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The Chesapeake Bay: A Study of Present and Furture Water Quality and Its Ecological Effects Volume I: Analysis and Projection of Water Quality

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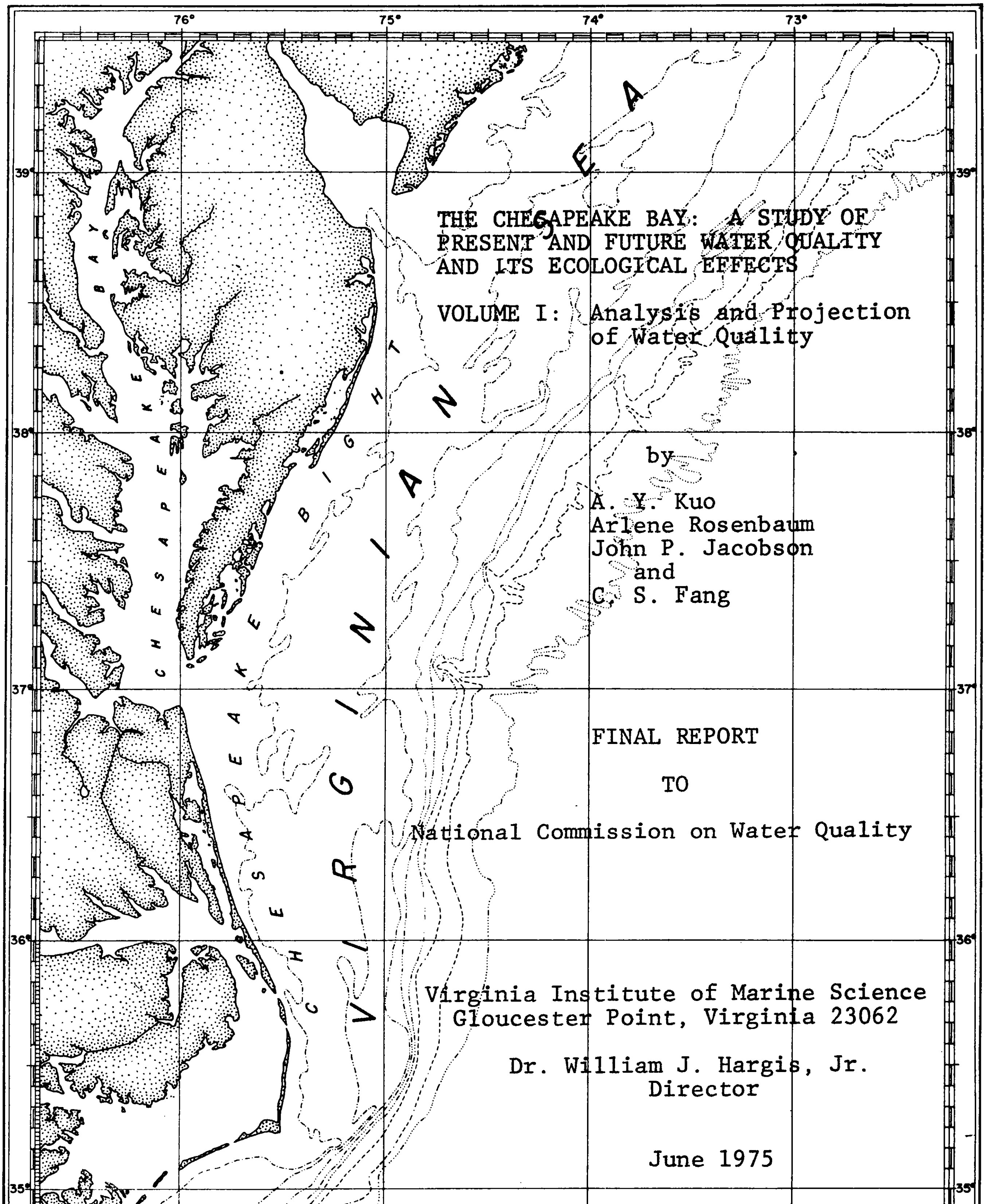

THE CHESAPEAKE BAY: A STUDY OF PRESENT AND FUTURE WATER QUALITY AND ITS ECOLOGICAL EFFECTS

VOLUME I: Analysis and Projection of Water Quality

by

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Arlene Rosenbaum
John P. Jacobson
and
C. S. Fang

FINAL REPORT

TO

National Commission on Water Quality

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

Dr. William J. Hargis, Jr.
Director

June 1975

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SUMMARY

This study, prepared for the National Commission on Water Quality, is an analysis of the present and future water quality in the Chesapeake Bay from the Susquehanna River at Conowingo, Md. to the Atlantic Ocean. The objectives addressed in this volume of the study are

1.) Description of the present conditions of water quality and water quantity with respect to temperature, salinity, nutrients and dissolved oxygen.

and 2.) Projection of future water quality conditions associated with the achievement of requirements and goals of the Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500, 86 Stat. 816.

The assessment of present and future biological and ecological conditions is addressed in Volume II.

A. General Setting

Chesapeake Bay is located in the States of Maryland and Virginia. It extends approximately north-south along the 76°10'W longitude from the mouth of the Susquehanna River (39°30.3'N latitude) to the Virginia Capes (37°N latitude) (See Figure II-1). The Bay proper is contained in subareas 206 and 208 as defined by the Water Resources Council.

Chesapeake Bay is the largest estuary on the Atlantic coast of the United States and one of the largest estuaries in the world. The Bay is approximately 289 km

(156 naut. mi.) long with a mean width of 22.4 km. (12.1 naut. mi.) and a maximum width of 47.6 km (25.7 naut. mi.). The mean depth is 8.05 m (26.4 ft.). The maximum depth is 53 m (174 ft.) at Blood Point Light, about 1/3 of the distance from the head of the Bay to the mouth.

Water movement in the Bay is governed by freshwater runoff from the drainage basin, tidal wave propagation from the mouth, and gravitational circulation resulting from a density gradient which is mainly a function of salinity distribution. Occasionally the circulation pattern is significantly altered by meteorological conditions, producing wind-driven currents and storm surges.

Several major municipalities are located on or near Chesapeake Bay, including Baltimore in Maryland, and Virginia Beach, Norfolk, Hampton and Newport News in Virginia. Other major municipalities found along tributaries of the Western Shore of the Bay are Washington, D. C. (Potomac River), Richmond (James River), Portsmouth (James River), and Chesapeake (James River).

The present population of the region-about 8 million-is expected to double by the year 2020. Four economic sectors account for the majority of the available jobs in the region: services, wholesale and retail trade, manufacturing, and public administration. In addition, in the counties immediately adjacent to the Bay proper, there is significant employment in agriculture, forestry , fisheries, construction, armed forces, transportation, communication and utilities, finance, insurance and real estate, and mining. Several of these latter sources of employment may have a large impact on water and land resources. Erosion and siltation are often associated with agriculture, construction and mining operations. Nutrients placed on the land during farming operations are often added to the Bay waters with land runoff.

The Chesapeake Bay is a major center for commercial fishing operations with total landings for 1971 within Chesapeake Bay of 445.3 million pounds worth 34.2 million dollars. While 85% of the catch (by weight) is landed in Virginia, the dollar value of Virginia landings is slightly under 50% of that for the entire Bay. The entire Bay and its tributaries are utilized in the fishery. The lower portions of tributaries, not the Bay proper, are the major fishing areas for shellfish and some fin fishes. The Bay system also supports a major recreational fishery, and boating and associated water sports other than fishing (water skiing, sailing, racing, etc.) occur throughout the Bay.

The Bay is also an important transportation route with port facilities at Baltimore and Hampton Roads. Small port facilities are found elsewhere around the Bay, sometimes associated with specific industrial plants.

B. Present Conditions

1. Water Quantity

The Chesapeake Bay drains portions of six states, Virginia, Maryland, Delaware, Pennsylvania, New York and

West Virginia, and has a drainage area of greater than 64,000 square miles. Five major rivers, the Susquehanna, Potomac, James, Rappahannock and York, contribute on the average 89% of the 23-year average 73,300 cubic feet per second (cfs) freshwater inflow into the Bay. The Susquehanna, entering at the head of the Bay, contributes about 51% of the freshwater input.

Annual average freshwater inflow rates vary greatly from year to year, ranging from 49,000 cfs in 1965 to 131,800 cfs in 1972 - the year Tropical Storm Agnes struck the Bay system. The 7-day 10-year low flow, a statistic which estimates the lowest flow rate likely to occur for 7 consecutive days on the average of every 10 years, is approximately 8000 cfs.

2. Temperature

The range of temperatures naturally experienced in the Chesapeake Bay is extreme in comparison with most coastal water bodies. The annual surface temperature range in the open Bay is approximately $0^{\circ}C$ to $29^{\circ}C$ ($32^{\circ}F$-$84^{\circ}F$). The temperature range of deep bottom waters is a bit less, $1^{\circ}C$ to $25^{\circ}C$ ($34^{\circ}F$-$77^{\circ}F$). Bacause it is latitudinally extensive, temperatures in the northern and southern portions of the Bay may differ markedly. Temperatures in the Virginia portion annually average about $0.5^{\circ}C$ ($0.9^{\circ}F$) warmer, although the region of the Bay mouth is generally cooler than elsewhere during the summer because its temperature is moderated by the influence of the ocean. Temperatures range more widely and fluctuate more quickly in shallow waters, where summer temperatures in excess of 30°C (86°F) are not uncommon.

Bay waters become progressively warmer from March to August. During this time strong vertical gradients in temperature exist at mid-depth along the middle portion of the Bay (nautical mile 125 to 65). The coolest waters are found in the bottom layers at the upper end of this deep middle portion of the Bay and in the bottom layers of the mouth. The warmest waters, with the possible exception of some surface values, are found at the head of the Bay.

In the cooling season from September through December, this temperature pattern is altered. The waters at the mouth of the Bay are warmer than those at the head and the vertical gradient results from warmer waters lying under cooler ones. The vertical gradient is more moderate than that of the summer season.

In January and February there is very little temperature variation either longitudinally or vertically.

3. Salinity

The rate of Susquehanna freshwater inflow is the principal influence on salinity distribution in the Bay. Temporal patterns may reflect long term climatic trends such as drought cycles, seasonal runoff patterns, or aperiodic events, such as extratropical storms and hurricanes. The recurring seasonal patterns are governed by the seasonal distribution of runoff, which is generally highest in spring and least in fall; thus, the salinity at any given location averages 2-7 ppt lower in spring than in fall.

The longitudinal variation in salinity is fairly regular along the surface of the Bay; values range from 25-30 ppt near the mouth to 0.1 ppt near the head.

Salinity is generally higher and less variable in bottom waters than on the surface. The surface and bottom salinities differ by 2 ppt to 9 ppt depending upon the location in the Bay and the time of year. This vertical stratification is most pronounced in the deep middle section of the Bay (nautical mile 110 to 165), from May through September. At the shallower head and mouth of the Bay, vertical stratification is most extreme from January through April.

4. Oxygen

Dissolved oxygen concentrations in the Bay are regulated by a complex of physical and biological processes which add or subtract oxygen from the water. Surface waters in the open Bay are at or near saturation levels throughout the year. Warming of the water in the spring decreases O_2 solubility and increases biochemical uptake rates. Circulation patterns in summer months cause vertical stratification of the water mass. These factors combine to cause oxygen depletion in deep waters of the middle and upper Bay in summer months. By mid-June, oxygen in deeper layers may be less than 1 ml/ℓ (1.43 mg/ℓ), while surface waters are nearly saturated at 5 ml/ℓ (7.1 mg/ℓ). With respect to the vertical dissolved oxygen distributions, in the critical summer months there are two distinct layers at most stations with depths greater than 10 meters. Since the deep channel is very narrow in comparison with the width of the Bay as a whole, the higher concentrations of the upper layer alone are more representative of cross-sectional average dissolved oxygen values. Average dissolved oxygen concentrations in the upper 4 meters always exceeded 5 mg/liter, according to the available data.

Most sewage in the Chesapeake Bay system is discharged into the tributary estuaries rather than the Bay proper. The oxygen-demanding portion of the sewage generally undergoes decay in the tributaries before reaching the Bay; it, therefore, has little impact on the oxygen profile of the Bay. Tributary nutrient loadings, however, particularly from the Susquehanna, may have some effect on oxygen concentrations through photosynthesis and respiration of phytoplankton populations.

5. Nutrients

The major nutrients in the Bay are derived from nutrient-rich freshwater inflows. The Susquehanna River is the major source of nutrients in the upper Bay. At Havre de Grace, Maryland where the river enters the Bay, total phosphorus ranges from 1.0 μg-at/ℓ (31 μg/ℓ) in the summer and fall to 1.5 μg-at/ℓ (46.5 μg/ℓ) during winter and spring. Nitrogen, mainly as nitrate, ranges from a high of 80 to 105 μg-at/ℓ (1.12 to 1.47 mg/ℓ) in the spring to about 50 μg-at/ℓ (0.7 mg/ℓ) during the remainder of the year. As one progresses down the Bay, concentrations of nitrogen decline while there may be a slight rise in phosphorus levels around the Baltimore area and a subsequent decline. In the lower Bay, phosphate levels are generally less than 1.0 μg-at/ℓ (31 μg/ℓ) and nitrate-nitrite levels range from 0.14 μg-at/ℓ (2μg/ℓ) to springtime highs of about 20 μg-at/ℓ (280 μg/ℓ).

6. Point Source Pollutant Discharges

The salinity of the Chesapeake Bay waters precludes its use for irrigation; hence, there are no irrigation return flows. Any irrigation runoff entering the Bay system is included with non-point sources. Urban drainage, whether sewered or not, was included with non-point sources. No provision was made for the irregular loadings associated with "combined sewers", since the water quality model deals only with steady-state conditions.

Two groups of point sources were considered in this study. The major tributaries of the Bay - the Susquehanna, Potomac, and James Rivers - were considered point sources for the purposes of the water quality model. In addition, all identifiable major (discharge $\geq$ 0.5 MGD; 3300 to 5000 population equivalents) municipal and industrial facilities discharging into the Bay or one of its tributaries at distances less than 10 nautical miles from the Bay were included.

There were 21 such sources which may be classified as follows:

Federal Facilities	3
Municipal	13
Industrial	5
Maryland	13
Virginia	8

The loads entering through the tributaries at various freshwater inflow levels are listed in Tables IV-3 through IV-5. The estimated discharges from the 21 other sources are listed in Table IV-7. Their locations are shown in Figure IV-1. The dominant point sources of biochemical oxygen demand (BOD) for the Chesapeake Bay are the municipal and industrial facilities of the Baltimore area. The loads from the Potomac and James Rivers have little effect on the Bay, since they are smaller and undergo greater dilution on entry to the Bay. (The Potomac loads, moreover, arise primarily from non-point sources). Other sources, such as Annapolis or the seasonal fish processors below the Potomac mouth, may have impact in the immediate vicinity of their outfalls, but not on the Bay as a whole, again due to dilution. Moreover, even the Baltimore BOD loads are relatively insignificant compared to non-point sources upstream of the Bay on the Susquehanna and the benthal demand in mid-Bay (See Figure VI-9).

In the cases of total phosphorus and total nitrogen, the dominant point source loads are those above the upstream boundary on the Susquehanna, as well as those in the Baltimore area. The relative significance of these loads compared to non-point source discharges varies with the freshwater inflow level. (See Figures VI-5 - VI-8 and Table IV-22.)

7. Non-Point Sources of Pollutants

The non-point sources of pollutants considered in the study consisted or runoff from (a) undeveloped land (forest, park, open), (b) agricultural land, (c) urban land, (d) suburban land, and (e) marshland drained by the Bay, from distances less than 10 nautical miles, either directly or through a tributary.

Yield rates of the various pollutants for each category of land use under several freshwater inflow conditions were estimated from literature values developed for the lower Susquehanna River basin. (See Tables IV-8 through IV-12.) These yield rates were applied to the lands surrounding the entire Bay to obtain mass emission rates. (See Tables IV-13 through IV-17.) These mass emission rates, therefore, are very rudimentary estimates. In cases where the loadings appear to be significant, such as total phosphorus under high freshwater inflow conditions, more study is needed.

The relative importance of non-point source loadings generally increased with increasing freshwater inflow. Even under low flow conditions the non-point source loads of BOD and total nitrogen from the lower Susquehanna basin are significant. Under higher freshwater conditions the impact of Susquehanna non-point source BOD loads decreases but the impact of phosphorus as well as nitrogen loads increases. Non-point source loads of both nitrogen and phosphorus on the Bay proper appear to become quite significant under higher freshwater flow conditions. (See Figures VI-5 through VI-8.)

C. Future Water Quality

1. Water Quality Model

A mathematical model was used to project the water quality in the Chesapeake Bay. The model is a one-dimensional tidal-time model which has been successfully applied to the James River.

The model is based on the equation describing the mass-balance of a dissolved or suspended substance in a water body. To facilitate the numerical computation, the Bay was divided into a number of volume elements, called reaches, by a series of lateral transects perpendicular to its axis. The concentration of a substance was represented by an average value within the volume element.

The mechanisms responsible for the change in amount of substances in each reach were expressed mathematically to formulate a mass-balance equation for substances such as sea salt, oxygen, biochemically degradable material, or any form of nutrients.

The mass-balance equation was solved by the implicit finite difference scheme. Values of various coefficients used in the model were estimated both from literature values and calibration. In particular, parameters used in calculating dispersion coefficients were determined by calibration and verification with salinity data. Decay and settling rates of BOD and nutrients were taken from the literature, since sufficient field data for calibration and verification was unavailable.

2. Water Quantity and Temperature

The water quality model for the Chesapeake Bay requires the freshwater discharges from the Susquehanna, Potomac and James as input data. These three rivers contribute about 83% of the total freshwater input to the Bay. The flows from other tributaries are estimated in the model by applying to the Susquehanna discharge the ratio of the tributary discharge area to the Susquehanna drainage. Therefore, in selecting the hydrologic conditions, the flow rates from the three major tributaries were determined.

Table V-2 summarizes the five freshwater flow conditions used in the model with typical water temperatures of the corresponding seasons associated with these flows. Except for the 7-day 10-year low flow, the flows were determined from the seasonal values of the lower quartile year of 1954.

