface Median Flow (%)		Including Air-Water Interface Low Flow (%)
Carbon	29	to	55	12	to	15
Nitrogen	60	to	90	59	to	89
Phosphorus	82	to	96	82	to	96

From the above tabulation, it can be concluded that the order of controllability of nutrients by wastewater treatment is (1) phosphorus, (2) nitrogen, and (3) carbon.

While 82 to 96 percent of the phosphorus entering the upper estuary can be controlled by removal at the wastewater treatment facilities, an additional reduction of phosphorus concentration occurs during periods of high runoff within the upper estuary itself. As reported by Aalto *et al* [1], large quantities of phosphorus (over 100,000 lbs/day) enter the upper estuary during high-flow periods at concentrations over 0.5 mg/l (1.5 mg/l as PO_4) during the rising portion of the river discharge hydrograph. However, high silt concentrations also accompany high flows.

[illegible]

SUMMARY OF NUTRIENT SOURCES

Upper and Middle Reaches of the Potomac Estuary

<u>Low-Flow Conditions</u>

(Potomac River Discharge at Washington, D. C. = 1200 cfs)

	Land Runoff (lbs/day)	Wastewater Discharges (lbs/day)	Air-Water Interface (lbs/day)
Carbon	170,000	160,000*	950,000**
Nitrogen	6,700	60,000	1,600***
Phosphorus	1,000	24,000	0

<u>Median-Flow Conditions</u>

(Potomac River Discharge at Washington, D. C. = 6500 cfs)

	Land Runoff (lbs/day)	Wastewater Discharges (lbs/day)	Air-Water Interface (lbs/day)
Carbon	350,000	160,000*	950,000**
Nitrogen	40,000	60,000	1,600***
Phosphorus	5,300	24,000	0

* Of the 160,000 lbs/day, 60,000 lbs/day are discharged as inorganic carbon

** The potential CO_2 obtainable from the atmosphere was determined by using only 0.1 percent of the transfer rate of 0.6 $mg/cm^2/min$ as indicated by Riley and Skirrow [15]

*** Based on a nitrogen fixation rate of five lbs/acre/year as reported by Hutchinson [14]

Large amounts of phosphorus are sorbed upon the silt particles and removed from the water system as sedimentation occurs in the upper reach of the estuary.

This deposition was also observed in the summer of 1970 (Figure 8). During the month of June, the average flow of the Potomac at Washington was approximately 6,000 cfs with a daily contribution of approximately 2,000 lbs/day of phosphorus to the upper estuary. During the period from July 10 to July 11, 1970, the flow increased to over 47,000 cfs contributing over 70,000 lbs/day of phosphorus. By July 13, the flow decreased to less than 19,000 cfs with the flow on July 22 being less than 5,000 cfs and the phosphorus contribution decreased to less than 3,000 lbs/day.

Although there was some dilution of high phosphorus concentrations, the large sediment load reduced the overall phosphorus concentration by a minimum of 20 percent in the reaches upstream and downstream from the major wastewater sources at River Mile 12.0. (See profiles for July 13 and July 22, 1970) This reduction during periods of high flow would tend to add to the controllability of phosphorus as tabulated earlier. The high percentage from wastewater discharges, especially during the early months of the algal growing season and the large losses to the sediments during high-flow periods made phosphorus an ideal nutrient to manage.

In periods of extremely high runoff, the concentration of nitrate in the waters entering the Potomac Estuary from the upper basin also increases; and at times, over 300,000 lbs/day of nitrogen enters the

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY

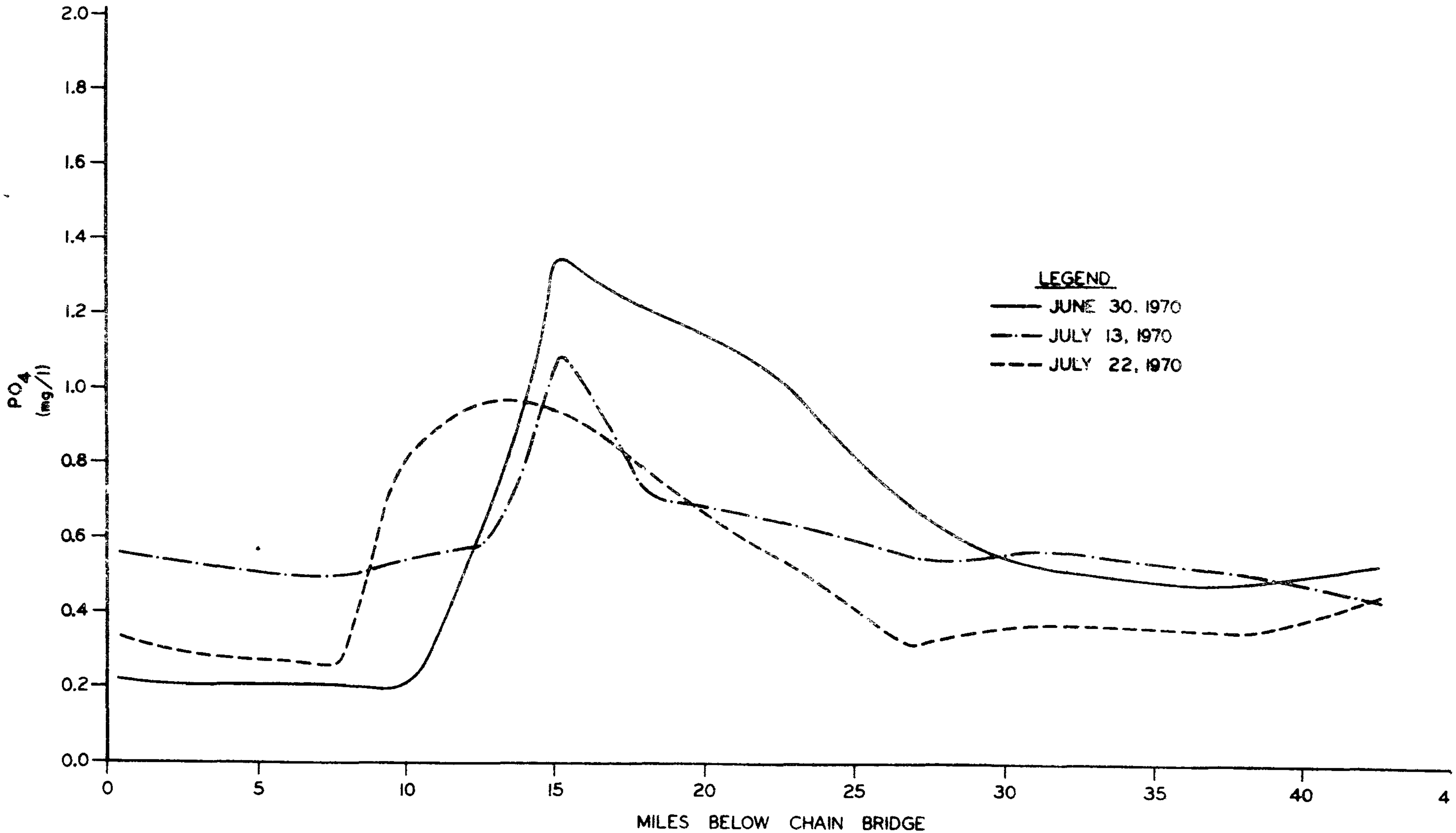


FIGURE 8

upper estuary. During the months of June through October, when blue-green algal growths become a nuisance, the contribution from the upper basin is small when compared to that from wastewater discharges (See Table 1).

Based on data as presented in Table 1, the amount of atmospheric nitrogen from rainfall, dustfall, and fixation by algae is approximately 1,600 lbs/day for the upper and middle Potomac Estuary. Extension of recent data from studies at the University of Wisconsin [31] indicate that approximately 5,000 lbs/day of nitrogen could be fixed by blue-green algae in the upper and middle reaches of the Potomac Estuary. Nevertheless, compared to all other sources, the contribution from the atmosphere including that by nitrogen fixing algae appears to be insignificant. Thus, during the summer months, algal control by management of nitrogen appears to be a feasible alternative to phosphorus control.

Under summer flow conditions, the alkalinity in runoff from the upper basin ranges from 80 to 100 mg/l, with wastewater discharges ranging from 100 to 150 mg/l. Including runoff and wastewater discharge sources only, approximately 60 to 70 percent of the total carbon entering the upper estuary is in the inorganic form.

Using only 0.1 percent of the transfer rate, the amount of carbon (CO_2) potentially available from the atmosphere is approximately 950,000 lbs/day (Table 1). With the upper reach of the estuary well mixed due to tidal action, recruitment of carbon from benthic decomposition also appears to be another significant source of inorganic carbon.

Data indicate that waters of the lower reach of the Potomac Estuary and Chesapeake Bay are high in alkalinity and inorganic carbon. As the salt wedge moves upstream, there appears to be some recruitment of alkalinity and inorganic carbon from the Chesapeake Bay into the lower and middle reaches of the Potomac Estuary [17]. When all potential sources are considered, it appears that the management of carbon for algal control is not a feasible alternative at the present time.

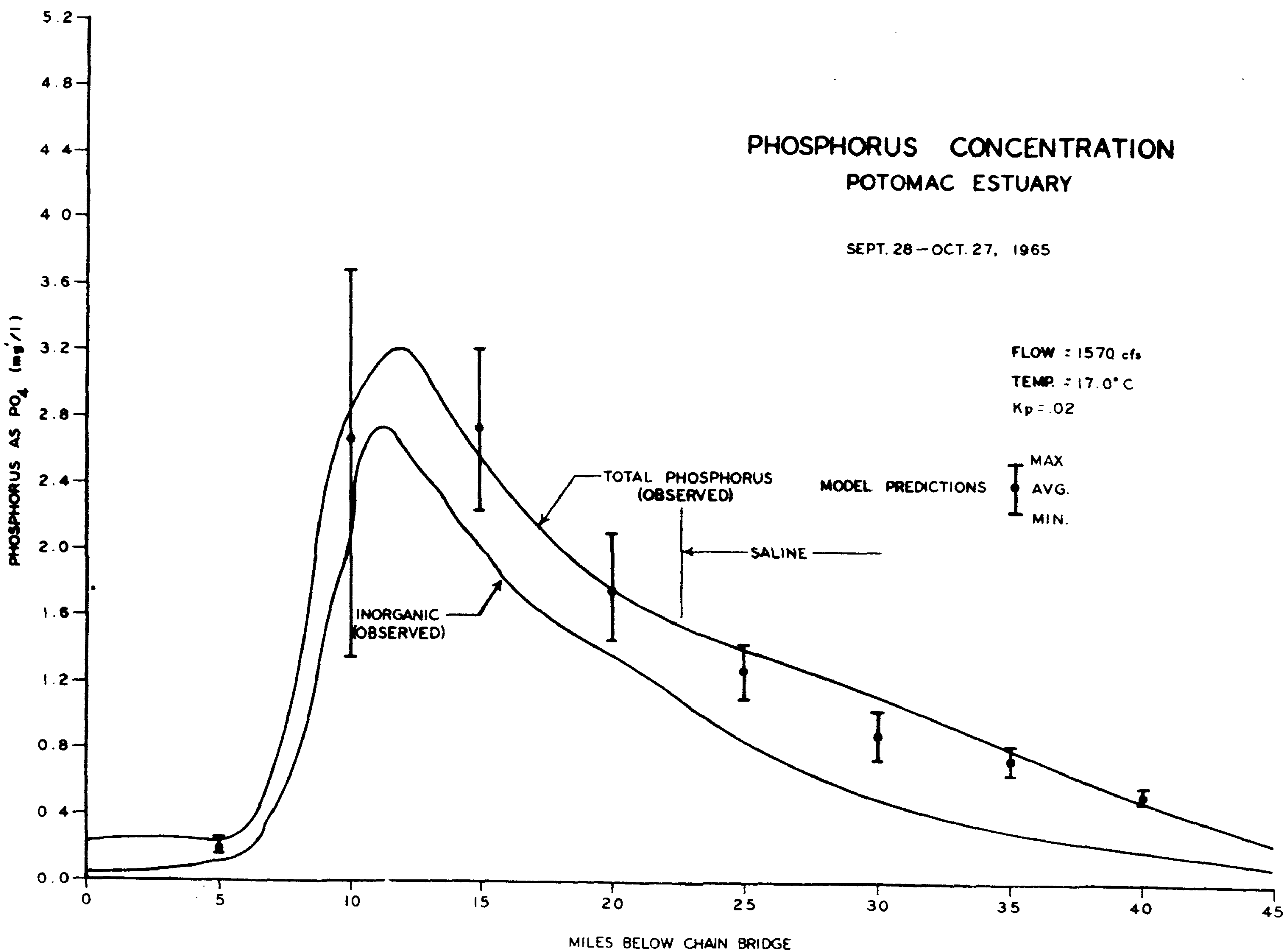
NUTRIENT TRANSPORT AND ALGAL STANDING CROP MATHEMATICAL MODELS

In investigating the role of nitrogen and phosphorus on the eutrophic conditions in the Potomac Estuary, a detailed study of the movement of these nutrients was made using a "real time" dynamic water quality estuary mathematical model [10]. Models were also developed for algal standing crops and dissolved oxygen.

Phosphorus movement in the estuary was simulated by using a deposition formulation based on second order reaction kinetics. As shown in Figures 9 and 10, the model accurately predicts the rate of phosphorus deposition. Figure 11 indicates that the deposition rate is greatly affected by temperature. Analyses of the bottom muds of the estuary also indicate that large quantities of phosphorus are being lost to sediments in the vicinity of the wastewater discharges.

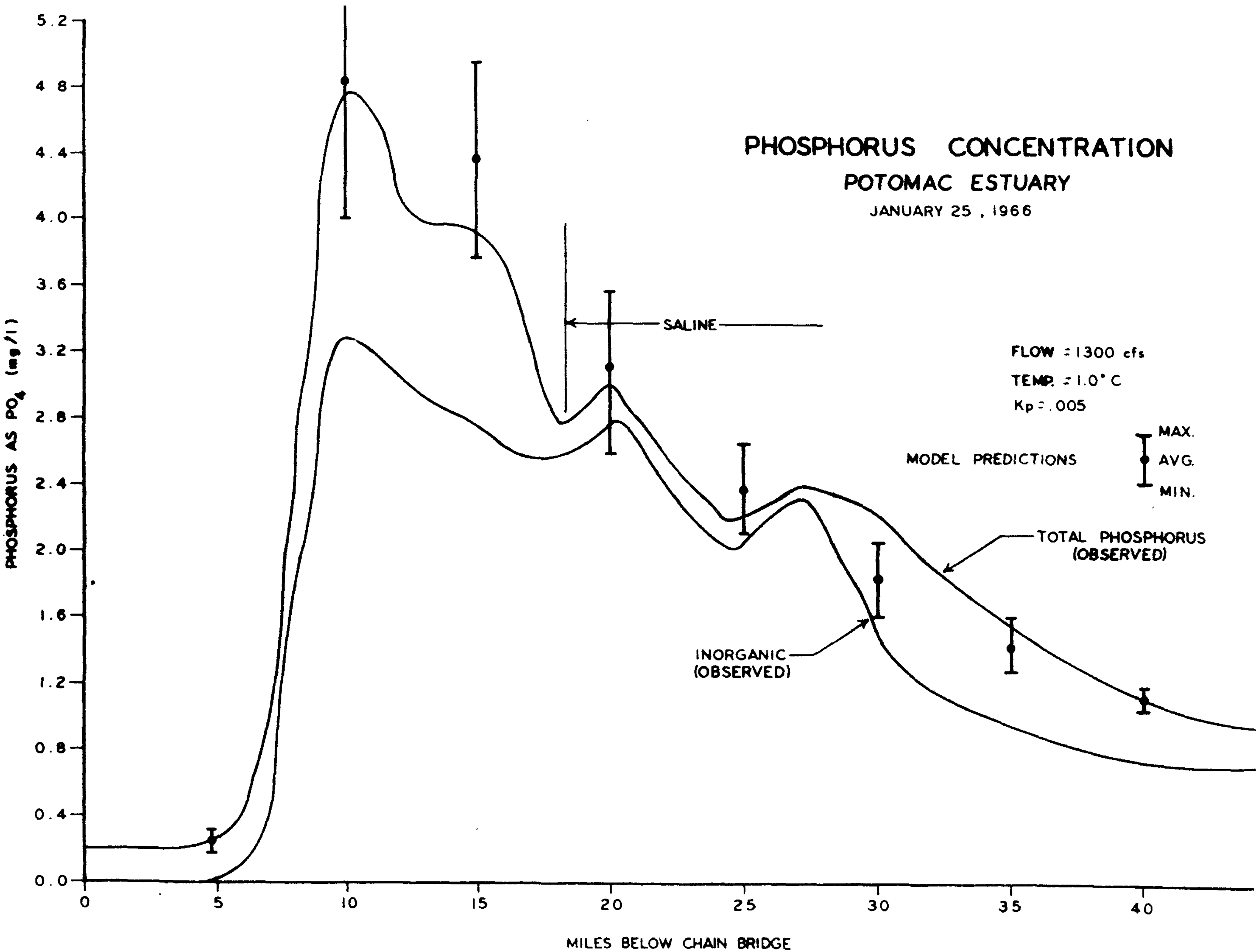
To determine if the phosphorus loss is related to algal growths, algal standing crops were predicted using a surrogate phosphorus mathematical model. In the model, the loss in phosphorus was converted to algal standing crops using a chlorophyll a/phosphorus weight relationship as given in Table 2. Based on six simulated standing crop studies, it appears that only 10 to 30 percent of the phosphorus losses from the aqueous system can be accounted for by uptake of algal cells.

In investigating the role of nitrogen in water quality management, a feedback system of the nitrogen cycle was incorporated into the dynamic estuary mathematical model similar to that proposed by Thomann et al [29]. The model, as shown in Figure 12, consists of six possible



PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPT. 28 — OCT. 27, 1965
FLOW = 1570 cfs
TEMP. = 17.0° C
Kp = .02
MAX
AVG.
MIN.
MODEL PREDICTIONS
TOTAL PHOSPHORUS (OBSERVED)
SALINE
INORGANIC (OBSERVED)
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40
45

FIGURE 9



PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
JANUARY 25, 1966
FLOW = 1300 cfs
TEMP. = 1.0° C
Kp = .005
MODEL PREDICTIONS
MAX.
AVG.
MIN.
SALINE
TOTAL PHOSPHORUS (OBSERVED)
INORGANIC (OBSERVED)
PHOSPHORUS AS PO4 (mg/l)
MILES BELOW CHAIN BRIDGE
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40