3. Projected Future Point Source Pollutant Loadings

The projected pollutant loadings from the Susquehanna River to the Bay resulting from the application of 1977 ("best practical technology") discharge standards to Susquehanna River point sources cannot be assessed without a model of the lower Susquehanna River. Instead, the pollutant loadings resulting from 50%, 70%, and 90% point source abatement calculated from literature values were used in the 1977 water quality projections (Tables VII-1 through VII-5). (The 100% point source abatement values, used for the 1985 {"elimination of discharge"} condition is also presented here).

All loadings to the Bay from the Potomac River are assumed to have originated from non-point sources. No decrease in Bay loadings from the Potomac due to point source abatement is expected.

The major contribution of pollutants from the James to the Bay is from the point sources and non-point sources (urban runoff) on both sides of the Hampton Roads. Ninety percent of the present total BOD loadings from the point sources in the Hampton Roads area is from the municipal sewage treatment plants, which all utilize primary treatment. The loadings associated with 1977 discharge standards, therefore, were determined by assuming the upgrading of all these plants to secondary treatment, (See Tables VII-6 through VII-10).

For all other point sources the discharge rates for 1977 ("best practical technology") were estimated from National Pollutant Discharge Elimination System (NPDES) permit limitations for 1977 or on the basis of secondary treatment of domestic sewage if permits were not available (Table VII-11). (Complete elimination of point sources was assumed for 1985).

A comparison of current estimated point source pollutant loadings with those projected for 1977 are presented in Tables VII-12 through VII-15. The overall anticipated percentage reductions, reflecting primarily reductions at the large Baltimore sources, are:

total phosphorus:	11
total nitrogen:	45
nitrogenous BOD:	52
carbonaceous BOD:	57

Since the Bethlehem Steel Co. is the only significant industrial point source and no NPDES permit beyond 1977 is available at the present time, it is assumed that the projected pollutant discharge rate in 1983 ("best available technology") will be the same as those of 1977. It is also assumed that all the municipal sewage treatment plants will apply secondary treatment both in 1977 and 1983; therefore, no separate estimate of point source discharge rates was made for 1983.

For each of the five selected flow conditions the model was run to simulate the water quality in the Bay proper under present, projected 1977 and 1985 pollutant loading conditions. The water quality parameters investigated include total phosphorus, total nitrogen and dissolved oxygen.

4. Total Phosphorus

Figures IX-1 through IX-5 show the total phosphorus distributions predicted by the model for each combination of pollutant loading and Susquehanna River flow condition discussed.

Under each flow condition there is a peak ranging from 0.067 - 0.083 mg P/liter in the Baltimore Harbor area for the present situation. This is primarily a result of Baltimore area point source effluents, but there is an increasing contribution from marshes at the head of the Bay at higher flow levels. The impact of the Baltimore area point sources may be somewhat overstated here. The effluent loads were estimated from general rather than actual values and they are, in fact, discharged into tributaries rather than the Bay proper and, therefore, are subject to some decay and settling before entering the Bay. Local maxima have been observed, however, in the Baltimore area of the Bay.

The rise in upstream boundary concentrations with increasing freshwater inflow for each set of curves is due to increasing contributions of non-point sources on the lower Susquehanna.

The peak total phosphorus concentrations resulting from the 10% Baltimore phosphorus discharge abatement proposed for 1977 would range from 0.054 to 0.077 mg P/liter with 50% Susquehanna point source abatement and from 0.044 to 0.077 mg P/liter with 90% Susquehanna point source abatement. The peak concentrations resulting from complete point source elimination (1985), both on the lower Susquehanna and the Bay, would range from 0.003 to 0.055 mg P/liter. As observed previously, the estimates of non point source loads on the Bay itself, particularly those of marshes (the largest source) were determined in a very rudimentary way.

5. Total Nitrogen

Figures IX-6 through IX-10 show the total nitrogen distributions predicted by the model for each combination of pollutant loading and Susquehanna River flow condition discussed.

In each curve the maximum concentration occurs at the upstream boundary of the Bay, reflecting the dominance of the Susquehanna nitrogen loads, especially those arising from non-point sources. At the lower flow levels a small rise in the Baltimore area is also seen on the present and 1977 curves, resulting from the point sources there. Again, the impact of these point sources may be somewhat more moderate than indicated here, because of decay and settling in the tributaries. The rise disappears at higher freshwater inflow levels. Increasing flow levels also correspond to a less pronounced decline of concentration with distance from the upstream boundary, leading to higher concentrations throughout the Bay.

Under present conditions the model concentrations in the Baltimore area of the Bay range from 0.275 to 1.232 mg N/liter. Concentrations in the Baltimore area resulting from the 46% Baltimore nitrogen discharge abatement anticipated for 1977 would range from 0.170 to 1.078 mg N/liter with 50% Susquehanna point source abatement and from 0.166 to 1.078 mg N/liter with 90% Susquehanna point source abatement. Complete point source elimination (1985), both on the Susquehanna and the Bay, would lead to concentrations in the range of 0.059 to 1.014 mg N/liter. The non-point sources of nitrogen are generated primarily on the lower Susquehanna rather than the Bay. Because this area has been more extensively studied with respect to nutrient non-point sources than has the Bay, these estimates are more reliable than those of the phosphorus non-point source loads.

6. Dissolved Oxygen

Figures IX-11 through IX-15 show the dissolved oxygen (DO) distributions predicted by the model for the present, proposed 1977, and proposed 1985 pollutant loading conditions at various freshwater inflow levels. The 1977 curves correspond to 50% Susquehanna point source biochemical oxygen demand (BOD) abatement.

At the two lower freshwater inflow levels under present conditions distinct DO minima result from Susquehanna River loadings in the upper Bay - 3.902 and 4.418 mg O/liter - and from the combination of Baltimore point sources and high benthal demand in mid-Bay - 4.000 and 4.084 mg O/liter. Point source BOD abatement at the 1977 level would lead to minimum concentrations at the upper end of the Bay of 4.427 and 4.818 mg O/liter and to minimum concentrations in mid-Bay of 4.194 and 4.300 mg O/liter. Complete point source BOD elimination would result in minimum concentration at the upper end of the Bay of 4.952 and 5.228 mg O/liter and to minimum concentrations in mid-Bay of 4.338 and 4.463 mg O/liter for the two low freshwater inflow conditions. At the three higher freshwater inflow levels no distinct DO minima are predicted but rather a general sag in mid-Bay would occur primarily because of benthic oxygen demand. At these high inflow levels a concentration of 6.0 mg O/liter would be exceeded throughout the Bay for all BOD loading conditions.

I. Introduction

This study was undertaken at the request of the National Commission on Water Quality. The objective was to evaluate the physical, chemical, and biological effects on Chesapeake Bay of achieving the abatement objectives delineated in the 1972 amendments to the Federal Water Pollution Control Act. The study involved three main tasks.

1.) Description of the present water quality conditions in the Chesapeake Bay from the Susquehanna River at Conowingo, Maryland to the Atlantic Ocean.

2.) Projection of future water quality conditions associated with the achievement of requirements and goals of the Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500, 86 Stat. 816.

3.) Assessment of the biological, ecological, and environmental impacts of the future water quality projections.

The first two tasks are addressed in Volume I and the final task in Volume II.

The material in Volume I pertains primarily to the Bay proper. Tributary conditions are discussed only insofar as they affect the Bay. Volume II contains a somewhat more extensive discussion of the tributaries.

Because the study utilized only existing data, estimates of varying sophistication were made where data gaps existed. The reliability of our findings would be enhanced by further field studies. Specific recommendations for such studies are made in Chapter VI, Section J.

II. Description of the Study Area

A. Geographic Setting

1. The water body

Chesapeake Bay is located in the States of Maryland and Virginia. It extends approximately north-south along the 76°10'W longitude from the mouth of the Susquehanna River (39°30.3'N latitude) to the Virginia Capes (37°N latitude) (Figure II-1). The Bay proper is contained in subareas 206 and 208 as defined by the Water Resources Council.

Chesapeake Bay is the largest estuary on the Atlantic coast of the United States and one of the largest estuaries in the world. The Bay is approximately 289 km (156 naut. mi.) long with a mean width of 22.4 km (12.1 naut. mi.) and a maximum width of 47.6 km (25.7 naut. mi.). The mean depth is 8.05 m (26.4 ft.). The maximum depth is 53 m (174 ft.) at Blood Point Light, about 1/3 of the distance from the head of the Bay to the mouth. The bathymetry of the Bay is summarized in Fig. II-2. The surface area of the Bay at mean low water is 6.481×10^3 km^2 (1887 naut. mi.^{2}) and the mean tidal volume is 5.383×10^{10} m^3 (1.86×10^{10} ft.^{3}).

The drainage area of the Bay is approximately 1.662×10^5 km^2 (64,159 mi.^{2}) including portions of Virginia, Delaware, Maryland, Pennsylvania, New York and West Virginia. The drainage basin lies within subareas 204, 205, 206, 207 and 208 as defined by the Water Resources Council. Five

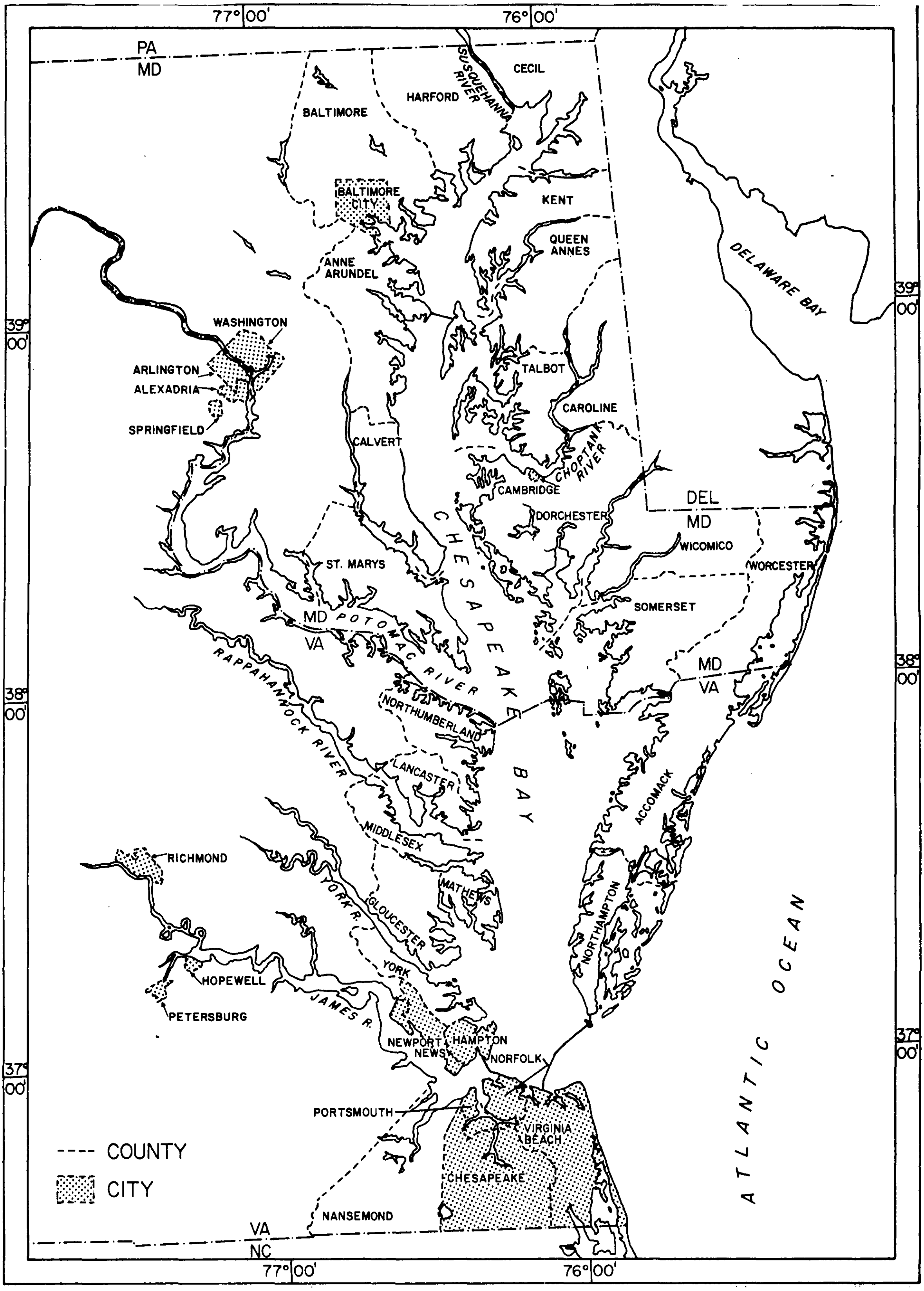


Figure II-1. The Chesapeake Bay with major political boundaries.

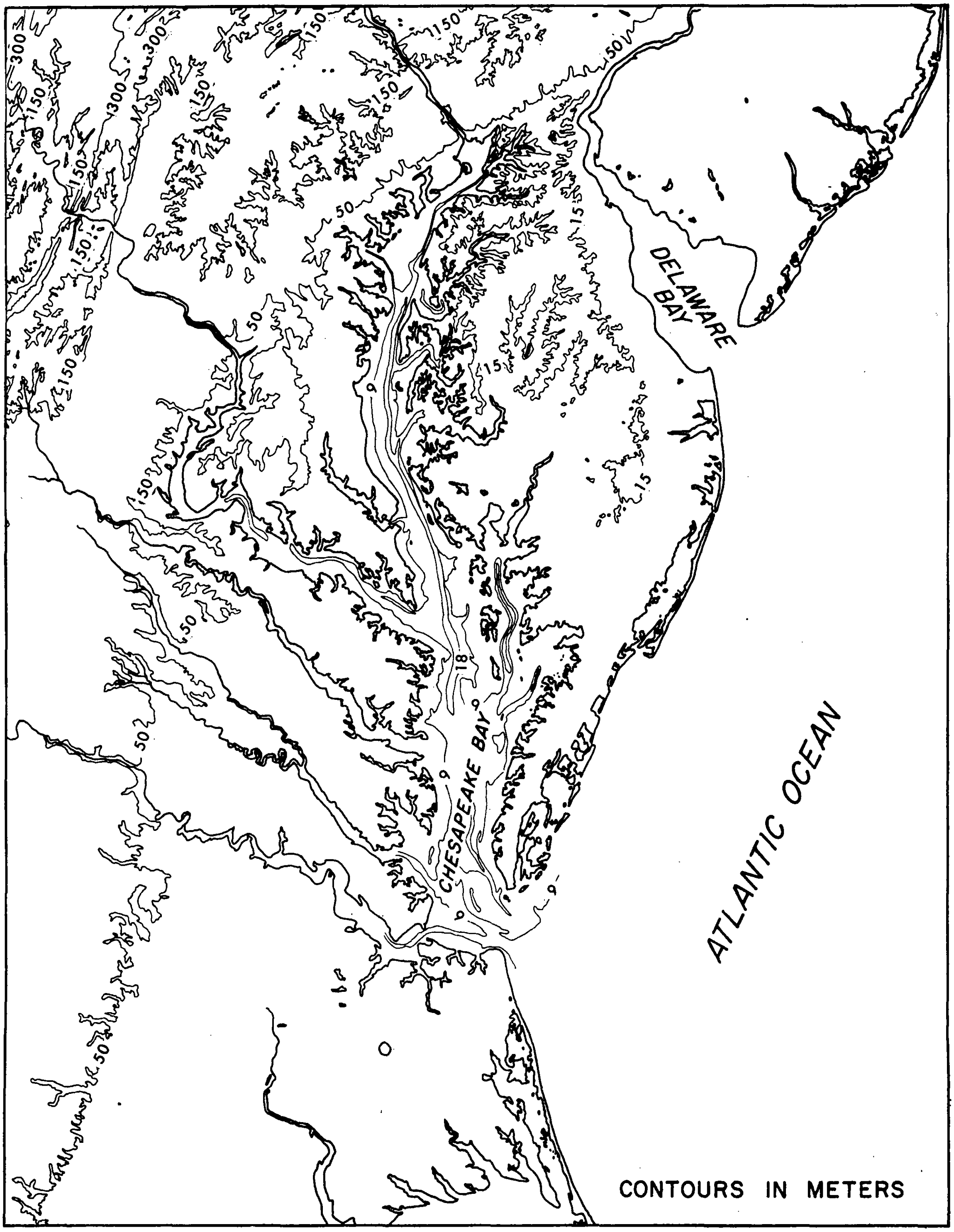


Figure II-2. Topography and Bathymetry of the Bay. The 15 m contour is shown only for the Eastern Shore where the elevation is very small. The 50, 150, and 300 m contours are shown for the Western Shore. For a more detailed view of the topography, refer to topographic charts published in the U. S. Geological Service.

major tributaries empty into the Bay: the Susquehanna, Potomac, Rappahannock, York and James.

The Chesapeake Bay was formed in recent geologic history by a rise in sea level after the last ice age. Thus the Bay is at most 10,000 years old. The Bay and its tributary estuaries are the drowned valley system of the Susquehanna River. The main channel of the ancestral course of the Susquehanna River coincides with the deepest portions of the Bay.

a. Circulation

Water movement in the Bay is governed by freshwater runoff from the drainage basin, tidal wave propagation from the mouth, and gravitational circulation resulting from a density gradient which is mainly a function of salinity distribution. Occasionally the circulation pattern is significantly altered by meteorological conditions, producing wind-driven currents and storm surges.

The five major tributaries contribute 89% of the freshwater inflow. The Susquehanna, entering at the head of the Bay, contributes about 51% of the freshwater input. The Potomac, James, Rappahannock and York, located along the western shore, contribute 18, 14, 4 and 2% of the freshwater inflow to the Bay and its tributaries is 2076 m^3 sec^{-1} (73,300 ft^3 sec^{-1}). The flushing rate for the Bay derived from freshwater inflow alone is about 0.35% day^{-1} which corresponds to a mean residence time of 285 days for a parcel of water in the Bay.

Tidal currents are the most obvious water motion in the Bay and its tributaries. Tidal currents in excess of 0.91 m $\sec^{-1}$ (3 ft $\sec^{-1}$) have been measured in the Bay. Generally, tidal currents are strong near the Bay mouth, decrease in mid-Bay, and increase again in the upper Bay. The tidal wave is nearly a progressive wave with a wave length of 322 km (200 mi) and an average phase speed of about 7.3 m $\sec^{-1}$ (24 ft $\sec^{-1}$), except near the head of the Bay. The relationship between tidal wave characteristics and the length of the Bay is such that the tide will be flooding in one section while it will be ebbing at a distance of one-half wave length away. The time of high tide at the head of the Bay lags behind that at the mouth by approximately 14 hrs. The tidal range decreases from 0.91 m (3 ft) at the Bay mouth to 0.30 m (1 ft) near Annapolis and increases again to 0.61 m (2 ft) at Havre de Grace. Geometric constriction and wave reflection at the head of the Bay cause the increased tidal range and deviation from a purely progressive wave form.