FIGURE 10

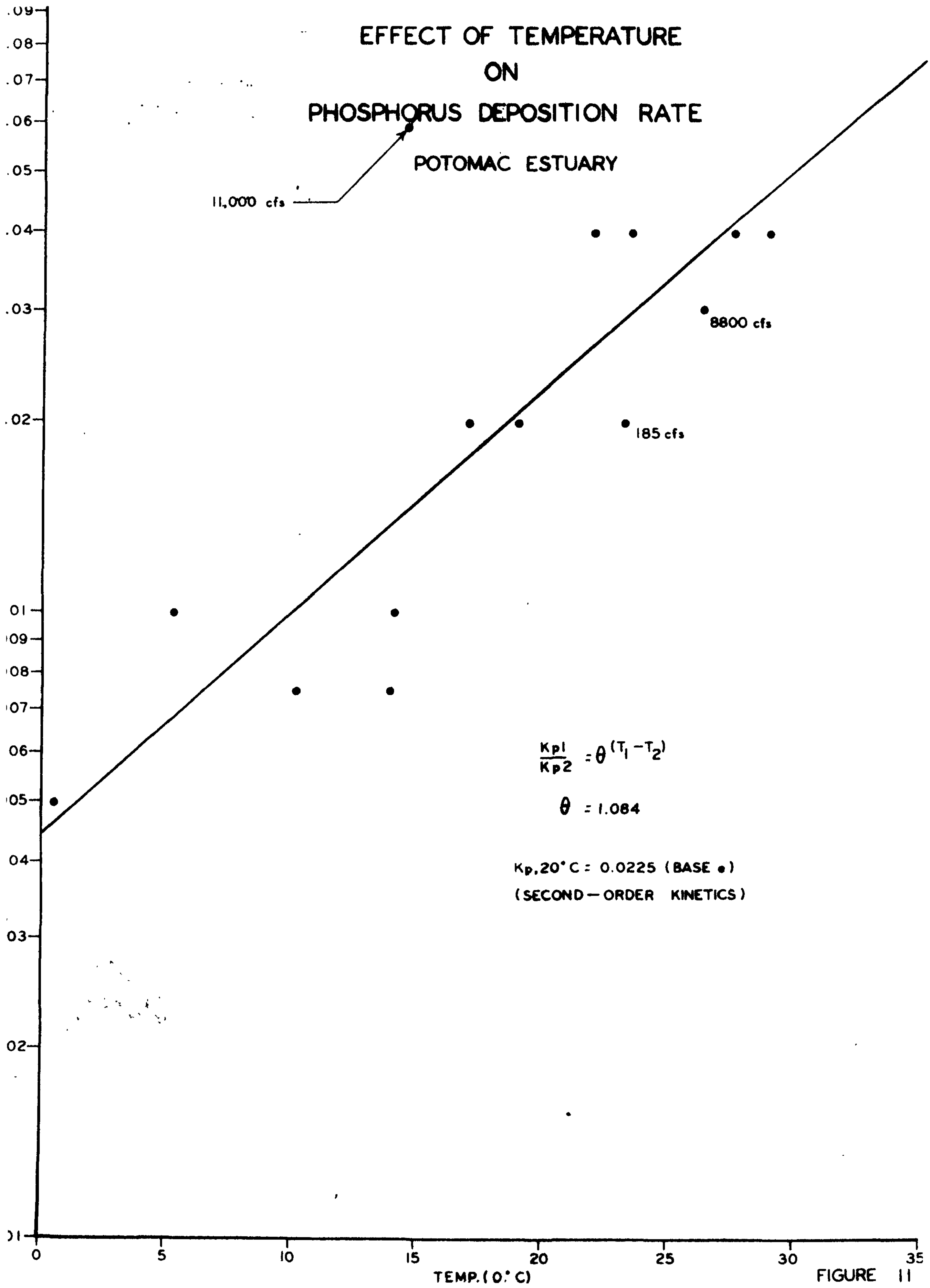

EFFECT OF TEMPERATURE
ON
PHOSPHORUS DEPOSITION RATE
POTOMAC ESTUARY
11,000 cfs
8800 cfs
185 cfs
$\frac{Kp1}{Kp2} = \theta^{(T_1 - T_2)}$
$\theta = 1.084$
Kp, 20° C = 0.0225 (BASE e)
(SECOND — ORDER KINETICS)
TEMP. (0.° C)
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
5
10
15
20
25
30
35

FIGURE 11

reactions: (1) chemical and biological decomposition of organic nitrogen to ammonia, (2) bacterial nitrification of ammonia to nitrite and nitrate, (3) phytoplankton utilization of ammonia, (4) phytoplankton utilization of nitrite and nitrate, (5) deposition of organic nitrogen, and (6) the death of the phytoplankton. With the area near Woodrow Wilson Bridge being light limited with respect to algal growths, the rate of phytoplankton utilization of ammonia appears to be less than that in the area near Indian Head.

For summer temperatures of 26°C to 29°C, first-order kinetic reaction rates have been established for the various processes given below:

Nitrification by bacteria	0.30 to 0.40
Nitrogen utilization by phytoplankton	0.07 to 0.09
Deposition of algal cells	0.005 to 0.05

The first two processes (nitrification and nitrogen utilization) including the reaction rates have been well established as shown in the predicted profiles (Figures 13 and 14). The effect of temperature on the nitrification process and the rate of nitrogen utilization by algal cells has also been formulated as shown in Figures 15 and 16.

Initial simulations indicate that the rate of recycling of nitrogen was not significant in the freshwater portions. As can be seen in Figures 13 and 14, there is a discontinuity in the nitrogen cycle at the point of saline intrusion. This discontinuity appears to be a result of the transformation from fresh to mesohaline organisms. It appears that the rate of decomposition of organic nitrogen is much slower than the rate of bacterial nitrification or the rate of nitrogen uptake by algal cells in that the predominant form of nitrogen in the middle and lower estuaries is organic.

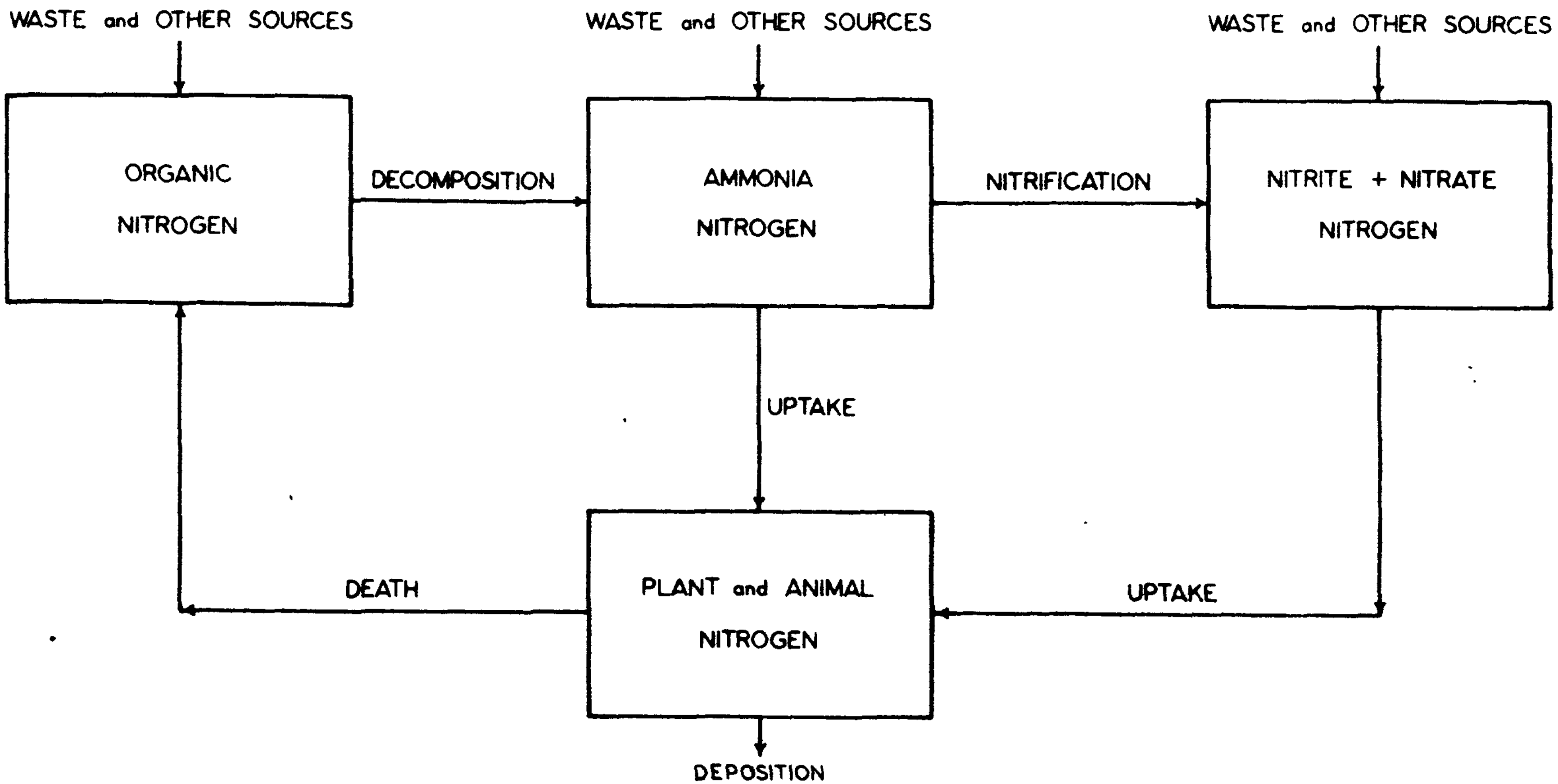
Table 2

DATA SUMMARY OF

ALGAL CHEMICAL COMPOSITION STUDIES

Potomac Estuary
June - October 1970

Nutrient	mg. of Nutrient / ug of Chlorophyll a	mg. of Nutrient / mg. of S. Solids
Carbon	0.045	0.331
Nitrogen	0.010	0.073
Phosphorus	0.001	0.006



SIMPLIFIED NITROGEN CYCLE

FIGURE 12

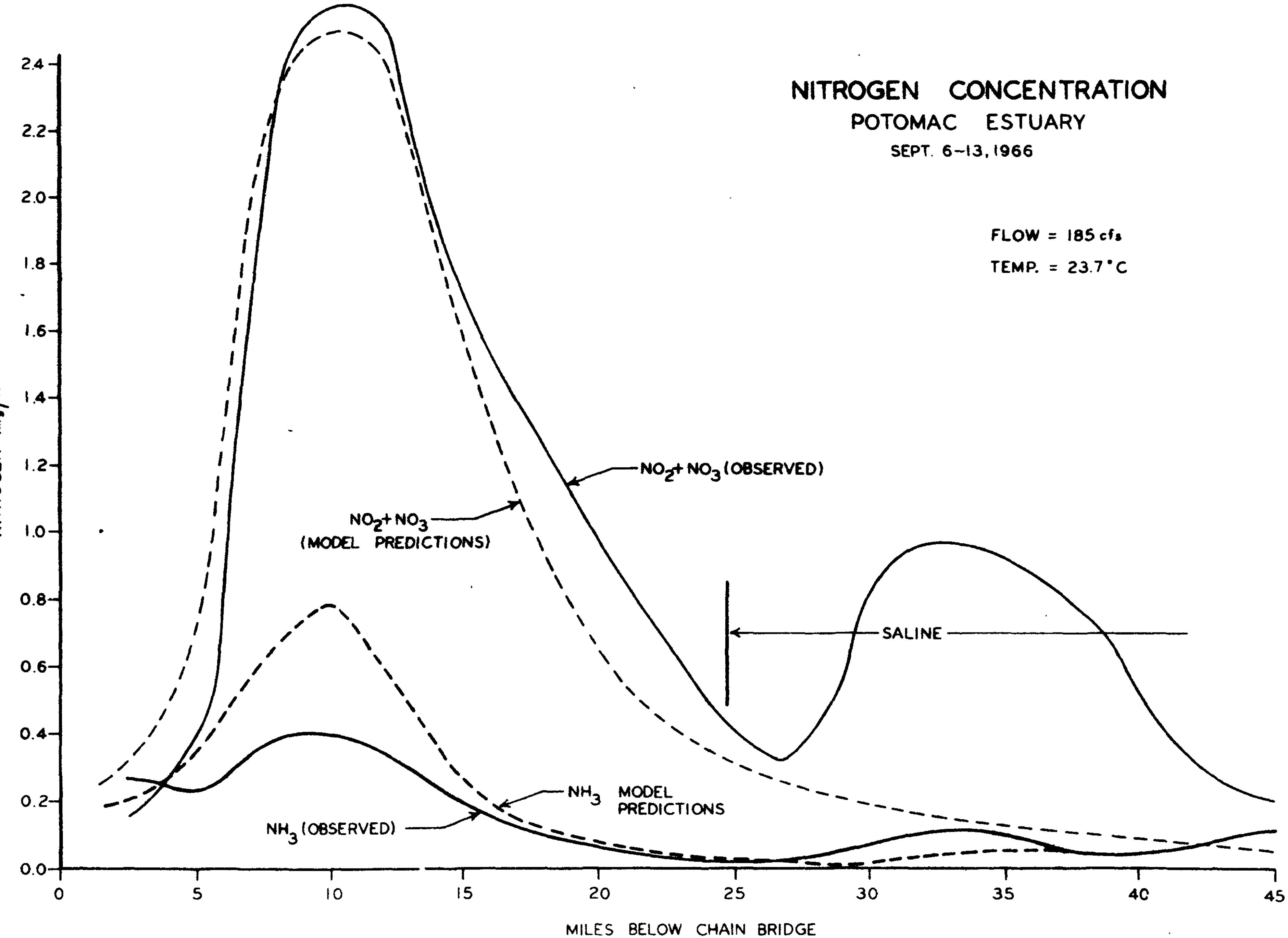

NITROGEN CONCENTRATION
POTOMAC ESTUARY
SEPT. 6-13, 1966
FLOW = 185 cfs
TEMP. = 23.7°C
$NO_2 + NO_3$ (OBSERVED)
$NO_2 + NO_3$
(MODEL PREDICTIONS)
SALINE
NH_3 MODEL
PREDICTIONS
NH_3 (OBSERVED)
NITROGEN (mg/l)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE 13

NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUGUST 19 – 22, 1968

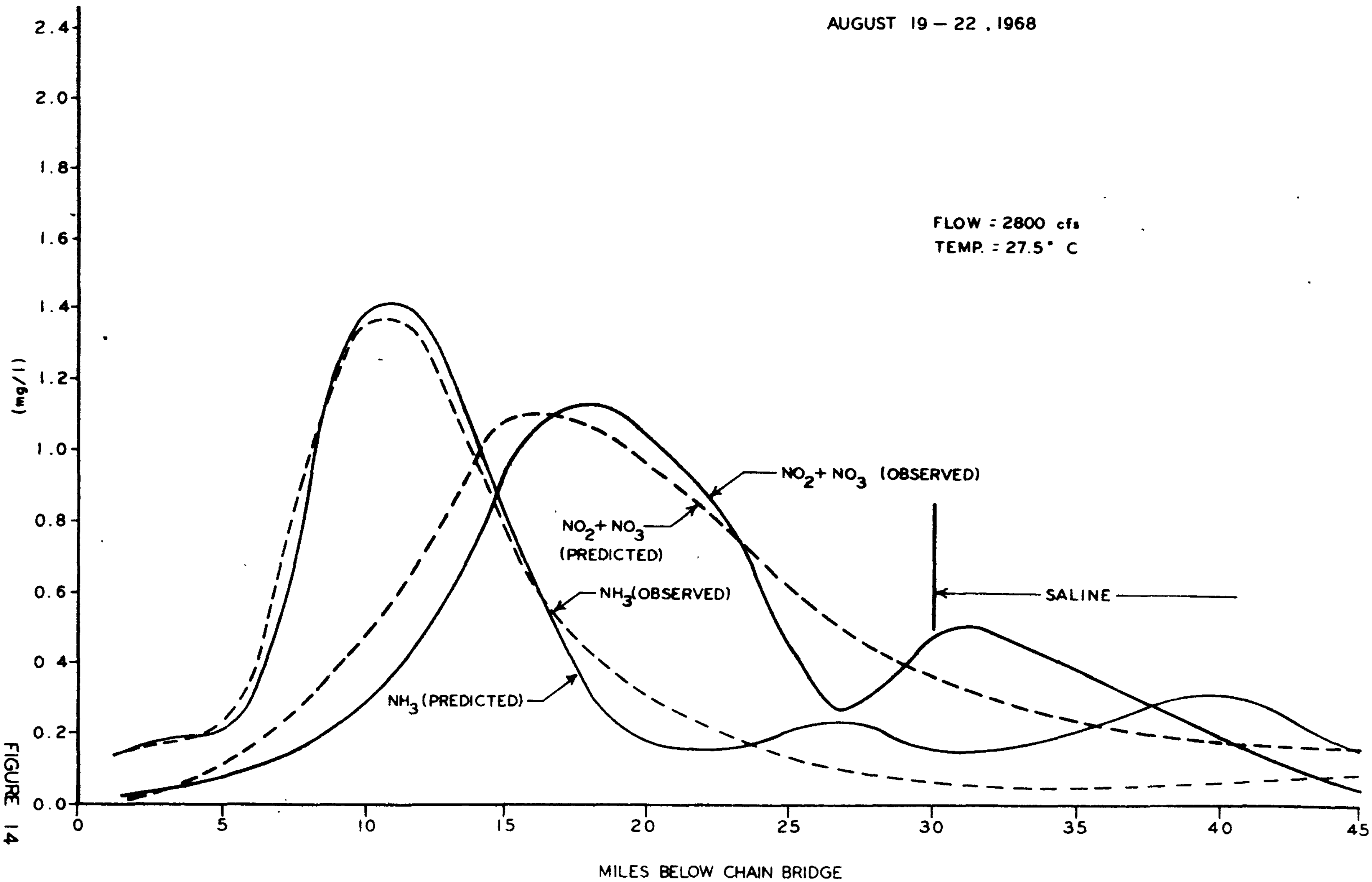
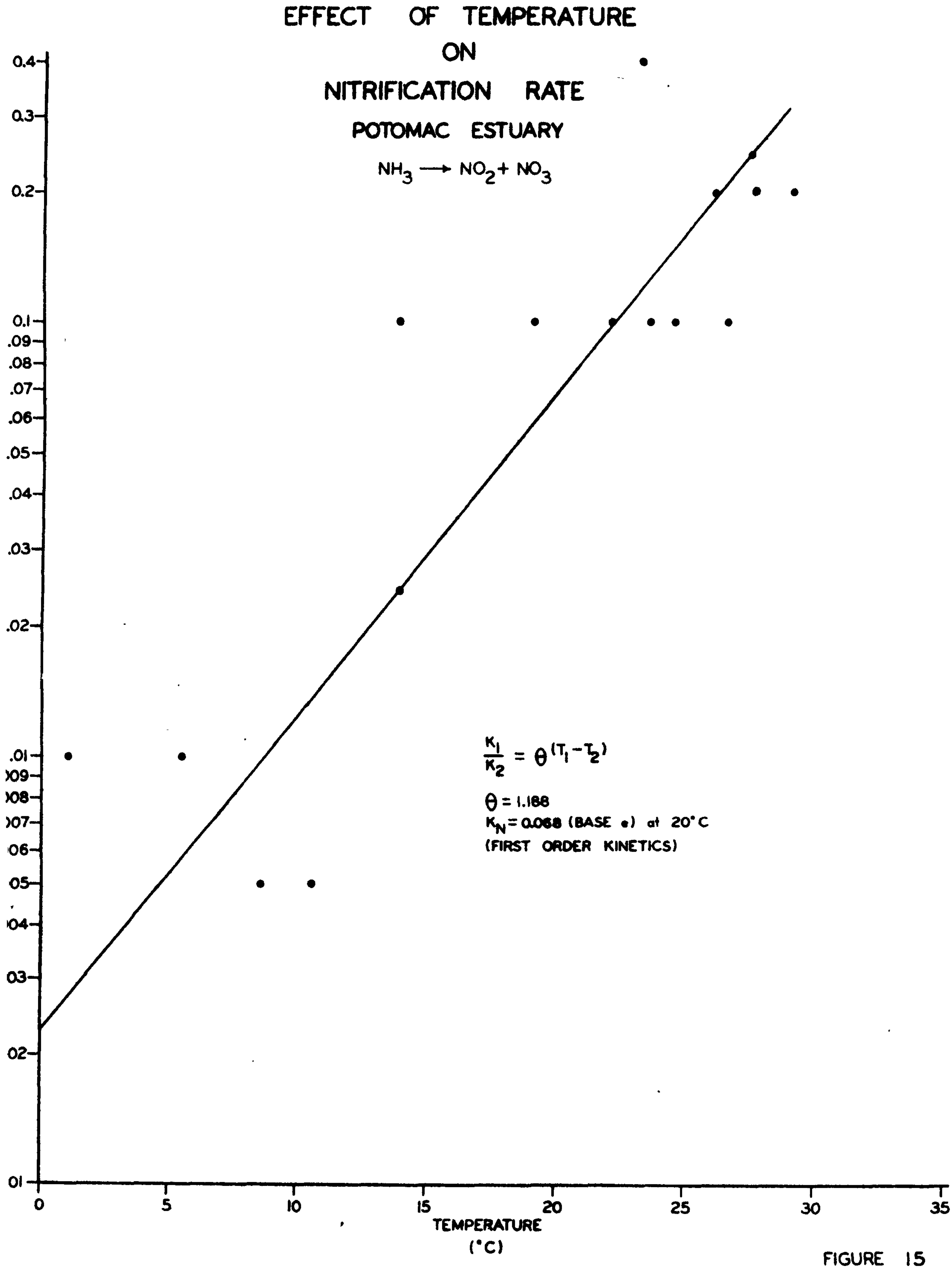


FIGURE 14



EFFECT OF TEMPERATURE
ON
NITRIFICATION RATE
POTOMAC ESTUARY
$NH_3 \longrightarrow NO_2 + NO_3$
$\frac{K_1}{K_2} = \theta^{(T_1 - T_2)}$
$\theta = 1.188$
$K_N = 0.068$ (BASE e) at 20°C
(FIRST ORDER KINETICS)
TEMPERATURE
(°C)