Tidal currents provide the energy for mixing of oceanic and freshwater in the Bay but do not produce a net transport of water. Superimposed on the oscillatory tidal currents is a net non-tidal circulation which serves as the main flushing mechanism. The non-tidal circulation is characterized by a seaward flow in the surface layers and a landward flow in the bottom layers in the absence of any unusual meteorological conditions. This non-tidal flow results from the interaction of freshwater runoff and gravitational circulation caused by the salinity distribution. As a result, the surface ebb current is faster and lasts longer than the ebb current at the bottom. In order to preserve continuity, the water that flows into and up the Bay in the bottom layers must be returned seaward in the upper layers, therefore there is a net vertical flow from the bottom layers to the surface layers. The seaward flow at the surface will always exceed the shoreward flow at the bottom by an amount equal to the volume of freshwater inflow. This non-tidal circulation greatly increases the flushing rate of the Bay. The flushing rate calculated from current measurements at the mouth of the Bay for 5-6 June 1973 is 1.4% day $^{-1}$, corresponding to a mean residence time of 71 days.

Two major factors influence non-tidal circulation in the Bay: (a) freshwater inflow from the rivers and (b) alternate warming and cooling of surface waters which alter the salinity/temperature structure during the year (Seitz 1971a). Salinity governs the dynamic structure of the Bay (Pritchard 1952), but temperature can significantly modify density stratification (Seitz 1971a).

b. Salinity and Temperature

The volume mean salinity of the Bay is about one-half that of sea water which enters the Bay during flood tide. An insignificant amount of water leaves the Bay via the Chesapeake-Delaware Canal near the head of the Bay, and therefore does not significantly affect salinity distribution. Salinity varies longitudinally along the Bay in a more or less regular manner from that of nearly full-strength sea water at the mouth to that of fresh inflowing Susquehanna River water at the head. Salinity increases from west to east across the Bay as a result of greater freshwater inflow on the western shore and the Coriolis effect. Salinity increases with depth, slowly in surface and bottom layers, and rapidly in an intermediate layer (halocline). The spatial distribution of salinity in Chesapeake Bay and the strength of the halocline are determined by freshwater inflow. Spring freshets and summer-autumn dry periods produce seasonal variations in salinity distribution throughout the Bay. The strength of the halocline decreases with decreasing freshwater inflow and may even disappear during dry periods.

The temperature in the Bay ranges annually from 0°C to approximately 29°C. There are, however, longitudinal variations along the axis of the Bay as great as 7°C in August. Temperatures in the Virginia half of the Bay average 0.5°C higher than those in the Maryland half (Schubel 1972). The water near the head of the Bay, however, is warmer than that near the mouth from March to August (Seitz 1971b). Longitudinal temperature differences are greatly decreased in September, and during the next three months the Upper Bay water is 2.5 - 5.0°C cooler than Bay mouth water. During January and February, the water at the head of the Bay is about 2^{o}C colder than that at the mouth. From September to December, bottom waters are warmer than surface waters although there is no sharp vertical gradient (thermocline). In January and February the water column is essentially isothermal. During the rest of the year, surface waters are warmer than bottom layers.

2. Major Topographic and Physiographic Features

The Chesapeake Bay cuts diagonally across the subareal portion of the Atlantic Coastal Plain. The Coastal Plain is a low, partially submerged land area extending from the Piedmont Plateau (Fall Line) to the edge of the Continental Shelf about 100 miles offshore at the 600 ft. (183 m) contour. The Eastern Shore of the Bay is a flat, low, almost featureless area with a maximum elevation of about 22.9 m (75 ft). The Western Shore is a rolling upland, in places almost four times the elevation of the Eastern Shore. The major tributaries of the Bay cut deep channels from the Fall Line across the Western Shore.

The major physiographic features of the Coastal Plain are the underlying basement rock consisting mainly of Pre-Cambrian crystalline rocks, and a series of southeasterly tilted layers of unconsolidated sedimentary formations. The basement rocks are exposed only in places where deep valleys have been cut by the major tributaries. The sedimentary layers overlying the basement rock consist of wedge-shaped layers of differing geologic age. The exposed sedimentary layers are progressively older from shoreline to the Fall Line. A series of scarps roughly parallel to the present shoreline mark the sea level in past geologic eras.

The Coastal Shoreline is generally irregular, broken and low, often with large marshy areas. In those cases where the shoreline is straight, it may be high and relatively rugged.

The upland portions of the basin including the head waters of the major tributaries are located on the Piedmont Plateau. The Piedmont Plateau is a broad undulating surface with low knobs and ridges. It rises gradually from the Fall Line on the east to the Appalachian Province on the west. This region is composed of an underlying layer of hard crystalline rocks. Highly folded metamorphosed sediments at the surface are intruded by igneous rock which found its way into folds and fissures.

3. Political Boundaries and Major Municipalities

The upper half of the Bay lies in the state of Maryland, the lower half in Virginia. These Maryland-Virginia line is located about one-third the distance from the Capes to the head of the Bay, crosses the Bay, and extends along the southern shore of the Potomac River. Twelve Maryland counties and eight Virginian counties lie along the shoreline of the Chesapeake Bay.

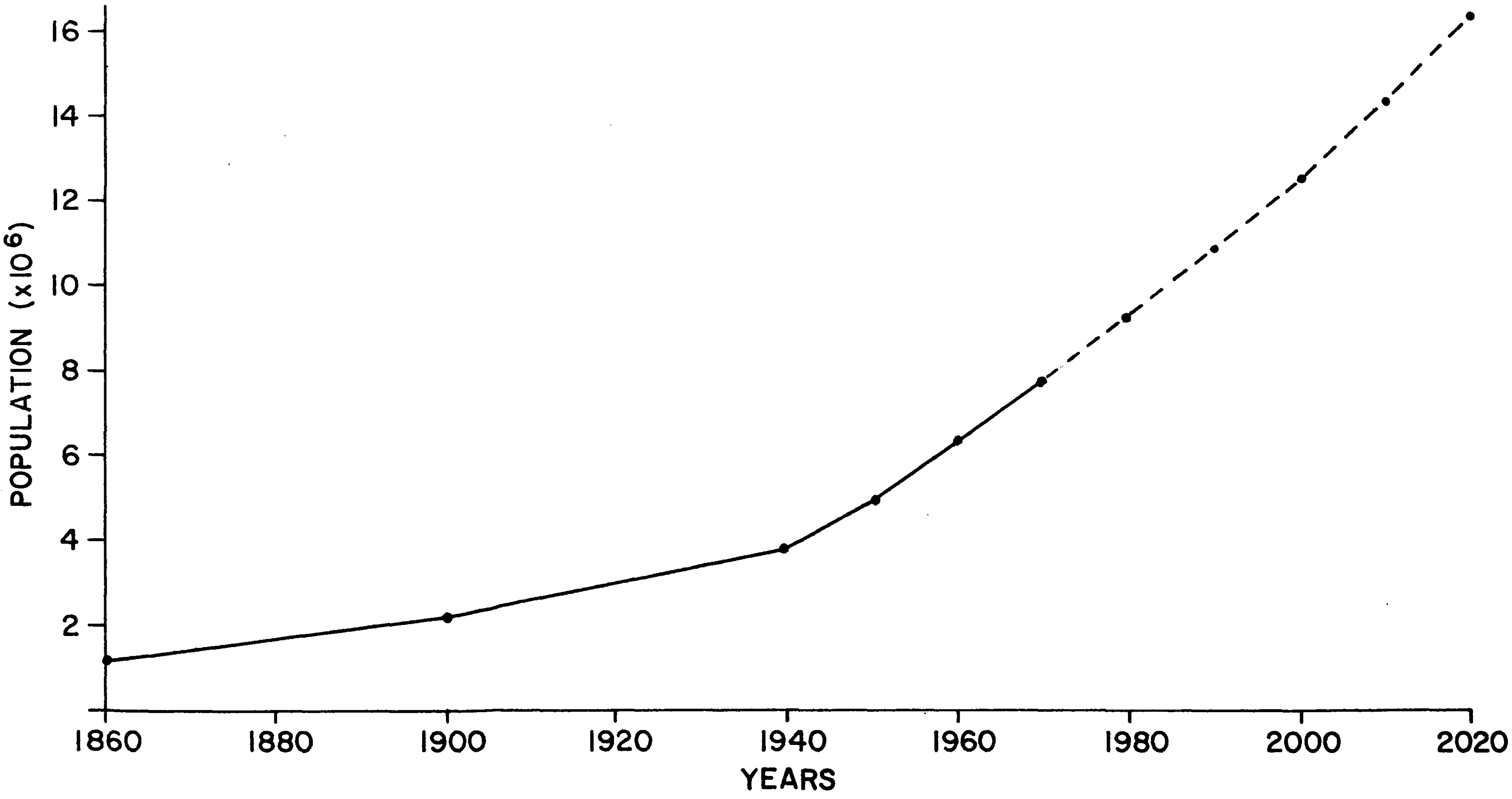
Several major municipalities are located on or near Chesapeake Bay (Fig. II-1). These include Baltimore City in Maryland, and Virginia Beach, Norfolk, Hampton and Newport News in Virginia. Other municipalities found along tributaries of the Western Shore of the Bay are Washington, D. C. (Potomac River), Richmond (James River), Portsmouth (James River), and Chesapeake (James River). Several smaller municipalities are also identified in Fig. II-1.

B. Demographic Characteristics and Major Economic Sectors

The Chesapeake Bay region was a predominantly agrarian society until after the Civil War. Since that time, the area has experienced continuous industrialization and urbanization which have placed environmental strains on the Bay system especially the Bay tributaries. Nevertheless agrarian activities are still significant in the study area.

The population trends and projections within the Chesapeake Bay Estuarine Area, which includes Washington, D. C., Richmond, and counties located along tributaries as defined by the Army Corps of Engineers, are shown in Fig. II-3. Prior to 1940, the rate of population increase was slow, but has since increased markedly. The present population of about 8 million is expected to double by the year 2020. The current concentration of the population in the major municipalities leaves large areas available for further growth.

Figure II-3. Population trends in the Chesapeake Bay region from 1860 to 1970 with projections to 2020 (drawn from data in Army Corps of Engineers, 1972).



Four economic sectors account for the majority of the available jobs in the region: services, wholesale and retail trade, manufacturing, and public administration.

1. Services

In 1970, the service sector employed the greatest percentage of the labor force in the area (25%). There were 859,000 jobs provided in services such as entertainment and recreation, non-profit organizations (labor unions, religious organizations and political organizations), professional services, and miscellaneous services (research laboratories, advertising, employment agencies, etc.). Education, health and professional services are the largest single sources of employment in the area. The Washington, D. C. subregion contains 46% of the total service workers.

2. Wholesale and Retail Trade

The second largest economic sector in the area (17% of labor force) is wholesale and retail trade. The bulk of retail trade is centered in Washington, D. C. and Baltimore City and environs.

3. Manufacturing

In 1970, the manufacturing sector employed 524,000 workers (16% of the labor force). The National average for this sector, however, is considerably higher (25%).

4. Public Administration

About 15% of the labor force in this area is involved in public administration as compared to the national average of 5%. As one would expect, the bulk of this type of employment is centered in Washington, D.C.

5. Other

In the counties immediately adjacent to the Bay proper, there is significant employment in agriculture, forestry and fisheries, which are the major economic activities in these counties. Also significant are construction, armed forces (well above the national average), transportation, communication and utilities, finance, insurance and real estate, and mining.

Several of these latter sources of employment may have a large impact on water and land resources. Erosion and siltation are often associated with agriculture, construction and mining operations. Nutrients placed on the land during farming operations are often added to the Bay waters with land runoff. While presently largely unquantified, these non-point sources of pollutant are probably highly significant in the Bay system.

C. Climate and Hydrological Characteristics

The climate of the Bay area is generally moderate as a result of the proximity to the Atlantic Ocean. The mean air temperature is $57^{\circ}F$ ($13.9^{\circ}C$). The mean air temperature at the head of the Bay is $54.5^{\circ}F$ ($12.5^{\circ}C$), while at the mouth of the Bay it is $59.7^{\circ}F$ ($15.4^{\circ}C$). The average precipitation per year is 44 in. (112 cm) with an average snowfall of 13 in. (33 cm). Rainfall is maximal in the summer months. Three types of storm activity occur in the area: extra-tropical storms or "lows", tropical storms or hurricanes, and thunderstorms. Approximately 60% of the annual precipitation or about 26 in. (66 cm) is lost per year through evapotranspiration. The winds are predominantly from the southwest with an average velocity of 10 mph (16.09 km hr^{-1}).

Average freshwater inflow from the major tributaries is summarized in section A-1. Extreme variations from these average flow conditions occur as a result of climatic variations and water usage along the drainage basin. Excessive rainfall has caused significant flooding affecting one or more of the tributaries at any given time. Floods are short duration phenomena which have been known to occur in all seasons of the year. The most recent major flood was in June 1972. Abnormally low rainfalls or droughts have been known to cause significant declines in freshwater runoff. A drought is a long-term phenomenon which occurred most recently in this drainage basin in the 1960's.

D. Land Uses

Land use patterns were reported by the Army Corps of Engineers (1972) in "Chesapeake Bay, Existing Conditions Report." The data are diagrammatically presented in Figures II-4 and II-5.

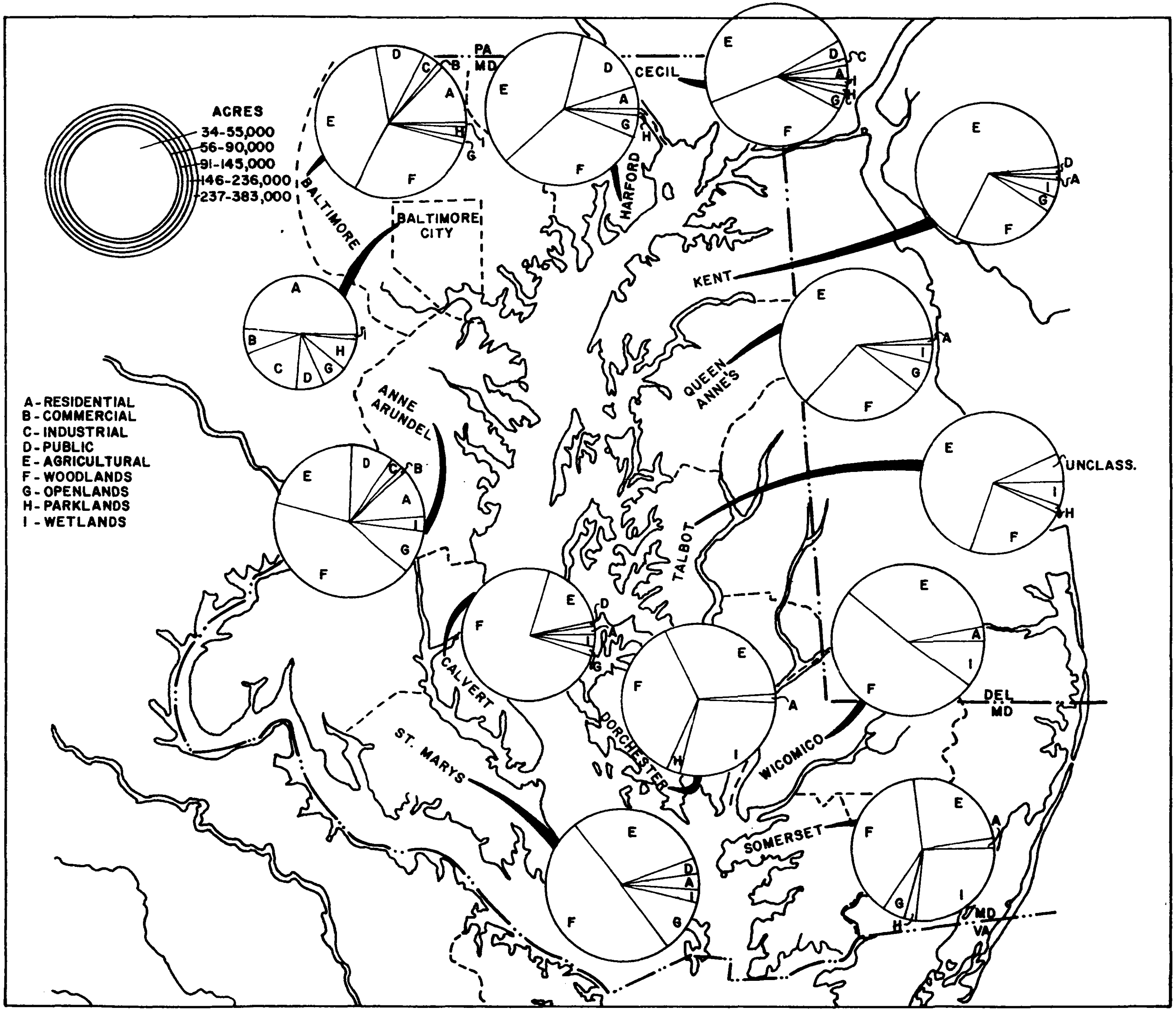


Figure II-4. Land-use patterns for Maryland counties adjacent to the Chesapeake Bay and Baltimore City.

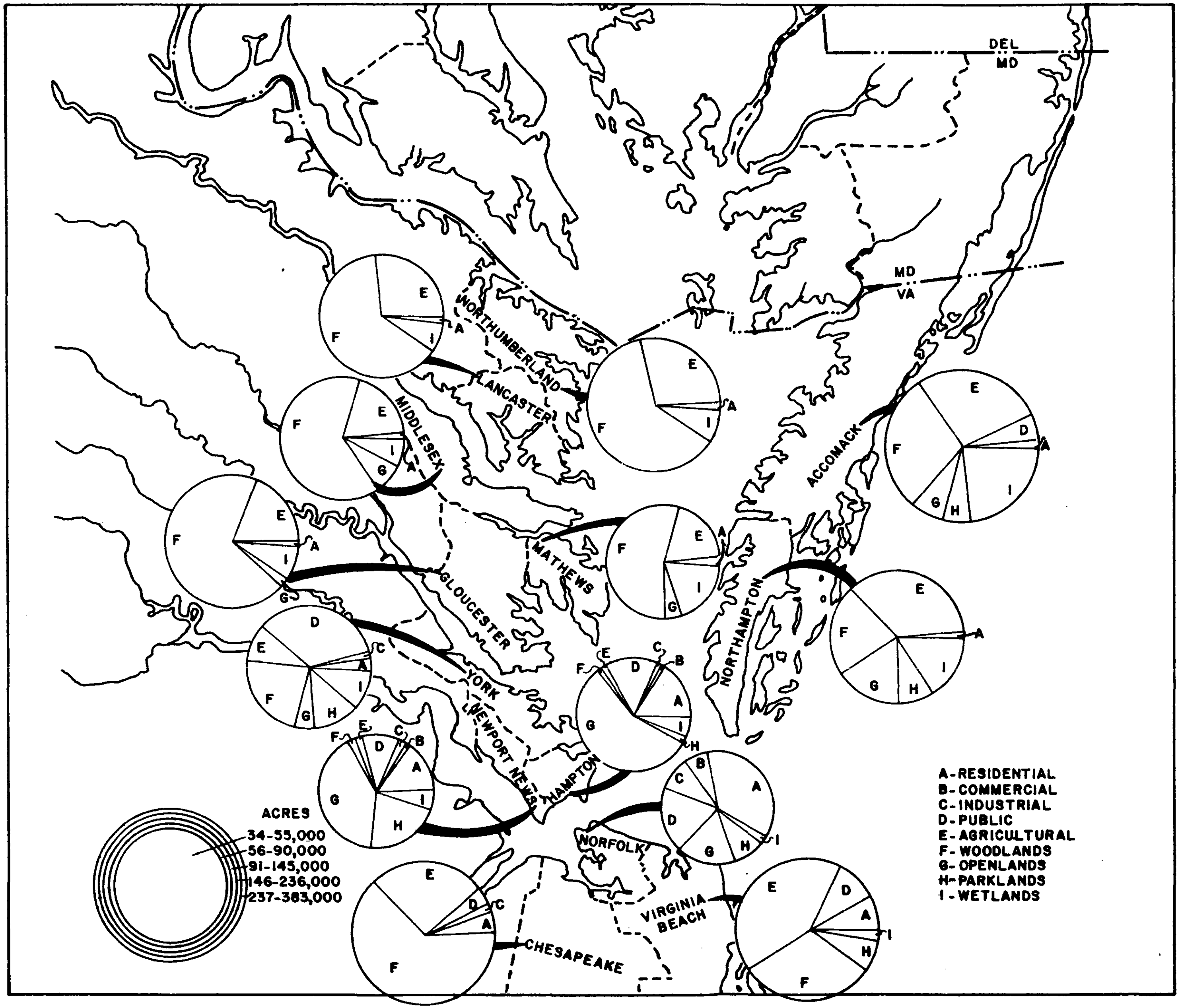


Figure II-5. Land use patterns for Virginia counties and major municipalities adjacent to the Chesapeake Bay.

The Bay area was largely an agrarian region prior to the Civil War. Since that time, some industrialization and urbanization have occurred. The bulk of the land area however remains agricultural or forested.

1. Residential

The major residential center in Maryland is located in Baltimore City and the adjacent counties of Baltimore, Harford and Anne Arundel. The major residential center in Virginia is the Hampton Roads area including the cities of Hampton, Newport News, Norfolk, Portsmouth, Chesapeake, Virginia Beach and York County. Even in these two centers, only Baltimore and Norfolk have more than 20% of the land committed to residential use.

2. Commercial

Major commercial centers are located in Baltimore City and Norfolk with a lesser center in Newport News-Hampton. In other areas only minimal amounts of land are committed to commercial operations.

3. Industrial

Industrial development is also centered in Baltimore City and Norfolk. While adjacent areas are important residential areas, they have experienced negligible industrial development.

4. Agriculture and Woodlands

Most land in the Bay area is devoted to agriculture and/or woodlands. Only Baltimore City and Norfolk have no land devoted to these activities, while Newport News and Hampton have only negligible amounts of land used in these ways. All other cities and counties except York County have over 58% of the land devoted to agriculture and woodlands.

5. Public

Areas which are primarily devoted to residential-commercial-industrial activities such as Baltimore and Harford counties in Maryland and Newport News, Hampton, and Norfolk, Virginia also have a significant area devoted to public use. The remainder of the Bay counties have only limited areas committed to public use. York County in Virginia has the largest area committed to public use with several large military bases.

6. Openlands

In Maryland, the major population center around Baltimore City has limited but significant openland areas available for further development. In the adjacent counties, fairly extensive agriculture and forest areas could be committed to other uses. St. Mary's County has the most open land (11.8%). Three rural counties (Dorchester, Talbot, and Wicomico), have no land designated as open land.

The residential-commercial-industrial center in Virginia on both sides of Hampton Roads has a large proportion of its area designated as open land.

7. Parklands

Only limited areas in Maryland are designated as parkland. Baltimore City has nearly 10% parkland. Kent and Queen Anne counties have no parklands. Other areas have only a small parkland area.

Newport News in Virginia has the largest proportion of its land area committed to parkland (21%). Other areas with significant areas in parkland are York County, Norfolk, Northampton County, Virginia Beach and Accomack County. Other cities and counties have only limited parklands.

8. Wetlands

In Maryland, the most significant areas devoted to wetlands are on the Eastern Shore in Dorchester and Somerset counties (29 and 27% respectively). Smaller, but significant wetland areas are found in all other counties of the Eastern Shore. Elevations increase more rapidly on the western shore, resulting in less wetland development.

Virginia wetlands are concentrated in Accomack, and Northampton counties on the Eastern Shore. However, about half of the wetlands are associated with the barrier island system facing the Atlantic Ocean. On the western shore, Mathews County has the largest proportionate area in wetlands (almost 20%). Other counties and cities on the western shore north of the James River have significant (5.8-8.5%) wetland areas. The highly developed south side of Hampton Roads including Chesapeake, Norfolk and Virginia Beach has limited wetlands (3%).

A more detailed discussion of wetlands will be included in the description of the environment of the Bay in Volume 2.

E. Water Use

The Chesapeake Bay is a major center for commercial fishing operations with total landings for 1971 within Chesapeake Bay of 445.3 million pounds worth 34.2 million dollars. While 85% of the catch (by weight) is landed in Virginia, the dollar value of Virginia landings is slightly under 50% of that for the entire Bay. The entire Bay and its tributaries are utilized in the fishery. The lower portions of tributaries, not the Bay proper, are the major fishing areas for shellfish and some fin fishes.

The Bay system also supports a major recreational fishery. The extent of recreational fishing within the Bay is not known, but may equal or exceed the commerical fishery in landings for some species such as spot, croaker, and striped bass.

Boating and associated water sports other than fishing (water skiing, sailing, racing, etc.) are known to occur throughout the Bay. No accurate data regarding the extent of this use are available, but this use is significant. A major limitation to boating and other related water sports is access in the form of boat ramps.

The Bay is also an important transportation route with port facilities at Baltimore City and Hampton Roads, two of the largest ports on the East Coast. Small port facilities are found elsewhere around the Bay, sometimes associated with specific industrial plants.

Swimming is also a common sport in the Bay. For 1970, there was an estimated demand of 45,807,000 activity days within the Bay. There are no accurate statistics regarding miles of shoreline established as swimming beaches, but it should be noted that many miles of the shoreline which might be suitable for swimming, are not accessible. Federal ownership of large amounts of the shoreline for military bases precludes use for recreation by non-military persons.

Water from the Bay and tributaries is used by industry, especially power generating plants for cooling. Industrial use often conflicts with other uses. The Bay and its tributaries are also used as receiving waters for industrial wastes and sewage wastes.

While sand and gravel are not dredged from the Bay for commercial production of building materials, there have been significant dredging operations to supply sand and gravel for special construction within the Bay. Sand is dredged for beach replenishment in various locations. Recently, Newport News Shipbuilding and Dry Dock Corporation has obtained sand for construction of new facilities from Willoughby Spit and Hampton Bar.

Fresh water for some municipal, industrial and other uses is obtained from ground water aquifers. The underlying basement rocks yield little fresh water. Overlying sedimentary layers yield fresh or brackish water. Brackish water is generally encountered at depths of several hundred feet to over 1000 feet. In some areas, e.g. Cambridge, Md., fresh water strata may be interlayed brackish water strata.

The major source of recharge of freshwater aquifers is precipitation. An estimated 20 to 25% of mean annual precipitation is added to the aquifer (500,000 gal d^{-1} mi^{-2}). Vertical leakage between aquifers is known to occur in many areas.

Ground water is generally available in adequate amounts, although local limitations may be significant. The quality is generally good, with most wells supplying soft water. The major water quality problems relate to silicate and iron which exceed U. S. Public Health Service standards. When necessary, these problems are readily handled by treatment. The ground water resource is presently considered to be under developed (Army Corps of Engineers 1972).

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III. Description of Water Quantity and Quality

This chapter includes information on coastal waters only, since the categories of ground water, running water, and still-standing water are not applicable to this study.

No data were available on light. Coliform contamination, toxic substances, and biological parameters are discussed in Chapter XI. Circulation patterns are discussed in Chapter II.

A. Data Sources and Limitations

Data on water quantity were obtained from publications of the Chesapeake Bay Institute of The Johns Hopkins University, the U. S. Geological Survey and the Virginia Department of Conservation and Economic Development. Data on water quality were obtained, for the most part, from publications of the Chesapeake Bay Institute and the Annapolis Field Office of the EPA.

Historical data on water quality are scattered. Much of the information is not comparable since it was not derived in a uniform manner; trends, therefore, are difficult to discern. A great deal of the available data is of limited value because of lack of attention to tidal phase during sampling. Data collected after Tropical Storm Agnes (June 1972) are inappropriate here because they relate to an unusual situation.

B. History

1. Hydrology

The Chesapeake Bay drains portions of six states, Virginia, Maryland, Delaware, Pennsylvania, New York and West Virginia and has a drainage area of greater than 64,000 square miles (165,688 km^2) (Seitz 1971a). Five major rivers, the Susquehanna, Potomac, James, Rappahannock and York Rivers contribute on the average 89 percent of the 23-year average 73,300 cubic feet per second (cfs) (2076 m^3/sec) freshwater inflow into the Bay. The Susquehanna, entering at the head of the Bay, contributes about 51% of the freshwater input. The Potomac, James, Rappahannock and York, located along the western shore, contribute 18, 14, 4 and 2% of the freshwater inflow, respectively (Wolman, 1968).

Flows vary greatly from year to year as shown in Figure III-1. During the drought of the mid-sixties, the average freshwater inflow for 1965 was only 49,000 cfs (1388 m^3/sec) while during 1972, the year Tropical Storm Agnes struck the Chesapeake Bay system, the yearly average freshwater inflow was 131,800 cfs (3732 m^3/sec) with average flows for 8 months greater than 100,000 cfs (2832 m^3/sec). Figure III-1 shows the yearly average flow duration curve, plotted from U. S. Geological Survey data. From this graph representative years of dry, normal and wet hydrology were selected to demonstrate the seasonal variation. 1968 was selected as the dry and lower quartile year, 1970 was selected as the normal year and 1973 was selected as the wet year.

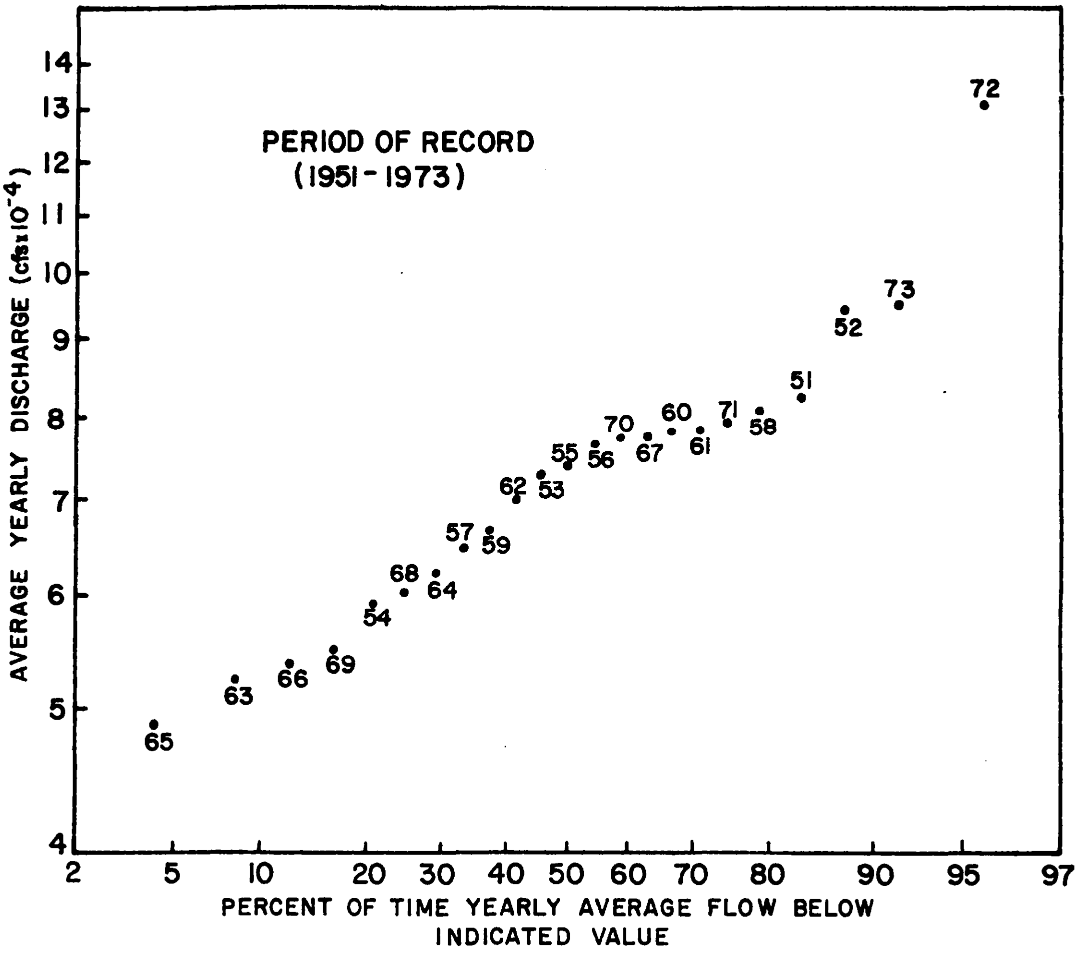


Figure III-1. Yearly average flow duration curve for the Chesapeake Bay. (U.S. Geological Survey data 1951-1973).

Figure III-2 shows a plot of the monthly average freshwater flows into Chesapeake Bay for these years, and the 23-year average monthly flows derived by the U.S. Geological Survey. Table III-1 shows the location of the Geological Survey's transects and the monthly average flows for 1968, 1970 and 1973 at these cross sections. These data are averaged data and, as such, do not adequately represent extreme events.

With respect to flushing and dispersion of pollutants, low inflows are considered most critical. The 7-day 10-year low flow from each of the 5 major river systems was estimated at locations above tidal influence for these rivers. Based on these data a low flow condition for the entire Bay can be estimated from drainage area considerations. Table III-2 lists the 7-day 10-year low flows for the major rivers. Assuming a linear relationship between drainage area and flow rate, the 7-day 10-year low flow for the entire Bay area is estimated to be about 5500 cfs. This estimate is probably somewhat low since the low flows are not likely to occur over the entire drainage area at the same time. An estimate of 8000 cfs seems reasonable for the 7-day 10-year low flow condition for the entire Bay system.

2. Temperature

The range of temperatures naturally experienced in the Chesapeake Bay is extreme in comparison with most coastal water bodies. The annual surface temperature range