FIGURE 15

EFFECT OF TEMPERATURE ON RATE OF NITROGEN UTILIZATION BY ALGAE

POTOMAC ESTUARY

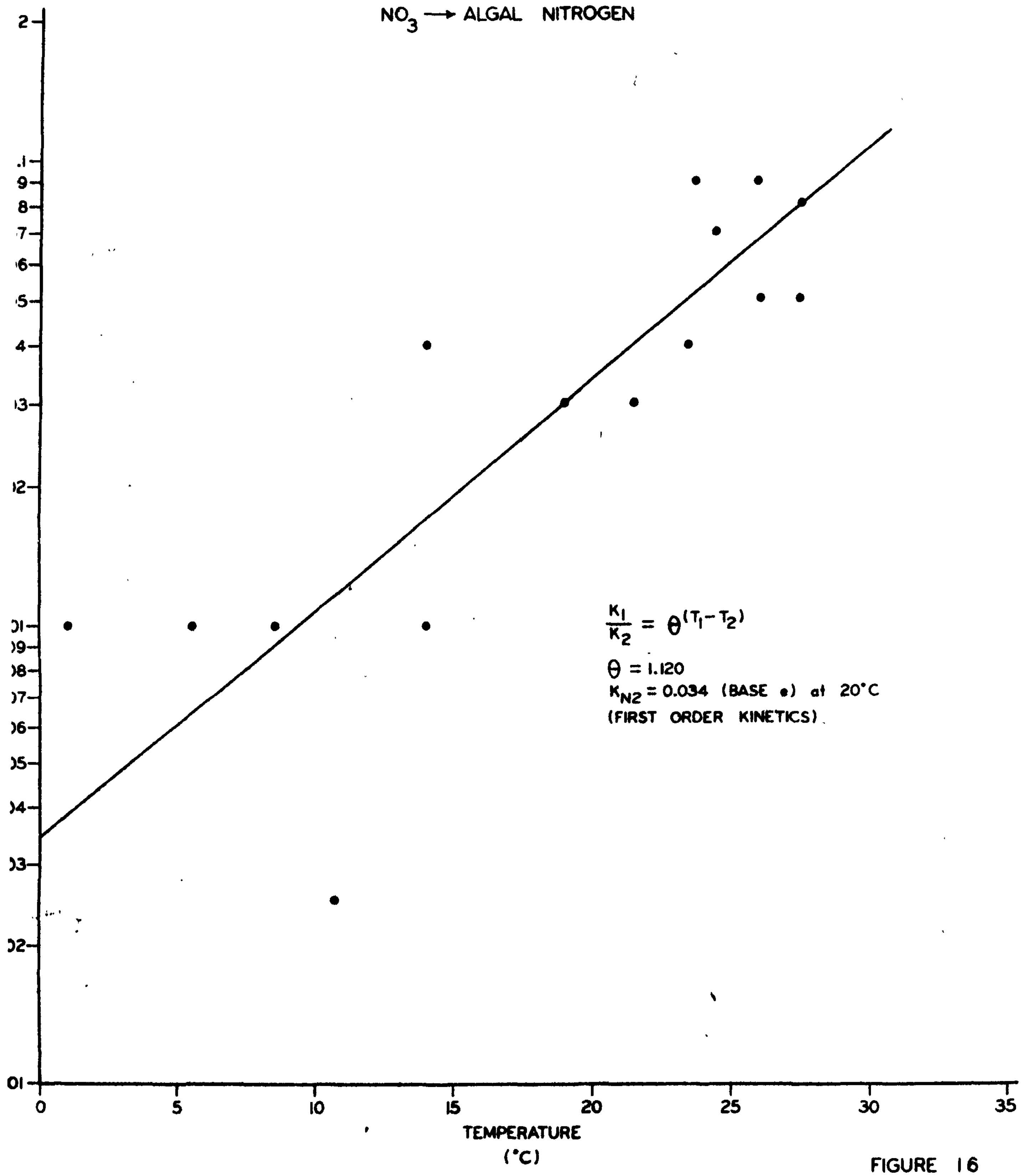


FIGURE 16

Using the weight ratio of nitrogen to chlorophyll a (Table 2) and the nitrogen model rates indicated above, the dynamic model was expanded to predict the concentration of chlorophyll a based on the utilization of inorganic nitrogen. In Figures 17 and 18, predicted profiles using the surrogate algal model and observed data are presented. The predicted maximum concentrations compare closely to the observed data in both distribution and magnitude. Eight other model predictions have been made and will be described fully in a report currently being prepared by CTSL.

A DO budget has been incorporated into the dynamic water quality model consisting of the following five linkages:

(1) Oxidation of carbonaceous matter,

(2) Oxidation of nitrogenous matter (ammonia and organic),

(3) Oxygen production and respiration of simulated algal standing crops based upon the nitrogen cycle,

(4) Benthic demand, and

(5) Reaeration from the atmosphere.

The model, which is also described in the CTSL report currently in preparation, has been verified for flow ranges from 212 to 8800 cfs. The average observed and predicted DO concentrations for the periods of September 22, 1968, and August 12-19, 1969, (Figures 19 and 20 respectively) demonstrate that the model can predict DO responses over a wide range of freshwater inflows.