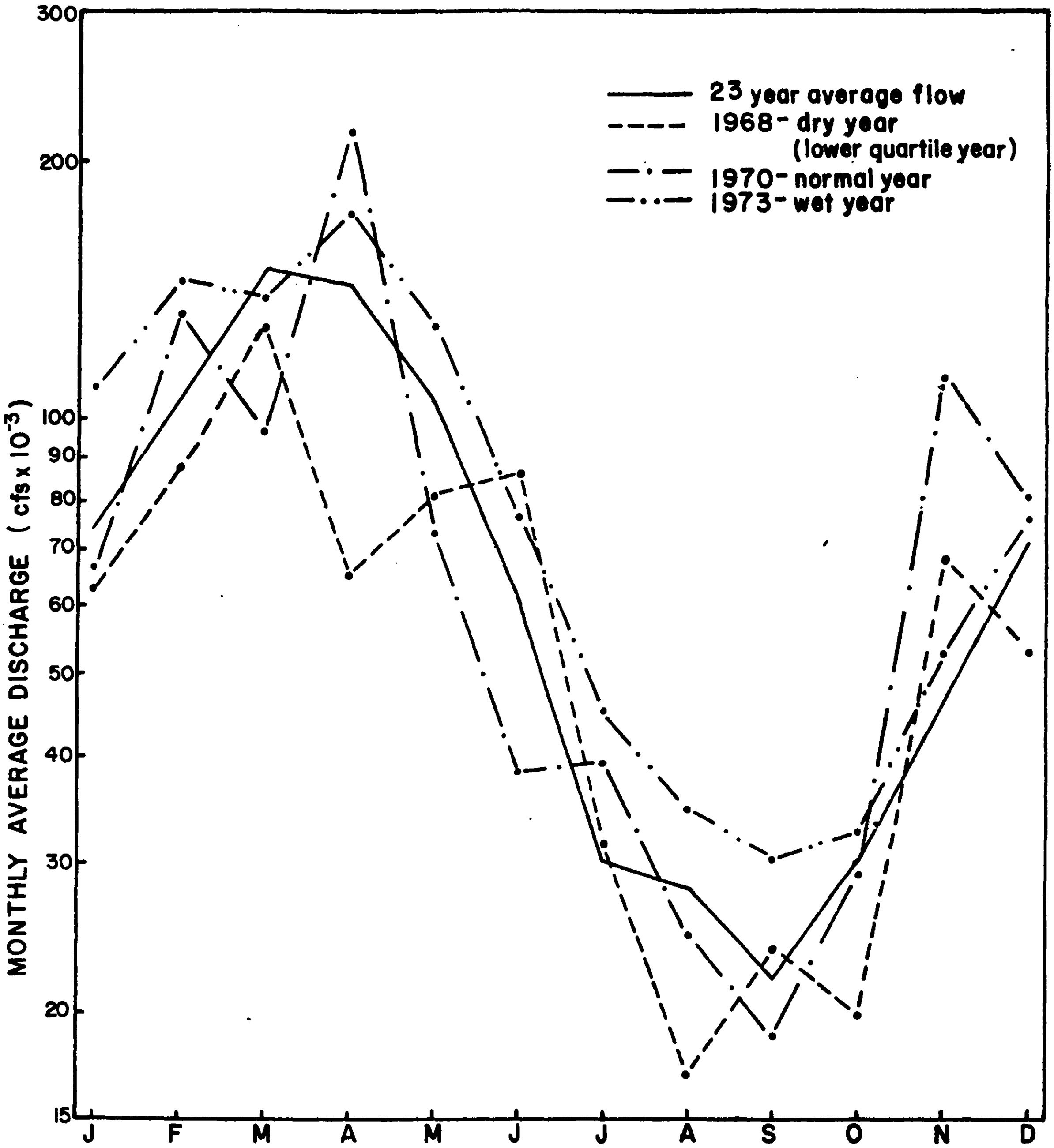
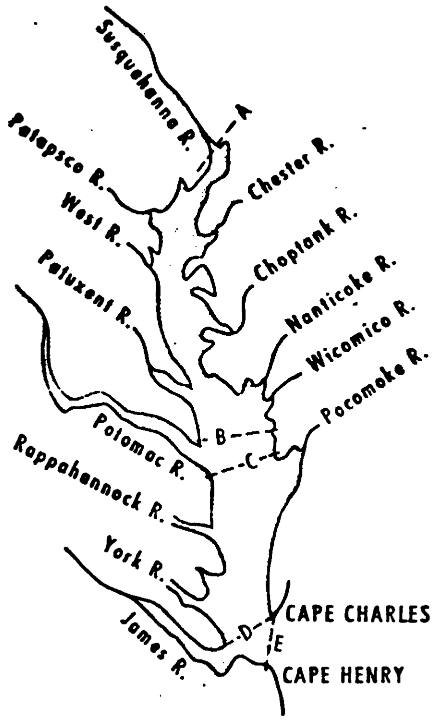
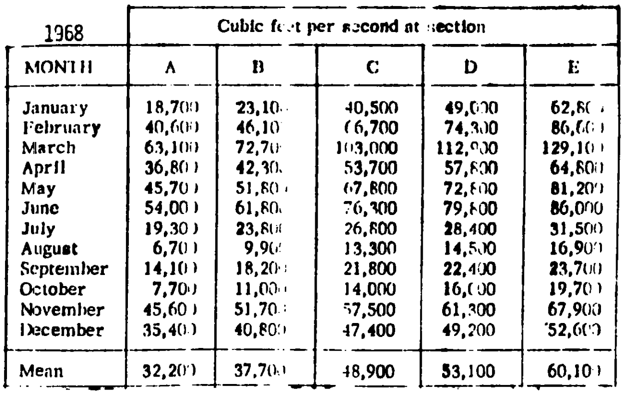


Figure III-2. Monthly average freshwater flow into the Chesapeake Bay. (U.S. Geological Survey data 1951-1973).

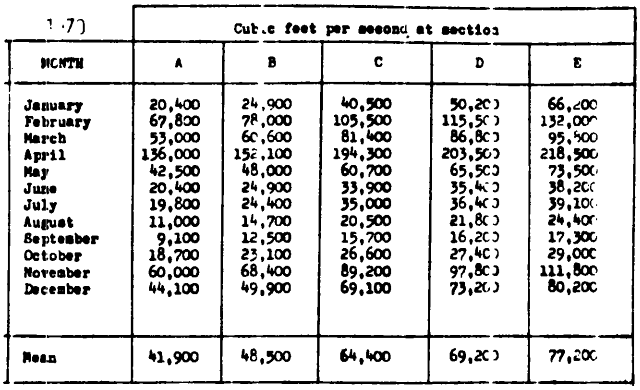


CUMULATIVE INFLOW TO CHESAPEAKE BAY
AT INDICATED CROSS SECTIONS

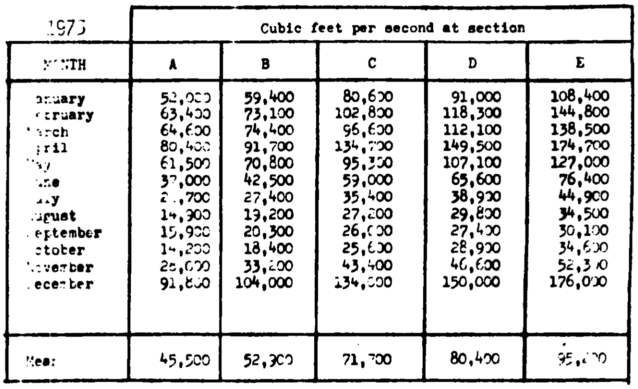
A	Mouth of Susquehanna R.
B	Above mouth of Potomac R.
C	Below mouth of Potomac R.
D	Above mouth of James R.
E	Mouth of Chesapeake Bay



1968	Cubic feet per second at section				
MONTH	A	B	C	D	E
January	18,700	23,100	40,500	49,000	62,800
February	40,600	46,100	66,700	74,300	86,600
March	63,100	72,700	103,000	112,900	129,100
April	36,800	42,300	53,700	57,800	64,800
May	45,700	51,800	67,800	72,800	81,200
June	54,000	61,800	76,300	79,800	86,000
July	19,300	23,800	26,800	28,400	31,500
August	6,700	9,900	13,300	14,500	16,900
September	14,100	18,200	21,800	22,400	23,700
October	7,700	11,000	14,000	16,000	19,700
November	45,600	51,700	57,500	61,300	67,900
December	35,400	40,800	47,400	49,200	52,600
Mean	32,200	37,700	48,900	53,100	60,100



1970	Cubic feet per second at section				
MONTH	A	B	C	D	E
January	20,400	24,900	40,500	50,200	66,200
February	67,800	78,000	105,500	115,500	132,000
March	53,000	60,600	81,400	86,800	95,500
April	136,000	152,100	194,300	203,500	218,500
May	42,500	48,000	60,700	65,500	73,500
June	20,400	24,900	33,900	35,400	38,200
July	19,800	24,400	35,000	36,400	39,100
August	11,000	14,700	20,500	21,800	24,400
September	9,100	12,500	15,700	16,200	17,300
October	18,700	23,100	26,600	27,400	29,000
November	60,000	68,400	89,200	97,800	111,800
December	44,100	49,900	69,100	73,200	80,200
Mean	41,900	48,500	64,400	69,200	77,200



1973	Cubic feet per second at section				
MONTH	A	B	C	D	E
January	52,000	59,400	80,600	91,000	108,400
February	63,400	73,100	102,800	118,300	144,800
March	64,600	74,400	96,600	112,100	138,500
April	80,400	91,700	134,700	149,500	174,700
May	61,500	70,800	95,300	107,100	127,000
June	37,000	42,500	59,000	65,600	76,400
July	21,700	27,400	35,400	38,900	44,900
August	14,900	19,200	27,200	29,800	34,500
September	15,900	20,300	26,000	27,400	30,100
October	14,200	18,400	25,600	28,900	34,600
November	26,000	33,200	43,400	46,600	52,300
December	91,800	104,000	134,000	150,000	176,000
Mean	45,500	52,300	71,700	80,400	95,200

Table III-1. Monthly average flows through various cross-sections of the Chesapeake Bay during 1968, 1970, 1973. (U.S. Geological Survey data 1951 - 1973).

Table III-2. 7-Day 10-Year Low Flow Conditions in the Major Rivers of the Chesapeake Bay.

River	Gauge Location	Drainage Area To Gauge Location (mi^2)	7 Day 10 Year Low Flow (cfs)	Total Drainage Area to River Mouth (mi^2)
Susquehanna	Marietta, Pa.	25,990[1]	2,600[1]	27,496[6]
Potomac	Washington, D.C.	11,560[2]	725[2]	13,922[6]
James	Richmond, Va.	6,757[3]	680[3]	10,155[6]
Rappahannock	Fredericksburg, Va.	1,599[4]	50[4]	2,608[6]
York				
1) Pamunkey	Hanover, Va.	1,072[5]	42[5]	2,609[6]
2) Mattaponi	Beulahville, Va.	619[5]	20[5]	
Total - Major Rivers		47,597	4,117	56,790
Total - Bay				64,159

Source:
1 - Busch & Shaw 1966
2 - Va. D.C.E.C. Planning Bulletin 209
3 - Va. D.C.E.C. Planning Bulletin 215
4 - Va. D.C.E.C. Planning Bulletin 221
5 - Va. D.C.E.C. Planning Bulletin 227
6 - Seitz 1971

in the open Bay is approximately 0°C to 29°C (32°F-84°F). The temperature range of deep bottom waters is a bit less, 1°C to 25°C (34°F-77°F). Because it is latitudinally extensive, temperatures in the northern and southern portions of the Bay may differ markedly. Temperatures in the Virginia portion annually average about 0.5°C (0.9°F) warmer, although the region of the Bay mouth is generally cooler than elsewhere during the summer because its temperature is moderated by the influence of the ocean. Temperatures range more widely and fluctuate more quickly in shallow waters, where summer temperatures in excess of 30°C (86°F) are not uncommon.

Figure III-3 depicts a typical seasonal oscillation of temperature in the mid-Bay. Year-to-year variations in this pattern are relatively small. Shorter term variations (e. g. diurnal) on the order of 1°C to 3°C (1.8°F-5.4°F) are common.

As seen in Figure III-3, the Bay waters become progressively warmer from March to August. During this time the upper section of the Bay (nautical mile 155 to 135) tends to be vertically homogeneous with respect to temperature i.e. there is little difference between surface and bottom temperatures. Strong vertical gradients in temperature, however, exist at mid-depth along the middle portion of the Bay (nautical mile 125 to 65). The coolest waters are found in the bottom layers at the upper end of this deep middle portion of the Bay and in the bottom layers of the mouth. The warmest waters, with the possible exception

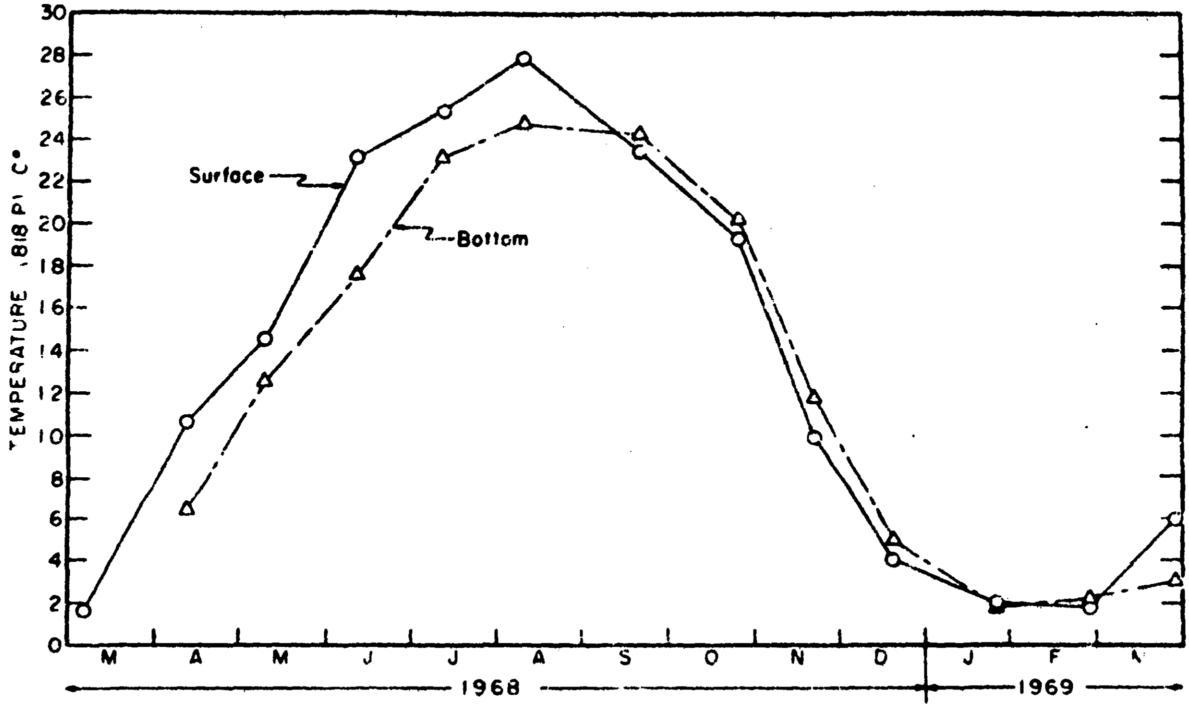


Figure III-3. Monthly variation of temperature at a station in the mid-Bay (from Seitz, 1971b).

of some surface values, are found at the head of the Bay.

In the cooling season from September through December, this temperature pattern is altered. The waters at the mouth of the Bay are warmer than those at the head and the vertical gradient results from warmer waters lying under cooler ones. This vertical gradient is more moderate than that of the summer season.

In January and February there is very little temperature variation either longitudinally or vertically (Seitz, 1971b).

3. Salinity

The rate of Susquehanna freshwater inflow is the principal influence on salinity distribution in the Bay (Schubel, 1972). Temporal patterns may reflect long term climatic trends such as drought cycles, seasonal runoff patterns, or aperiodic events, such as extratropical storms and hurricanes. The recurring seasonal patterns are governed by the seasonal distribution of runoff, which is generally highest in spring and least in fall; thus, the salinity at any given location averages 2-7 ppt lower in spring than in fall (Figs. III-4 and III-5).

The longitudinal variation in salinity is fairly regular along the surface of the Bay; values range from 25-30 ppt near the mouth to 0.1 ppt near the head. The longitudinal salinity gradient near the head, however, tends to be much steeper than near the mouth, since a pronounced front may be produced at the meeting of fresh Susquehanna River water with saline Bay water (Seitz 1971b).

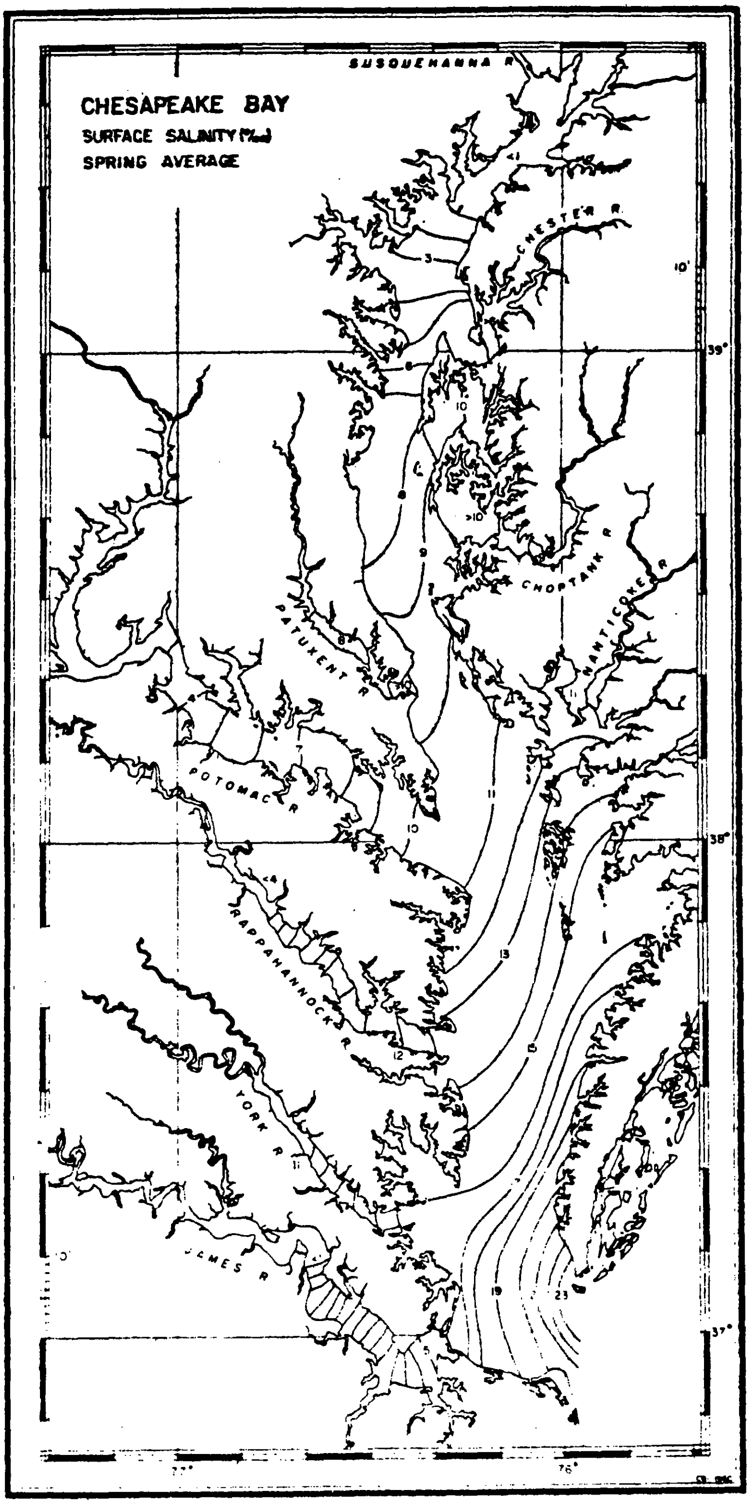


Figure III-4. Average surface salinity distribution in Chesapeake Bay during the spring months (from Stroup and Lynn, 1963).

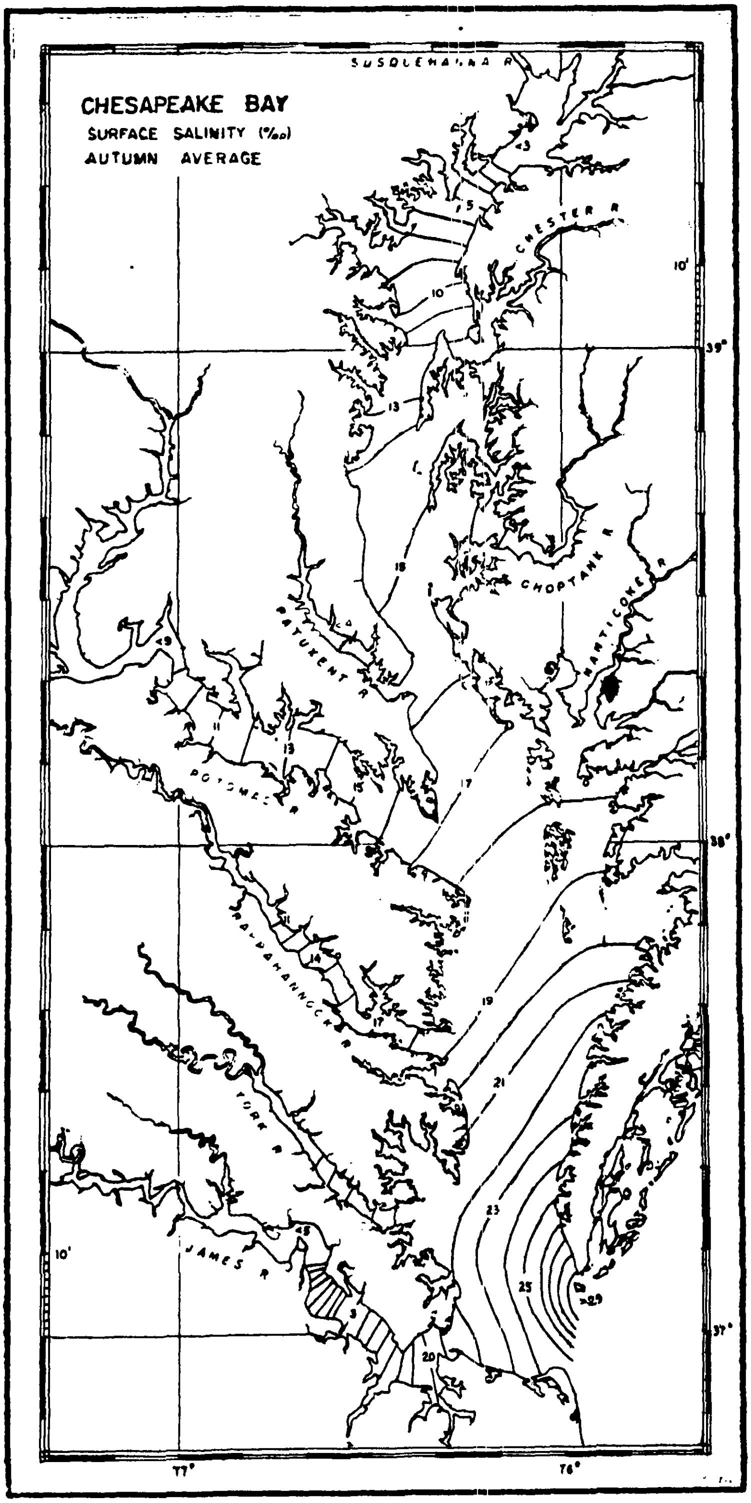


Figure III-5. Average surface salinity distribution in the Chesapeake Bay during the fall months (from Stroup and Lynn, 1963).

Salinity is generally higher on the eastern side of the Bay because of greater freshwater inflow on the western shore and the Coriolis effect.

Salinity is generally higher and less variable in bottom waters than on the surface (Fig. III-6). The surface and bottom salinities differ by 2 ppt to 9 ppt depending upon the location in the Bay and the time of year. This vertical stratification is most pronounced in the deep middle section of the Bay (nautical mile 110 to 165), from May through September, particularly in May (Seitz, 1971b). At the more shallow head and mouth of the Bay, vertical stratification is most extreme from January through April.

4. Oxygen

Dissolved oxygen concentrations in the Bay are regulated by a complex of physical and biological processes which add or subtract oxygen from the water. Surface waters in the open Bay are at or near saturation levels throughout the year. Warming of the water in the spring decreases O_2 solubility and increases biochemical uptake rates. Circulation patterns in summer months cause vertical stratification of the water mass. These factors combine to cause oxygen depletion in deep waters of the middle and upper Bays (Figs. III-7 and III-8). By mid-June, oxygen in deeper layers may be less than 1 ml/ℓ (1.43 mg/ℓ), while surface waters are nearly saturated at 5 ml/ℓ (7.1 mg/ℓ).

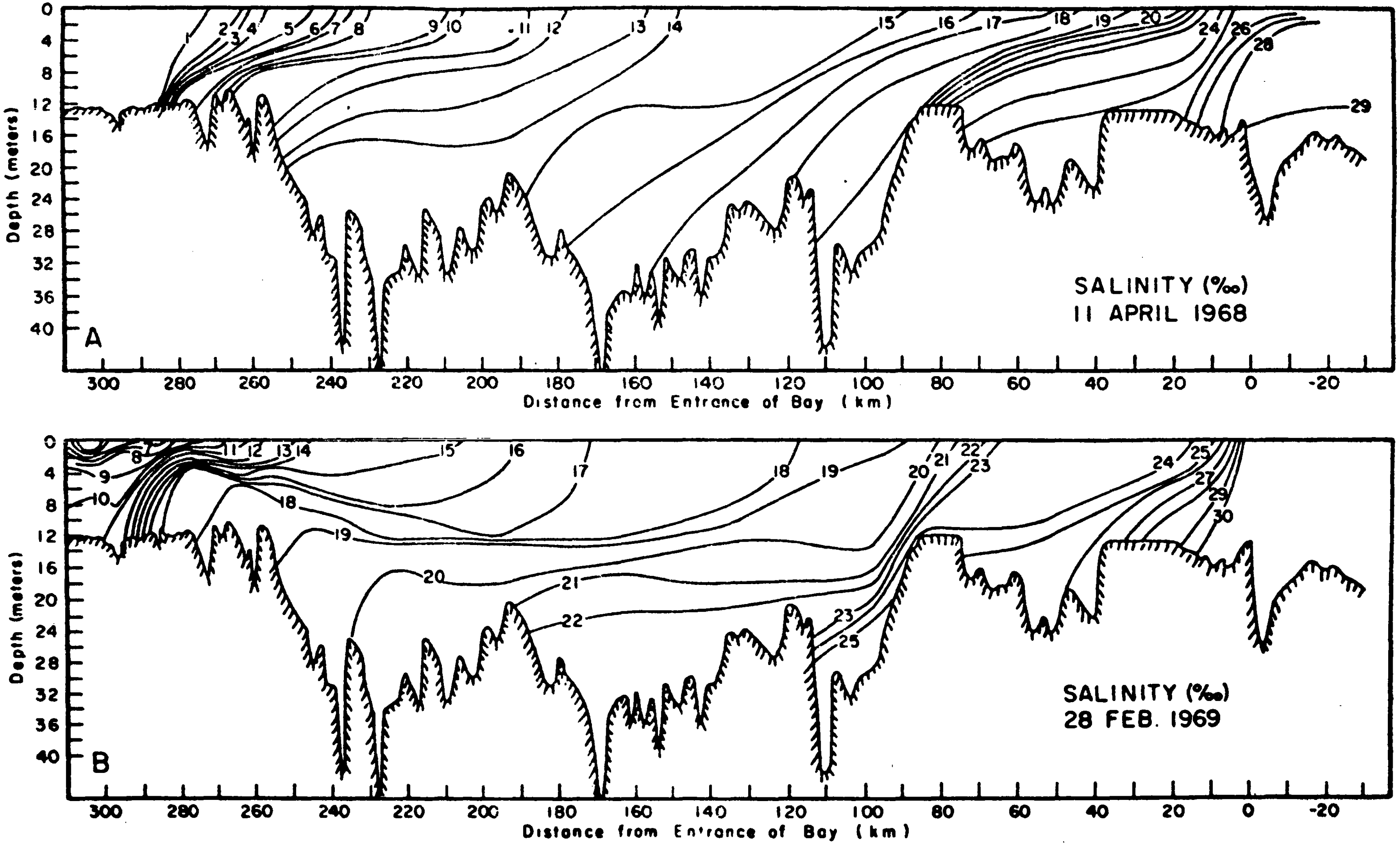


Fig. III-6. Longitudinal salinity distribution along axis of Chesapeake Bay during a period of high river flow (upper panel) and low river inflow (lower panel) (from Seitz. 1971b).

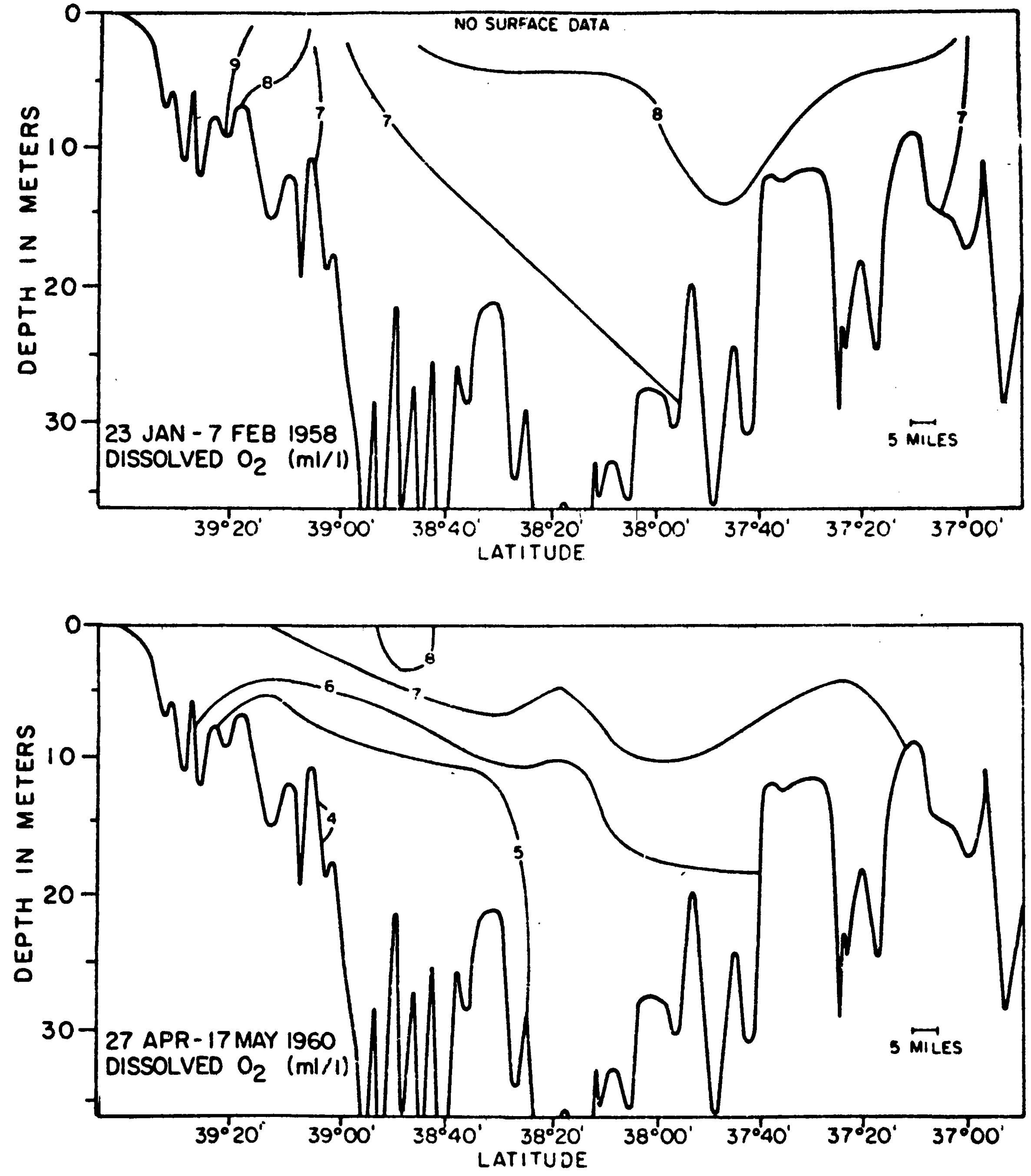


Fig. III-7. Longitudinal distributions of dissolved oxygen along axis of Chesapeake Bay (from Schubel, 1972).

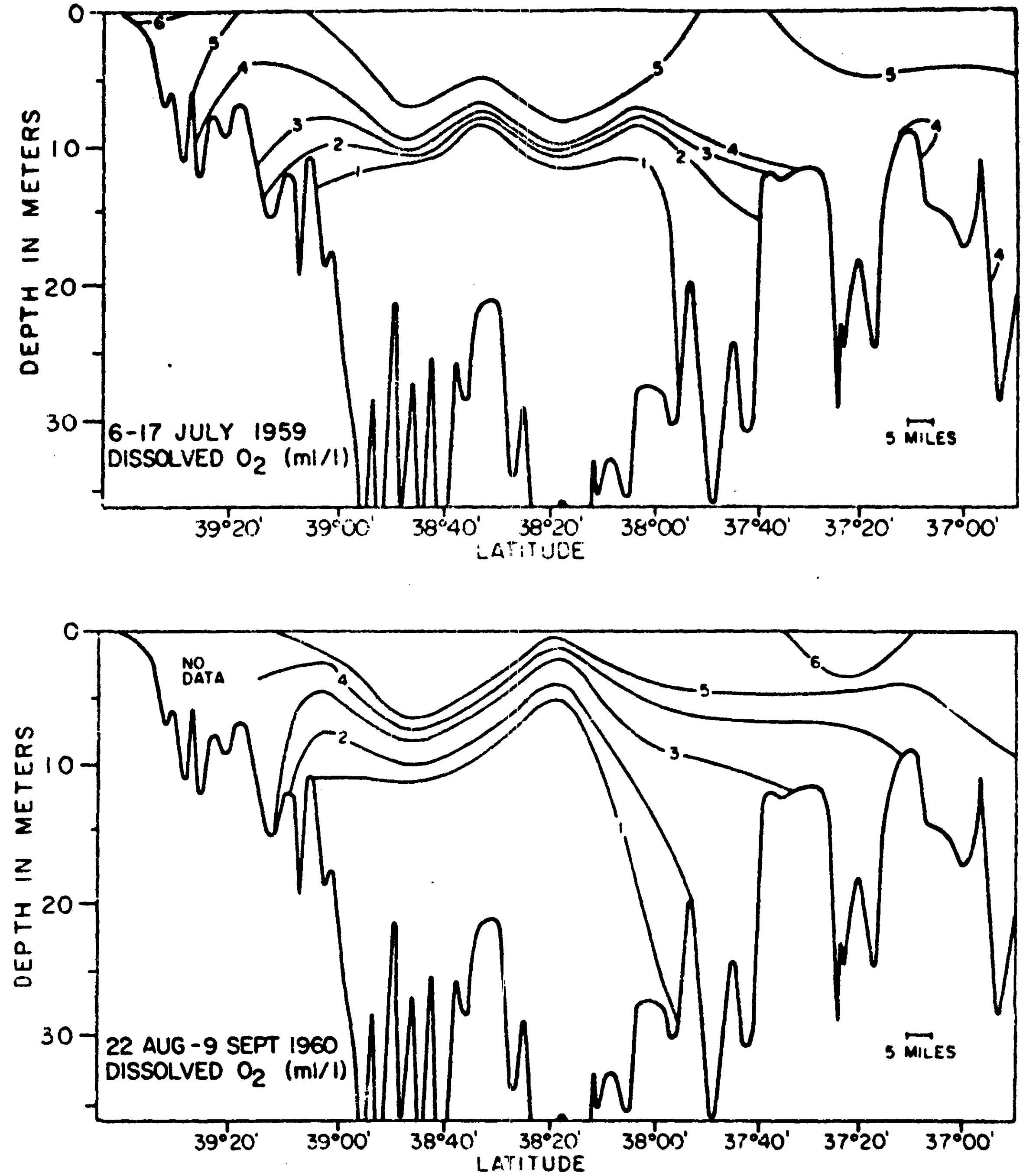


Fig. III-8. Longitudinal distributions of dissolved oxygen along axis of Chesapeake Bay (from Schubel, 1972).

By mid-summer oxygen at depths greater than 12 m may be less than 0.1 ml/ℓ (0.14 mg/ℓ). Fall cooling mixes the water column and bottom waters are oxygenated; the entire water column becomes nearly saturated.

Oxygen depletion in some tributary estuaries in the upper Bay has been attributed to nutrient loading from sewage treatment plants or non-point sources (principally septic field drainage) (Schubel, 1972). Most sewage is discharged into tributaries rather than directly into the Bay (Brush, 1974) and the degree to which this source contributes to the development of oxygen depression in the Bay itself is unknown. Several authors (Schubel, 1972; Flemer, 1972) have expressed the opinion that the upper Bay is at the limits of its capacity to assimilate nutrients without serious worsening of dissolved oxygen conditions.

5. Nutrients

The major nutrients in the Bay are derived from nutrient-rich freshwater inflows. The Susquehanna River is the major source of nutrients in the upper Bay. At Havre de Grace, Maryland where the river enters the Bay, total phosphorus ranges from 1.0 µg-at/ℓ (31 µg/ℓ) in the summer and fall to 1.5 µg-at/ℓ (46.5µg/ℓ) during winter and spring. Nitrogen, mainly as nitrate, ranges from a high of 80 to 105 µg-at/ℓ (1.12 to 1.47 mg/ℓ) in the spring to about 50 µg-at/ℓ (0.7 mg/ℓ) during the remainder of the year (Schubel 1972). As one progresses down the Bay, concentrations of nitrogen decline while there may be a slight rise in phosphorus levels around the Baltimore area and a subsequent decline. In the lower Bay, phosphate levels are generally less than 1.0 μg-at/ℓ (31 μg/ℓ) and nitrate-nitrite levels range from 0.14 μg-at/ℓ (2 μg/ℓ) to springtime highs of about 20 μg-at/ℓ (280 μg/ℓ) (Zubkoff, et al., 1973).

The distribution of nitrite and nitrate in the upper Bay is depicted in Figures III-9 and III-10.

C. Present Conditions

1. Temperature, Salinity and Hydrology

Figures III-11 through III-13 show the longitudinal temperature and salinity distributions along an axis of the Chesapeake Bay during low slack water on three different occasions. The salinity profiles, corresponding to low, average, and high Susquehanna River freshwater discharge levels, respectively, were those used to calibrate the mathematical water quality model. The freshwater inflows (calculated as described in Chapter IV), which prevailed at the time of the profiles are shown in Table III-3. Since the model is one-dimensional the salinity data were used to calculate cross-sectional average salinity profiles as described in Chapter VI (see Figures VI-1 through VI-3).