CHLOROPHYLL CONCENTRATION
POTOMAC ESTUARY
SEPTEMBER 6-7, 1966

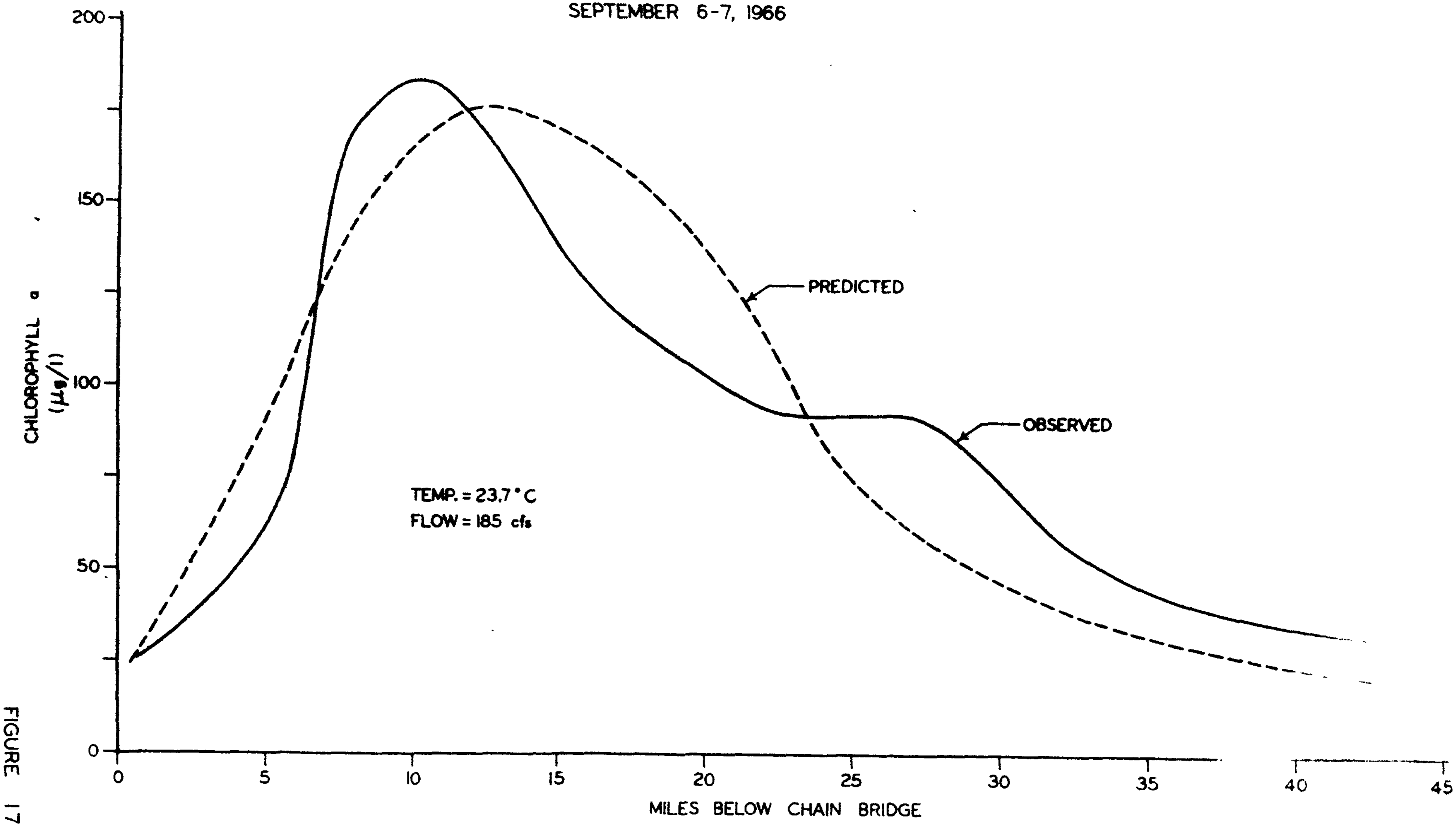


FIGURE 17

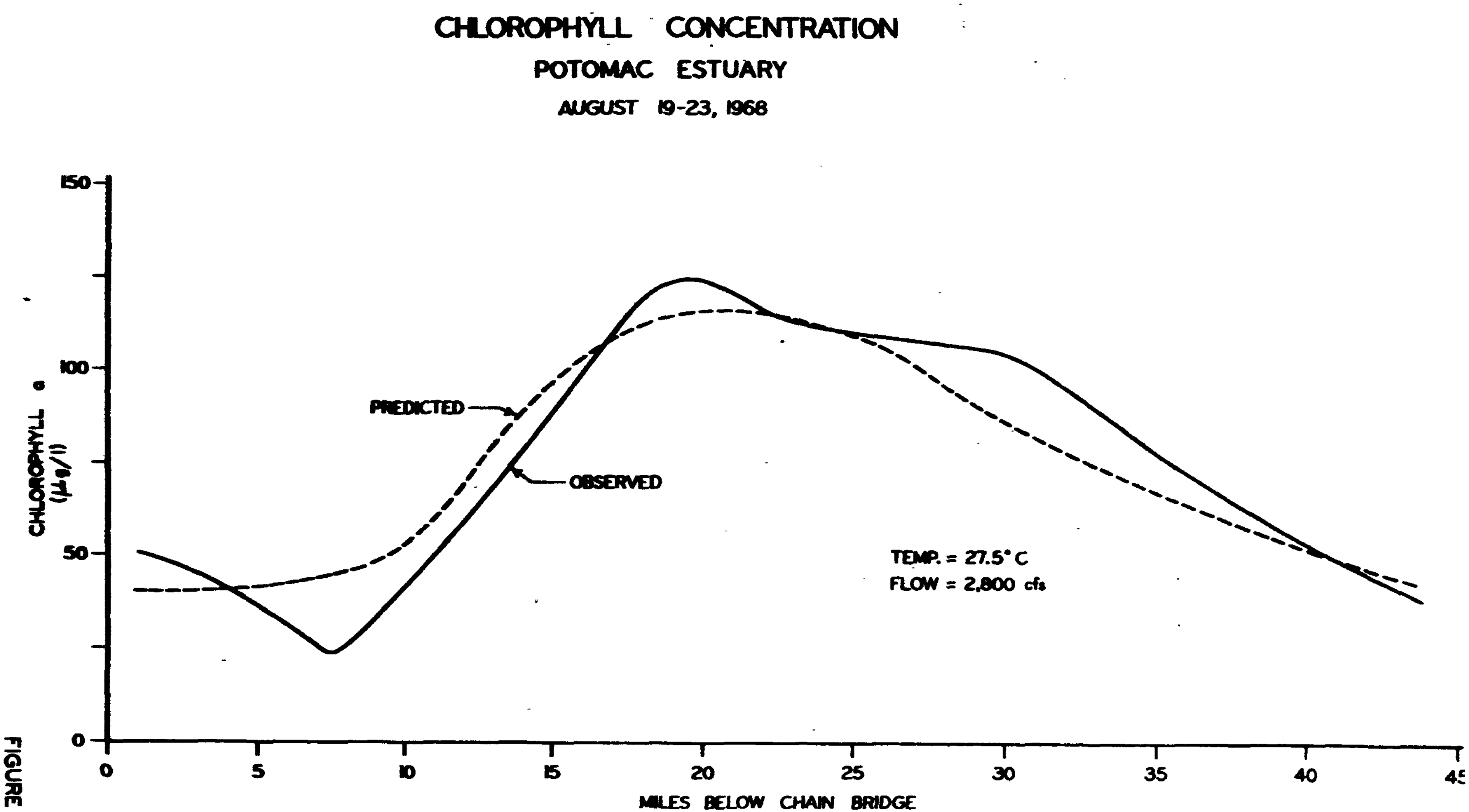

CHLOROPHYLL CONCENTRATION
POTOMAC ESTUARY
AUGUST 19-23, 1968
CHLOROPHYLL a (μg/l)
150
100
50
0
PREDICTED
OBSERVED
TEMP. = 27.5° C
FLOW = 2,800 cfs
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE 18

DO CONCENTRATIONS
POTOMAC ESTUARY
SEPT. 22, 1968

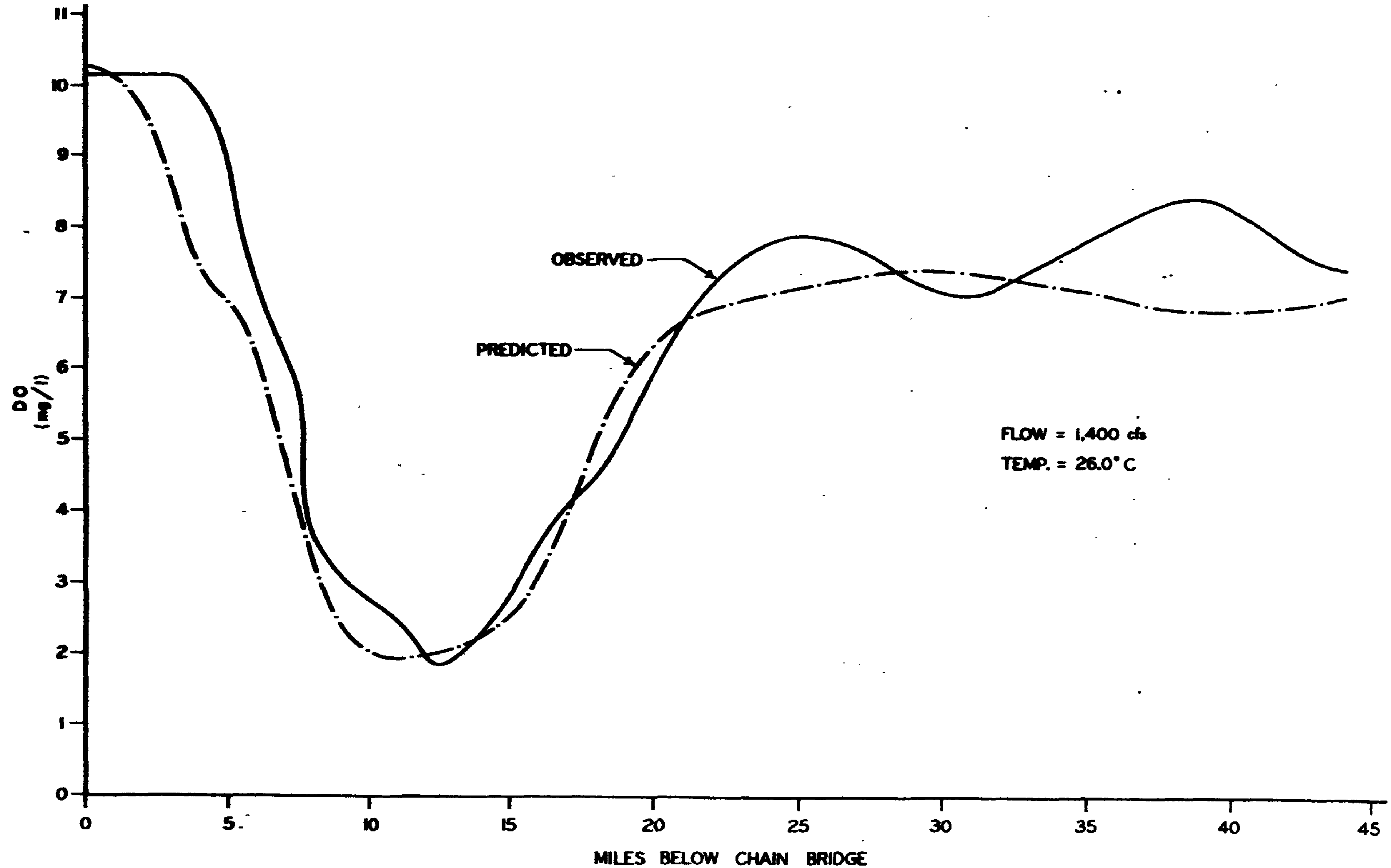


FIGURE 19

DO CONCENTRATIONS

POTOMAC ESTUARY

AUG. 12-17, 1969

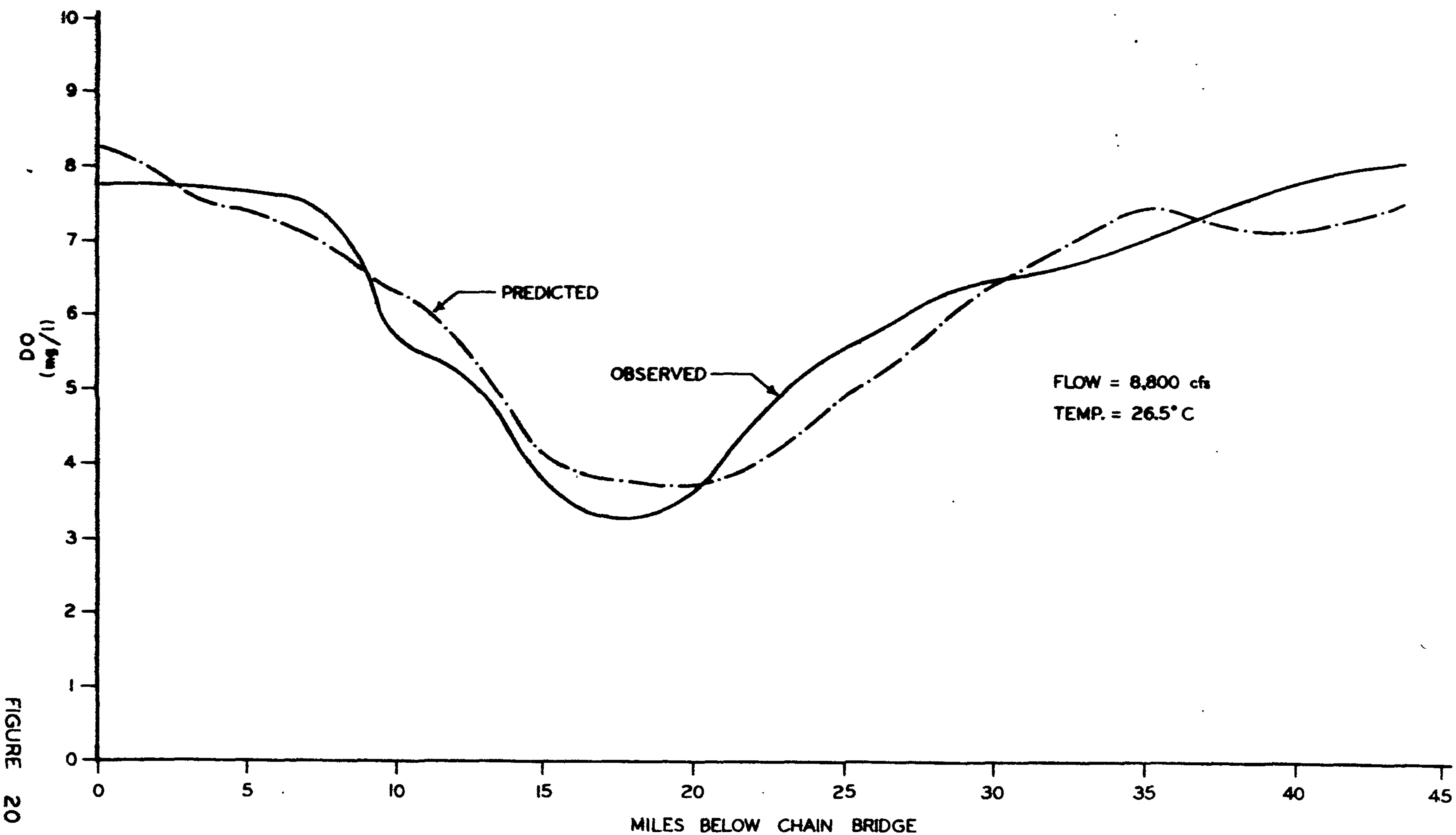


FIGURE 20

The basic coefficients used in the DO budget model were:

Process	Rate (base e) at 20°C	Temperature Coefficient θ (T1 - T20)
Carbonaceous oxidation	0.230	1.047
Nitrogenous oxidation	0.068	1.188
Algal utilization of nitrogen	0.034	1.120
Reaeration from the atmosphere	*	1.021

The remaining processes in the DO budget are given below:

Algal oxygen production rate = 0.012 mg O_2/hr/ug chlorophyll a

Algal respiration rate = 0.008 mg O_2/hr/ug chlorophyll a

Euphotic zone = 2 feet

Respiration depth = full depth of water column

Algal oxygen production period = 12 hours

Algal respiration period = 24 hours

Benthic demand rate = 1.0 gr O_2/day sq meter

The five linkages provide a mechanism for not only investigating the effects of the various components on the dissolved oxygen budget but also for establishing the algal standing crop limits and nutrient criteria.

* Based on a velocity and depth formulation

EUTROPHICATION CONTROL

For purposes of water quality management, the upper Potomac Estuary may be considered eutrophic when undesired standing crops become the predominant plant life as is now occurring with the nuisance blue-green alga species. The major objectives for controlling the blue-green algal standing crop in the upper estuary are fourfold:

1. To reduce the dissolved oxygen (DO) depression caused by respiration and the decay of algal growths especially in waters over 10 feet in depth. At times, DO depressions of more than 3.0 mg/l below saturation occur even during daylight hours.

2. To minimize the increase of ultimate oxygen demand which is a result of the conversion of inorganic carbon and nitrogen to oxidizable organic compounds by algal cells. Currently, more UOD is added to the upper Potomac Estuary in the summer months as a result of algal growth than from wastewater discharges.

3. To enhance the aesthetic conditions in the upper estuary. Large green mats develop during the months of June through October and create objectionable odors, clog marinas, cover beaches and shorelines, and in general reduce the potential of the estuary for recreational purposes such as fishing, boating, and water skiing.

4. To reduce any potential toxin problem and objectionable taste and odors caused by blue-green algae if the upper estuary is to be used as a supplemental water supply.

To aid in defining an algal standing crop limit, a subjective analysis using chlorophyll concentrations was developed incorporating conditions having possible effects on water quality. Four major interferences are offered in this analysis (Table 3) including the desired reduction in the chlorophyll standing crop for each of the parameters.

The desired maximum limit of 0.5 mg/1 DO below saturation was set to allow for assimilation of waste discharges and naturally occurring oxygen demanding pollutants. To minimize the effects of increased organic loads and sludge deposits caused by algal growths, an upper limit of 5.0 mg/1 of total oxygen demand is proposed.

Of the four interferences, the most stringent reduction percentage is in the control of growths to prevent nuisance conditions. From the above analysis, a 75 to 90 percent reduction in chlorophyll concentration will be required in the Potomac Estuary, or chlorophyll levels of approximately 25 ug/1.

Table 3

SUBJECTIVE ANALYSIS OF ALGAL CONTROL REQUIREMENTS

Water Quality or Water Use Interference	Indications of Interference	Magnitude of Current Interference*	Desired Limit	Required Percentage Reduction of Current Standing Crop
DO Depression Caused by Decay and Respiration	mg/1 of DO Below Saturation	1.5 to 3.0 mg/1	0.5 mg/1	65-85
Increase in Total Oxygen Demanding Load	mg/1 of Increase in Ultimate BOD	15 to 30 mg/1	5.0 mg/1	65-80
Recreational & Aesthetic Nuisance Conditions	Chlorophyll Concentration	100 to >250 ug/1	25 ug/1**	75-90
Toxins, Taste, & Odor	Undefined	Unknown	Unknown	Unknown

* Under nuisance bloom conditions, chlorophyll concentrations range from 100 to >250 ug/1

** Average over entire water column

ESTABLISHMENT OF NUTRIENT CRITERIA

Various investigators studying algal growth requirements have discussed the concentrations of nitrogen and phosphorus needed to stimulate algal blooms. In a recent study of the Occoquan Reservoir, located on a tributary of the Potomac Estuary, Sawyer [27] recommended limits of inorganic nitrogen and inorganic phosphorus of 0.35 and 0.02, respectively. Mackenthun [24] cites data indicating upper limits of inorganic nitrogen at 0.3 mg/l and inorganic phosphorus at 0.01 mg/l at the start of the growing season to prevent blooms. FWQA's Committee on Water Quality Criteria recommends an upper limit of 0.05 mg/l of total phosphorus for estuarine waters [9]. No recommendations for inorganic nitrogen were presented other than that the naturally occurring ratio of nitrogen to phosphorus should not be radically changed.

Pritchard [25], studying the Chesapeake Bay and its tributaries, suggests that if total phosphorus concentrations in estuarine waters are below 0.03 mg/l, biologically healthy conditions will be maintained. Pritchard suggested no limit for nitrogen. Jaworski et al [16], reviewing historical data for the upper Potomac Estuary, indicated that if the concentrations of inorganic phosphorus and inorganic nitrogen were at or above 0.1 and 0.5, respectively, algal blooms of approximately 50 ug/l would result. Chlorophyll a of 50 ug/l or over was considered indicative of excessive algal growths. Studies of the James River Estuary, a sister estuary to the Potomac, by Brehmer and Haltiwanger [4] indicate that nitrogen appears to be the rate limiting nutrient.

Recently, the management of carbon in controlling algal blooms has been suggested by Kuentzel [20] and Lange [21]. Studies by Kerr et al [19] also suggest that inorganic carbon is apparently directly responsible for increased algal populations in waters that they have studied. The Kerr studies indicate that the addition of nitrogen and phosphorus indirectly increases algal growth by stimulating growth of large heterotrophic bacterial populations. No criteria for nitrogen, phosphorus, or carbon were indicated by Kerr.

In addition to the data reviewed above and that cited by numerous investigators not reported, six methods were used to develop the nutrient requirements for the Potomac Estuary. The six were:

1. Algal chemical composition analyses,
2. Analysis of the nutrient data on an annual cycle and profile basis,
3. Nutrient bioassay,
4. Nutrient and algal mathematical modeling,
5. Comparison with an estuary currently not eutrophic, and
6. Review of historical nutrient and ecological trends in the Potomac Estuary.

1. Algal Composition Analysis

An analysis of the chemical composition of blue-green algae in the Potomac was made during the summer months of 1970. Summary data in terms of micrograms of chlorophyll a and grams of suspended solids are presented in Table 2.

Based on data in Table 2, an algal bloom of 100 ug/l chlorophyll a contains the following:

Parameter	Concentration
S. Solids	14.2 mg/l
Carbon	4.5 mg/l
Nitrogen	1.0 mg/l
Phosphorus	0.1 mg/l

For the Potomac Estuary, which can be considered a slow-moving continuous culture system, concentrations equal to or less than 1.12 mg/l of carbon, 0.25 mg/l of nitrogen, and .025 mg/l of phosphorus would be theoretically required to maintain a 25 ug/l chlorophyll a level. Upper limits of nutrients using this method should be considered minimal concentrations, since no loss to sediments is assumed.

2. Analysis of Data on an Annual Cycle and Longitudinal Profile Basis

Nutrients not removed from the waters are still capable of supporting the growth of algae and other organisms if there is an adequate supply of the remaining nutrients in the smallest quantity needed for growth. Using the disappearance of a specific nutrient both seasonally and along longitudinal profiles, insight can be gained as to the possibility that the nutrient is limiting algal growth. This assumes that other environmental factors do not restrict growth.

From Indian Head to Smith Point, which is the area of pronounced algal growth, there is over 0.15 mg/l of phosphorus in the waters even under maximum bloom conditions. (In Figure 2, inorganic phosphorus concentrations are given.) Data indicated that in the upper and middle reaches of the Potomac, phosphorus is in excess and thus is not rate limiting. In the lower reach near Piney Point, the total phosphorus concentration is often 0.04 mg/l and thus phosphorus could be limiting for this reach.

When the NO_2 + NO_3 and NH_3 concentrations shown in Figures 3 and 4 are reviewed, it is evident that practically all of the inorganic nitrogen had disappeared in the reach between the Smith Point and Route 301 Bridge stations by late July 1969 and by mid-August 1970. This depletion occurred even though the summers of 1969 and 1970 had relatively high flows. Based upon the disappearance of inorganic nitrogen, it appears that nitrogen becomes a major factor in limiting algal growth in the middle and lower estuary.

To determine if carbon was limiting algal growth in the bloom area of the Potomac Estuary, a review of historical alkalinity data was made. Total and inorganic carbon analyses were also conducted during the latter part of 1969 and throughout 1970.

During August and September 1970, river flows were low with air temperatures reaching 95°F during most of the days in September. Dense algal blooms extended from Hains Point to Smith Point. Carbon concentrations obtained during a sampling cruise on September 20, 1970, were as follows:

Station	Organic Carbon (mg/l)	Inorganic Carbon (mg/l)
Hains Point	7.2	12.2
Wilson Bridge	10.2	15.4
Piscataway	10.5	8.6
Indian Head	10.5	15.0
Smith Point	8.5	7.7
Route 301 Bridge	6.1	6.1

The above data obtained during the mid-day hours of September 20, 1970, indicate that large quantities of inorganic carbon were available for algal growth even during periods of dense blooms. The 1969 data, historical alkalinity data, and other 1970 cruise data also substantiate the September 1970 findings.

3. Bioassay Studies

To determine further what nutrients were limiting algal growth in the Potomac, bioassay tests as developed by Fitzgerald [11] [12] were employed. Tests for both phosphorus and nitrogen were conducted in the Potomac from Piscataway Creek to Route 301 Bridge for the period June through October 1970.

Using the rate of ammonia absorption by algal growths, it is possible to determine if the algal cells have surplus nitrogen or if they are nitrogen starved. Tests made during June and early July indicate that ammonia was either released or absorbed at a low rate in the range of 10^{-6} mg N/hr/ug chlorophyll a. The cells had adequate nitrogen available for growth as was also indicated by the high nitrate concentration in the water, especially at the upper stations above Indian Head.

Tests for the latter part of July and August exhibited rates of absorption that were approximately twice as high for the Indian Head station as for the lower station at Maryland Point. In addition, when compared to the earlier data, the absorption rates were considerably higher ranging in the area of 10^{-4} mg N/hr/ug chlorophyll a.

Bioassay tests for October 13, 1970, as tabulated below, show a significant increase in ammonia absorption rates between the Piscataway station and the Smith Point station farther downstream.

Station	NH_3 In Water (mg/l)	$NO_2 + NO_3$ In Water (mg/l)	Ammonia Nitrogen Absorbed (mg N/hr/ug chloro)
Piscataway	.110	2.560	+ 6.0×10^{-5}
Indian Head	.150	.684	+ 6.0×10^{-5}
Possum Point	.001	.220	+ 2.3×10^{-4}
Smith Point	.001	.150	+ 1.3×10^{-4}

The higher rates of ammonia absorption for Possum and Smith Points and the low concentration of inorganic nitrogen indicates that this reach of the Potomac is becoming nitrogen limited.