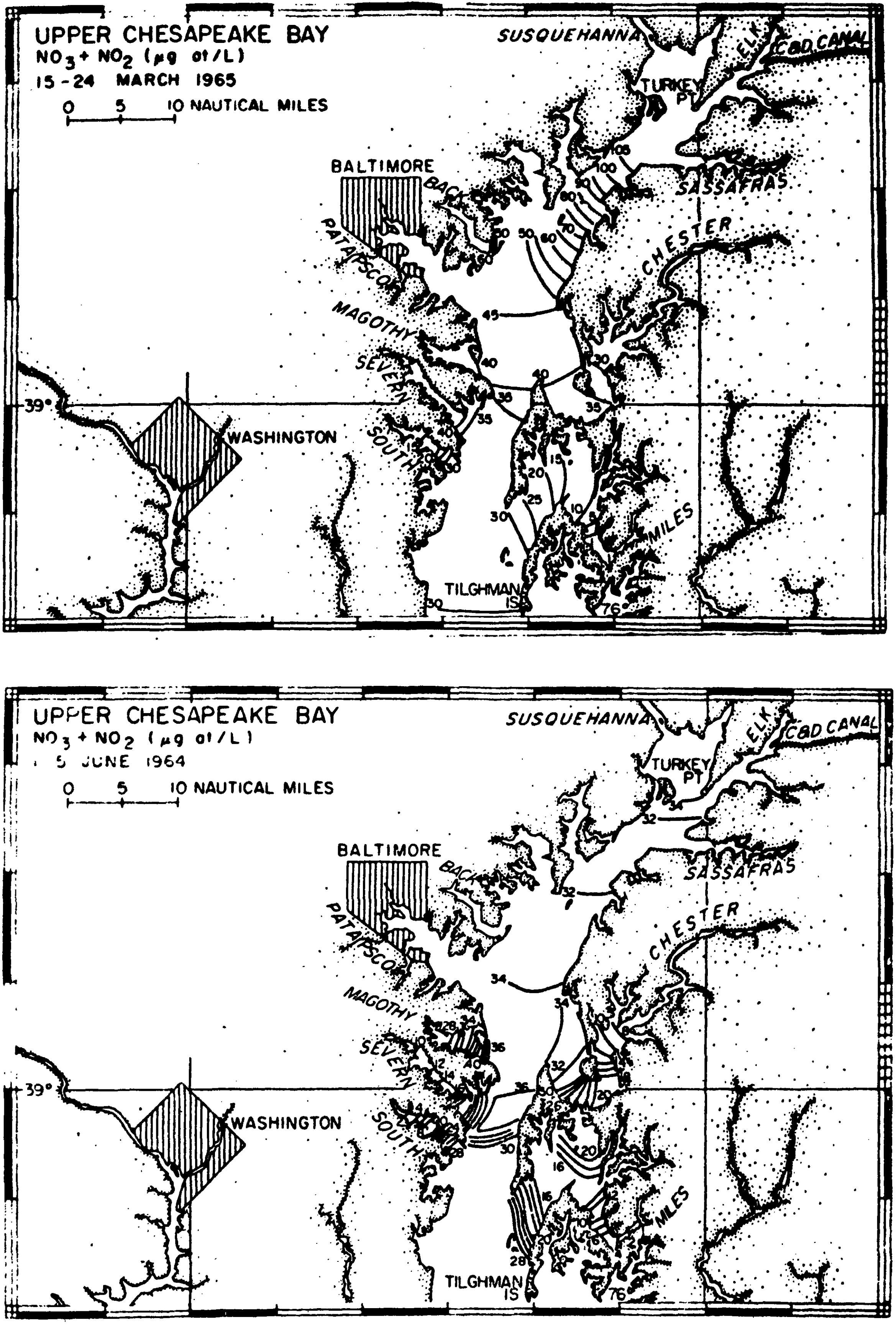


Fig. III-9. Surface nitrate distributions ($NO_3 + NO_2$) in upper Chesapeake Bay (from Schubel 1972).

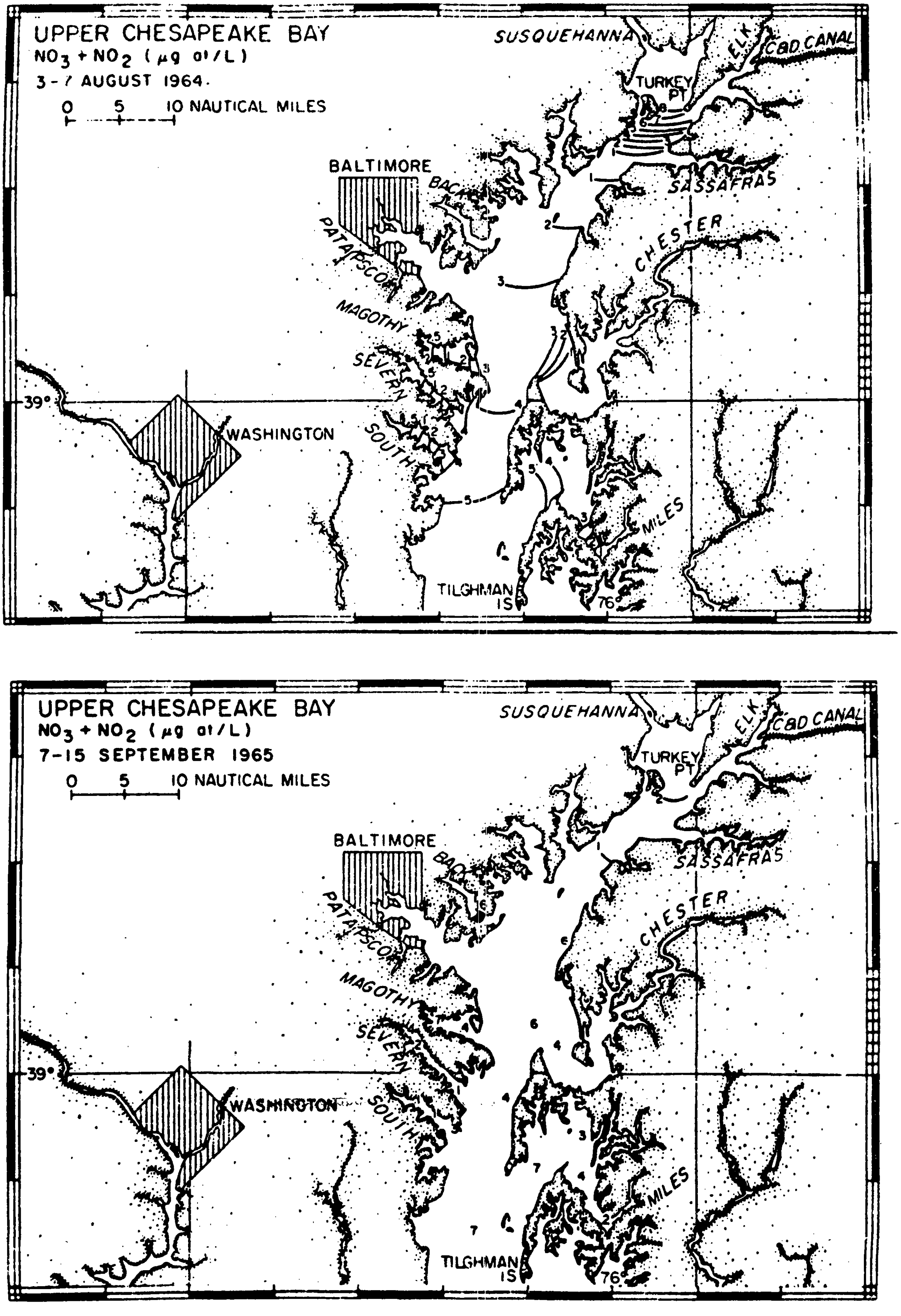


Fig. III-10. Surface nitrate distributions ($NO_3 + NO_2$) in upper Chesapeake Bay (from Schubel 1972).

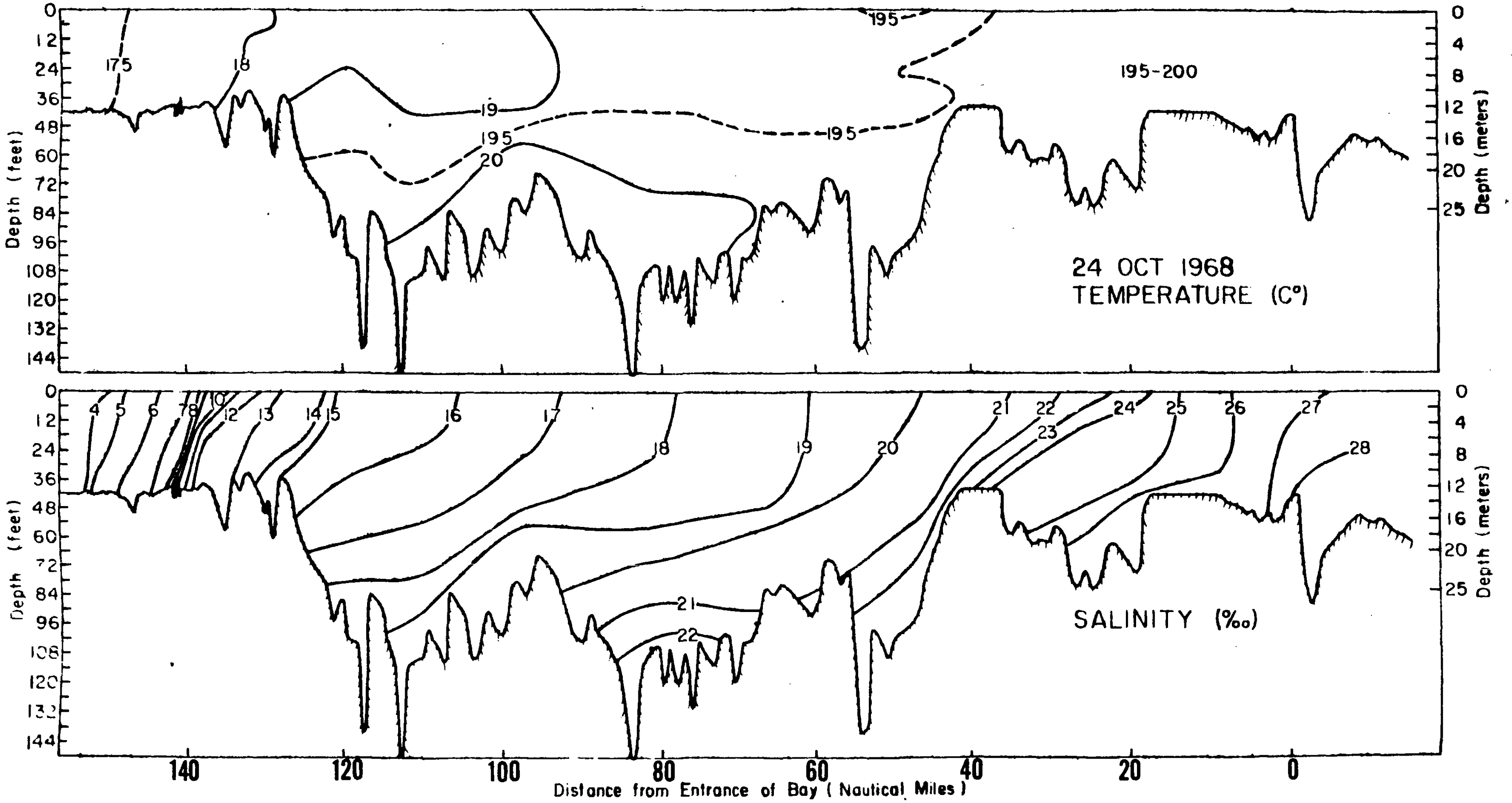


Figure III-11. Longitudinal temperature and salinity profiles along an axis of the Chesapeake Bay during a period of low freshwater inflow. (From: Seitz 1971b).

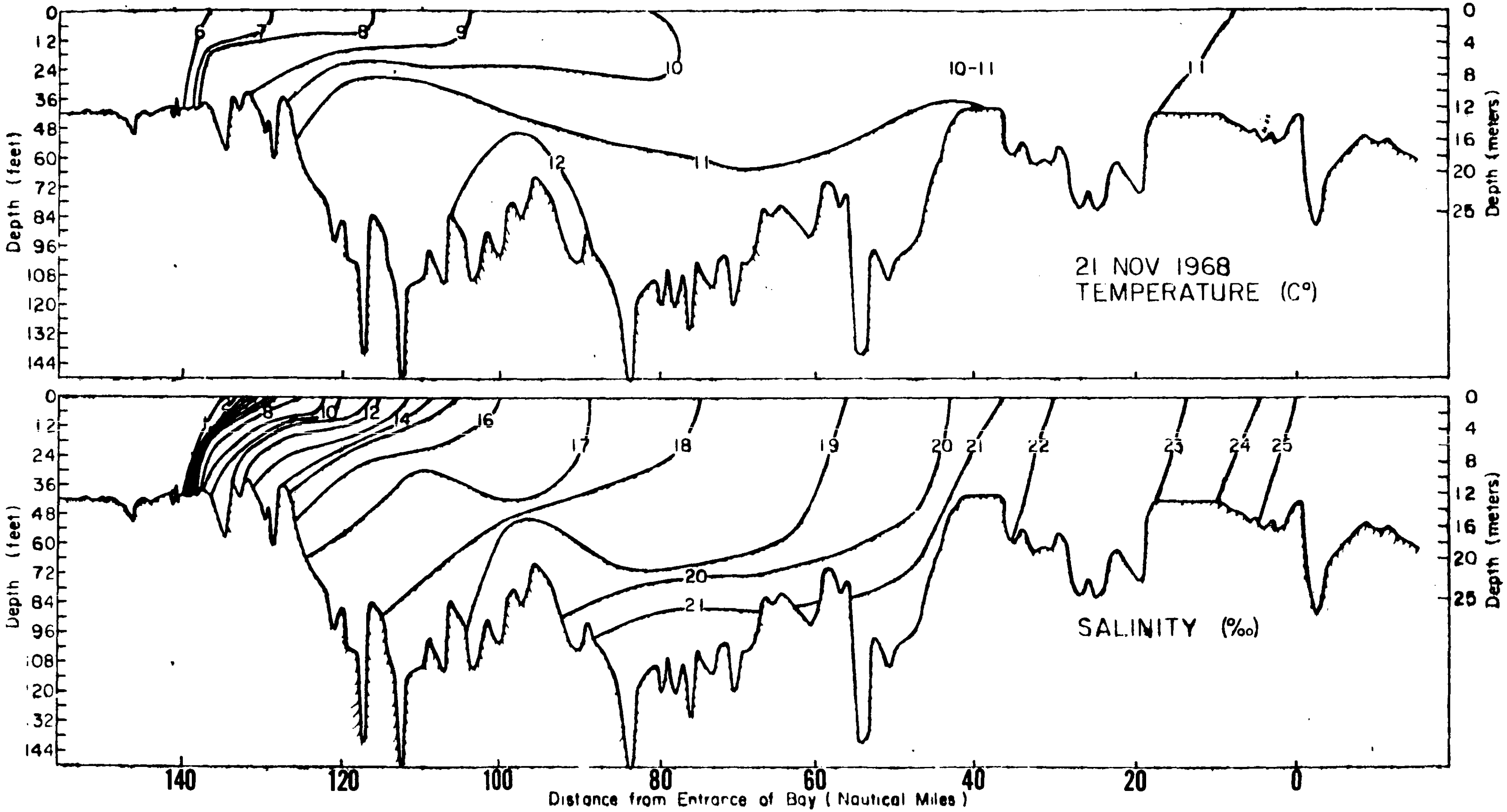


Figure III-12. Longitudinal temperature and salinity profiles along an axis of the Chesapeake Bay during a period of average freshwater inflow. (From: Seitz, 1971b).

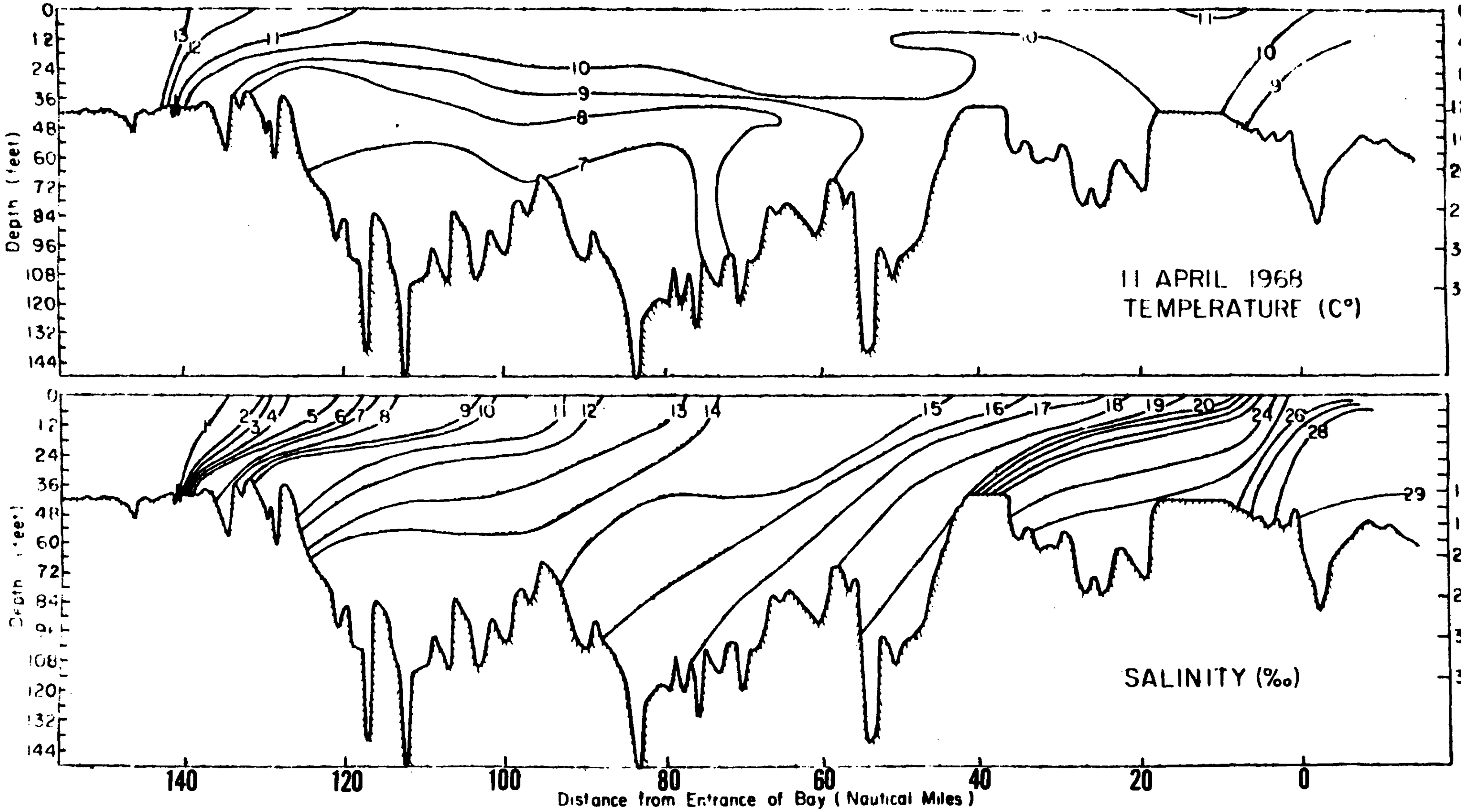


Figure III-13. Longitudinal temperature and salinity profiles along an axis of the Chesapeake Bay during a period of high freshwater inflow. (From: Seitz 1971b).