Two tests, an extraction procedure and an enzymatic analysis [12], were used to determine if algal growth was phosphorus limited. The phosphorus extraction bioassay studies indicated very little difference summer

30 m²

betwe

(Figu

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loe

but

These criteria [illegible] removal for enhancement of [illegible] eutrophication trends [illegible] should also create an environment [illegible] succession which has occurred [illegible] occurred in the lakes [illegible] Washington [illegible] when wastewater [illegible]

b. [illegible]

Studies [illegible] sharp transition from freshwater [illegible] corresponding to rapid in areas [illegible] the [illegible]-mile reach at Maryland Point [illegible] phytoplankton and zooplankton population [illegible] are less than two parts per thousand. [illegible] dominate the lower end of the transition [illegible] salinities in summer approximating [illegible]

Based on [illegible] it appears that the growth of massive [illegible] apparently restricted to the freshwater portions. In the [illegible] environment, dinoflagellates were often encountered [illegible]

These observations [illegible] in estuarine water quality management:

(1) Fairly [illegible] may be identified within a given reach of the estuary, [illegible] given stress,

(2) There is insufficient [illegible] data to generalize on nutrient parameters [illegible] portions of a given estuary.

Therefore, at the present [illegible] nutrient criteria have been established for the [illegible] Potomac Estuary.

WASTEWATER TREATMENT REQUIREMENTS

Under controlled conditions, as reported by various investigators, reductions in the standing crop of algae can be achieved by the management of either carbon, nitrogen, or phosphorus or by a combination of these basic nutrients. The decision as to which nutrient or nutrients in a natural system should be controlled by removal from point sources may depend upon many factors including the four listed below:

1. Level of algal reduction required to minimize adverse effects on water quality,

2. Minimum nutrient requirements to maintain a given algal standing crop,

3. Controllability and mobility of a given nutrient within the system, and

4. The overall water quality management needs, such as DO enhancement, eutrophication reversal, and reduction of potentially toxic matter including heavy metals.

In establishing the overall wastewater management program for the Potomac Estuary, the need for a high degree of carbonaceous and nitrogenous UOD removal was determined along with the need for a 75-90 percent reduction in algal standing crop. Since carbon can only be controlled to a maximum of 55 percent, excluding any contribution from air-water or water-mud interfaces, control of either nitrogen or phosphorus or both is required. To provide for algal control, maximum concentration limits for both nitrogen and phosphorus were adopted.

Limits for both were incorporated for the following reasons:

(1) Since the flow of the Potomac River is very flashy, neither phosphorus nor nitrogen can be controlled throughout the estuary at all times. To reduce eutrophication in the entire estuary for years having average or above average flow conditions, phosphorus control appears to be more feasible. However, in the middle and upper estuary during low-flow years, nitrogen control appears to be more effective. This is because the nitrogen criterion for restricting algal growth is ten times that for phosphorus (0.30 versus 0.03 mg/l) while the nitrogen loading from the wastewater treatment facilities is 2.4 times that of phosphorus (60,000 versus 24,000 lbs/day). Considering only the magnitude of the limiting nutrient concentrations and the magnitude of the percentage of the wastewater contribution, this results in more than a fourfold advantage in removing nitrogen over that of phosphorus.

(2) Various investigators report that increases in nitrogen and/or phosphorus can increase heterotrophic activity which in turn stimulates algal growth, and

(3) There is compatibility between wastewater treatment requirements for dissolved oxygen enhancement and eutrophication control.

Compatibility of treatment requirements is probably one of the most important considerations of the four factors influencing the selection of wastewater treatment unit processes. For example, to maintain the dissolved oxygen standard in the upper estuary under summer conditions, a high degree of carbonaceous and nitrogenous oxygen demand removal is required, whereas the control of algal standing crops is predicated on phosphorus and nitrogen removal. To obtain a high degree of carbonaceous oxygen demand removal, a chemical coagulation unit process is usually required beyond secondary treatment. This unit process will also remove a high percentage of phosphorus. The removal of the nitrogenous demand can be satisfied by one of two methods: (1) by converting the unoxidized nitrogen to nitrates (commonly called nitrification), or (2) by removal of nitrogen completely. If a unit process such as biological nitrification-denitrification is employed, both the DO and algal requirements for nitrogen can be met.

Thus with proper selection of wastewater treatment unit processes, it is feasible not only to enhance the DO by removing the carbonaceous and nitrogenous UOD but also to reduce nuisance algal growth by removing nutrients.

A WATER QUALITY MANAGEMENT PROGRAM

The conferees of the Potomac River-Washington Metropolitan Area Enforcement Conference agreed on May 8, 1969, to limit the amount of UOD, phosphorus, and nitrogen which could be discharged into the upper estuary from wastewater treatment facilities. The water quality management program currently being developed recognizes a need not only for high degrees of wastewater treatment for the removal of carbonaceous and nitrogenous UOD but also a need for the control of eutrophication.

Segmenting the upper estuary into three 15-mile zones (Figure 21), maximum lbs/day loadings were established for Zone I equivalent to 96 percent removal of BOD_5, 96 percent of phosphorus, and 85 percent of nitrogen. These percent removals were also adopted for discharges in Zone II until firmer loadings could be developed.

Since May 1969, more detailed loadings have been developed and presented to the conference in the December 1970 progress meeting [18]. The program calls for the construction of advanced wastewater treatment facilities by 1977 capable of removing the above designated percentages of carbon, nitrogen, and phosphorus, with possible advancement of the construction deadline to December 1974.

Present worth cost of the additional wastewater treatment required, including operation, maintenance, and amortization for the time period 1970 to 2020 has been estimated to be $1.2 billion with a total average annual cost of $54.8 million. The unit processes assumed include

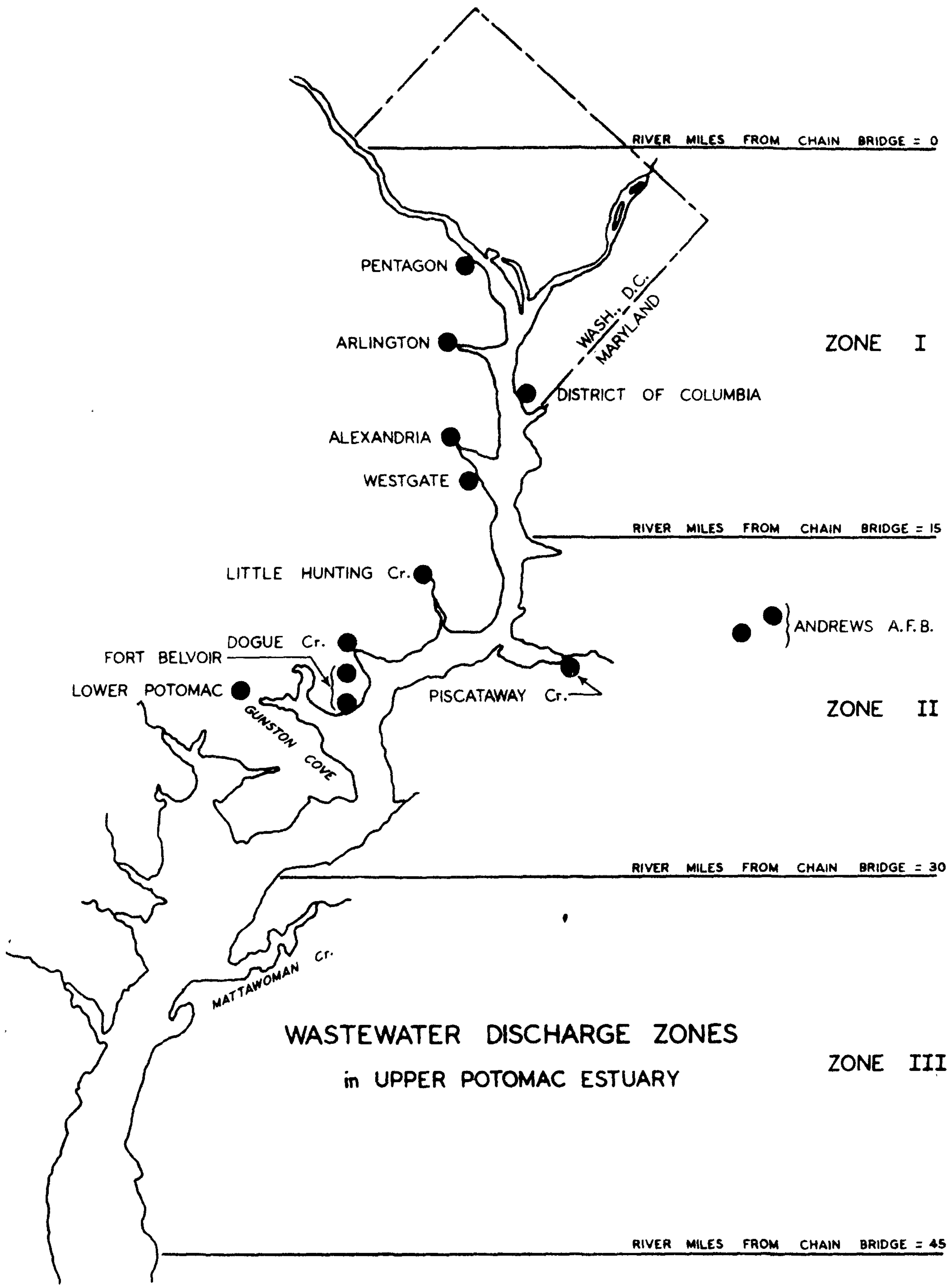
RIVER MILES FROM CHAIN BRIDGE = 0
PENTAGON
WASH., D.C.
MARYLAND
ZONE I
ARLINGTON
DISTRICT OF COLUMBIA
ALEXANDRIA
WESTGATE
RIVER MILES FROM CHAIN BRIDGE = 15
LITTLE HUNTING Cr.
ANDREWS A.F.B.
DOGUE Cr.
FORT BELVOIR
LOWER POTOMAC
PISCATAWAY Cr.
GUNSTON COVE
ZONE II
RIVER MILES FROM CHAIN BRIDGE = 30
MATTAWOMAN Cr.
WASTEWATER DISCHARGE ZONES
in UPPER POTOMAC ESTUARY
ZONE III
RIVER MILES FROM CHAIN BRIDGE = 45

FIGURE 21

activated sludge, biological nitrification-denitrification, lime clarification, filtration, effluent aeration and chlorination. On a per capita basis, the cost of the wastewater removal program is estimated to be approximately $13.50 to $18.30/person/year.

The program being developed will not only enhance the water quality of the estuary to meet minimum designated standards but will render it a feasible source of municipal water supply. Studies indicate that either indirect or direct reuse of renovated wastewater is a viable alternative in meeting the water supply needs for the Washington, D. C. Metropolitan Area [15] [17].

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