Table III-3. Model freshwater flows (cfs)

Date of Field Sampling	James	Potomac	Susquehanna
October 24, 1968	3080[1]	2031[1]	6945[3]
November 21, 1968	4616[1]	6944[1]	38739[3]
April 11, 1968	11050[2]	22800[2]	84300[3]

[1] Data reduced from U.S. Dept. of Interior Geol. Survey (1969)

[2] Date reduced from U.S. Dept. of Interior Geol. Survey (1968)

[3] Data reduced from U.S. Dept. of Interior Geol. Survey (1972)

The temperature distributions reflect the seasonal variations discussed in the previous section. Temperatures generally increase as one moves from head to mouth or from surface to bottom in the October and November profiles. This pattern is reversed in the April profile. The vertical temperature gradient in the middle section of the Bay is much more pronounced in April than in the other two months, as expected.

The salinity profiles also reflect some of the seasonal trends discussed. Salinities decrease from mouth to head regularly. The longitudinal gradient is steepest at the head of the Bay in the three profiles. A rather steep longitudinal salinity gradient also occurs near the mouth of the Bay in the April profile. Vertical salinity gradients are only moderate in the October and November profiles, and as expected, are largely restricted to the deep middle section of the Bay. More extreme surface to bottom salinity differences occur in April but are observed at the ends of the Bay to a greater degree than in the middle. These particular profiles were chosen for calibration of the water quality model because of their relatively moderate vertical salinity stratification - a phenomenon difficult to handle with a one-dimensional model.

2. Oxygen

Figures III-14 through III-25 show monthly dissolved oxygen (DO) profiles along the axis of the

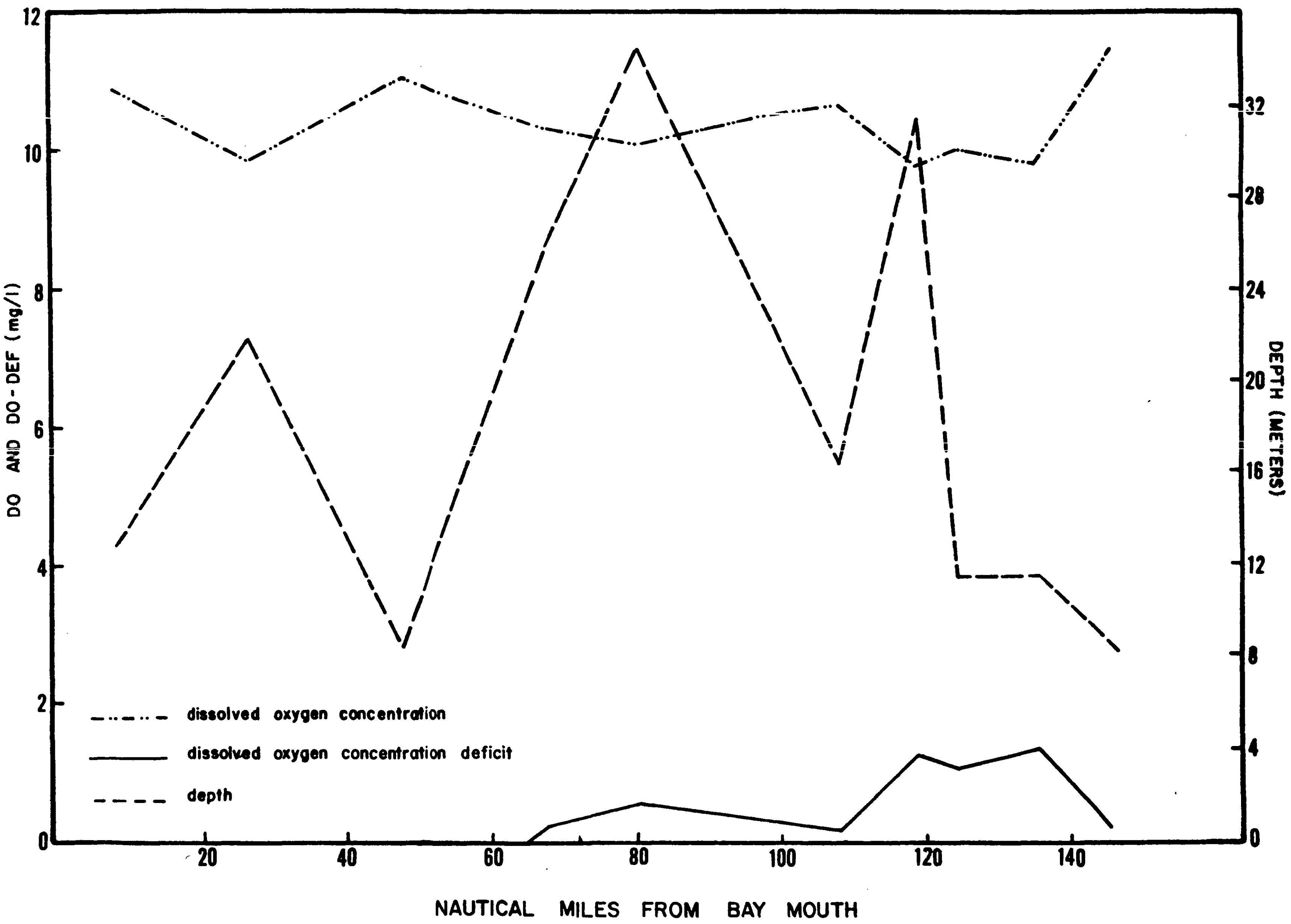


Figure III-14. Dissolved oxygen and oxygen deficit profiles for April 7-10, 1969.

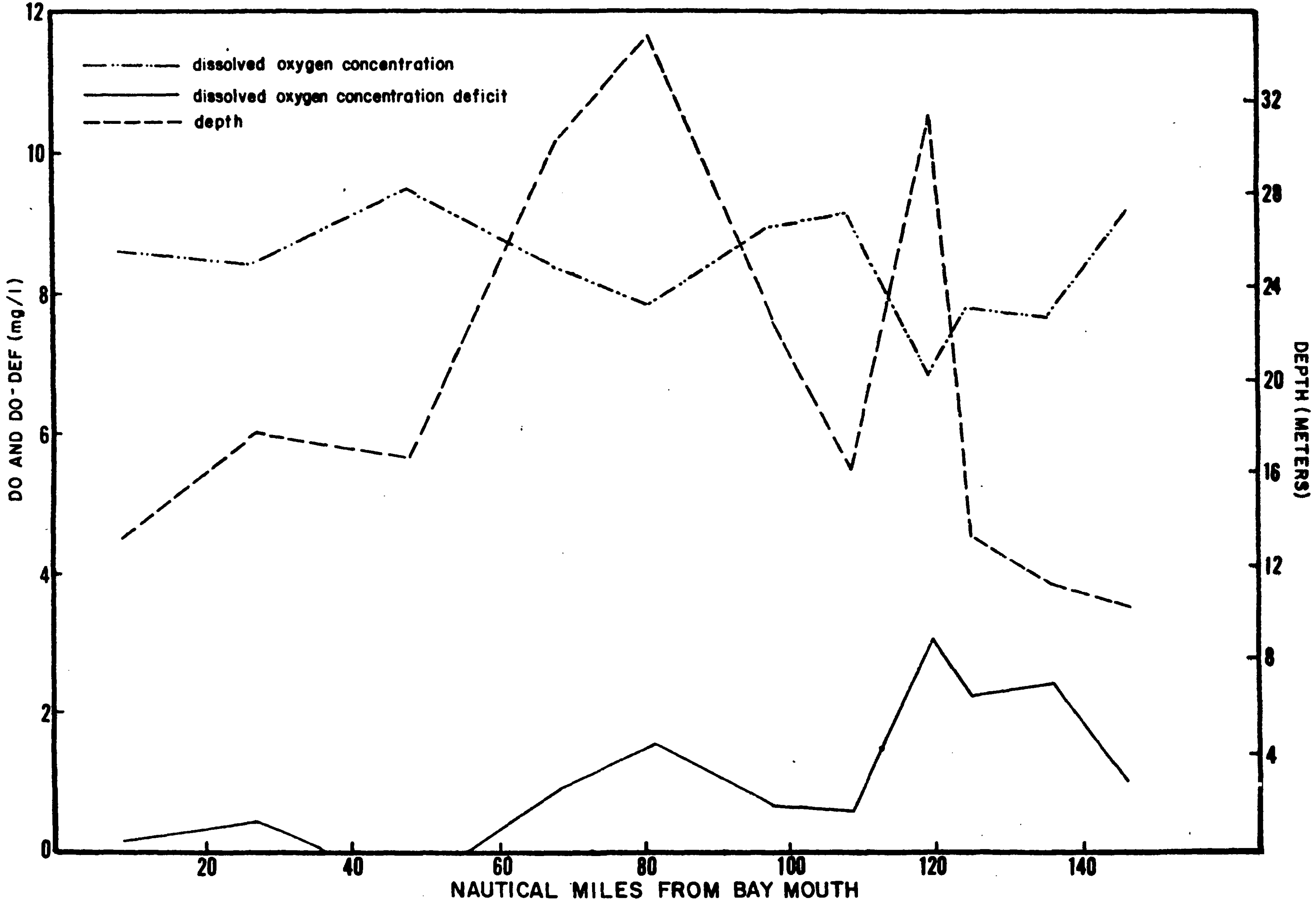


Figure III-15. Dissolved oxygen and oxygen deficit profiles for May 1-4, 1969.

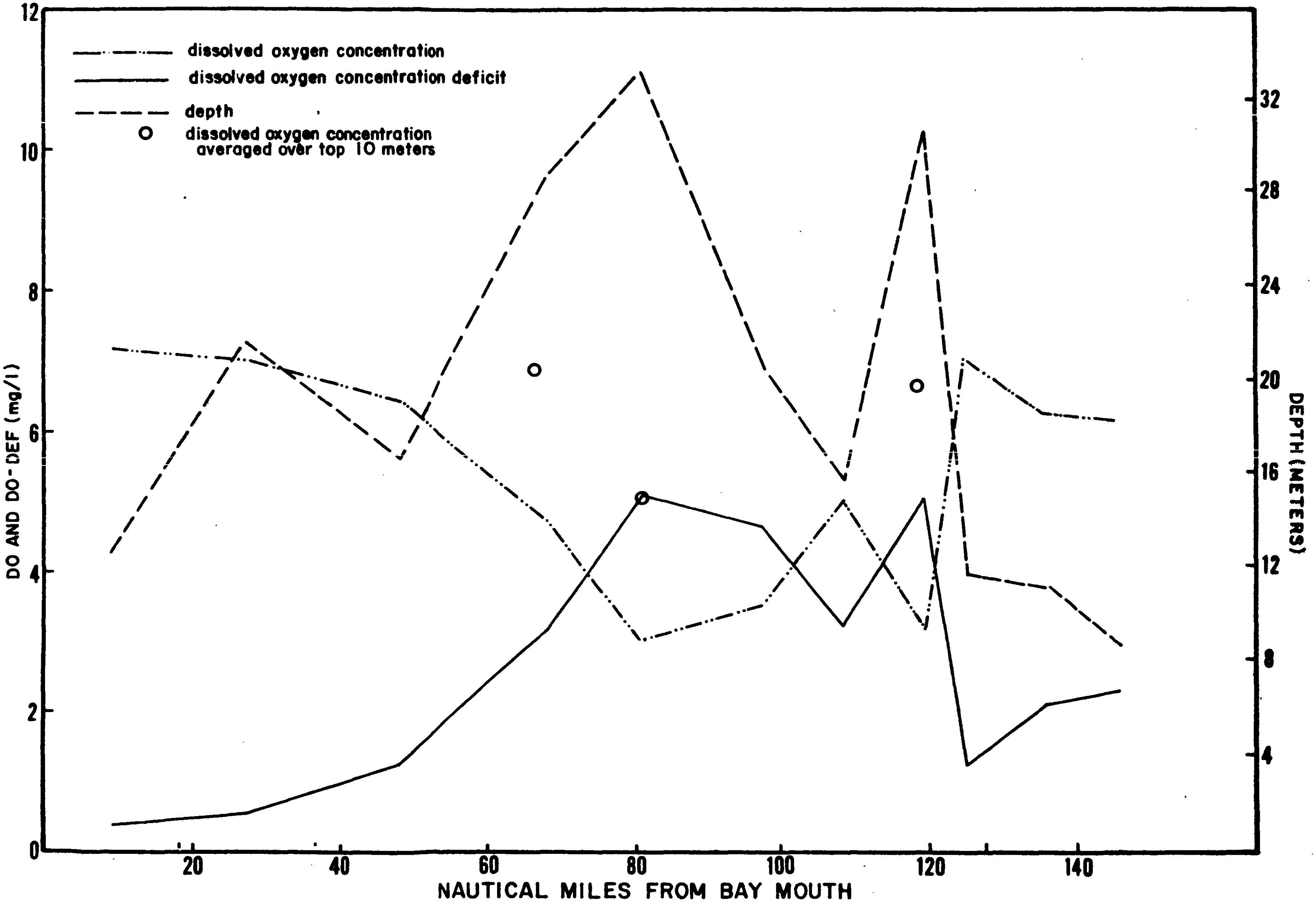


Figure III-16. Dissolved oxygen and oxygen deficit profiles for June 2-5, 1969.

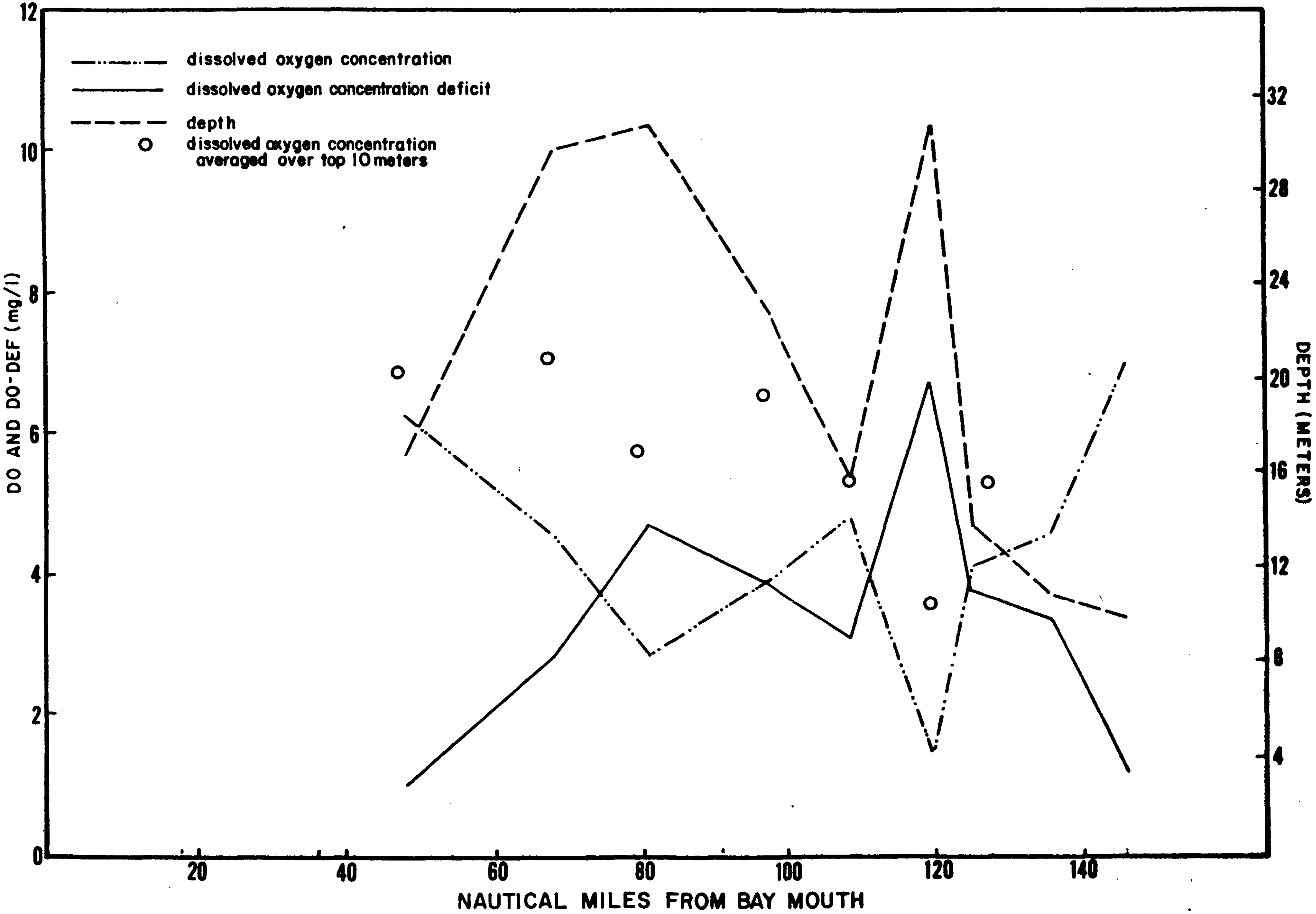


Figure III-17. Dissolved oxygen and oxygen deficit profiles for July 7-9, 1969.

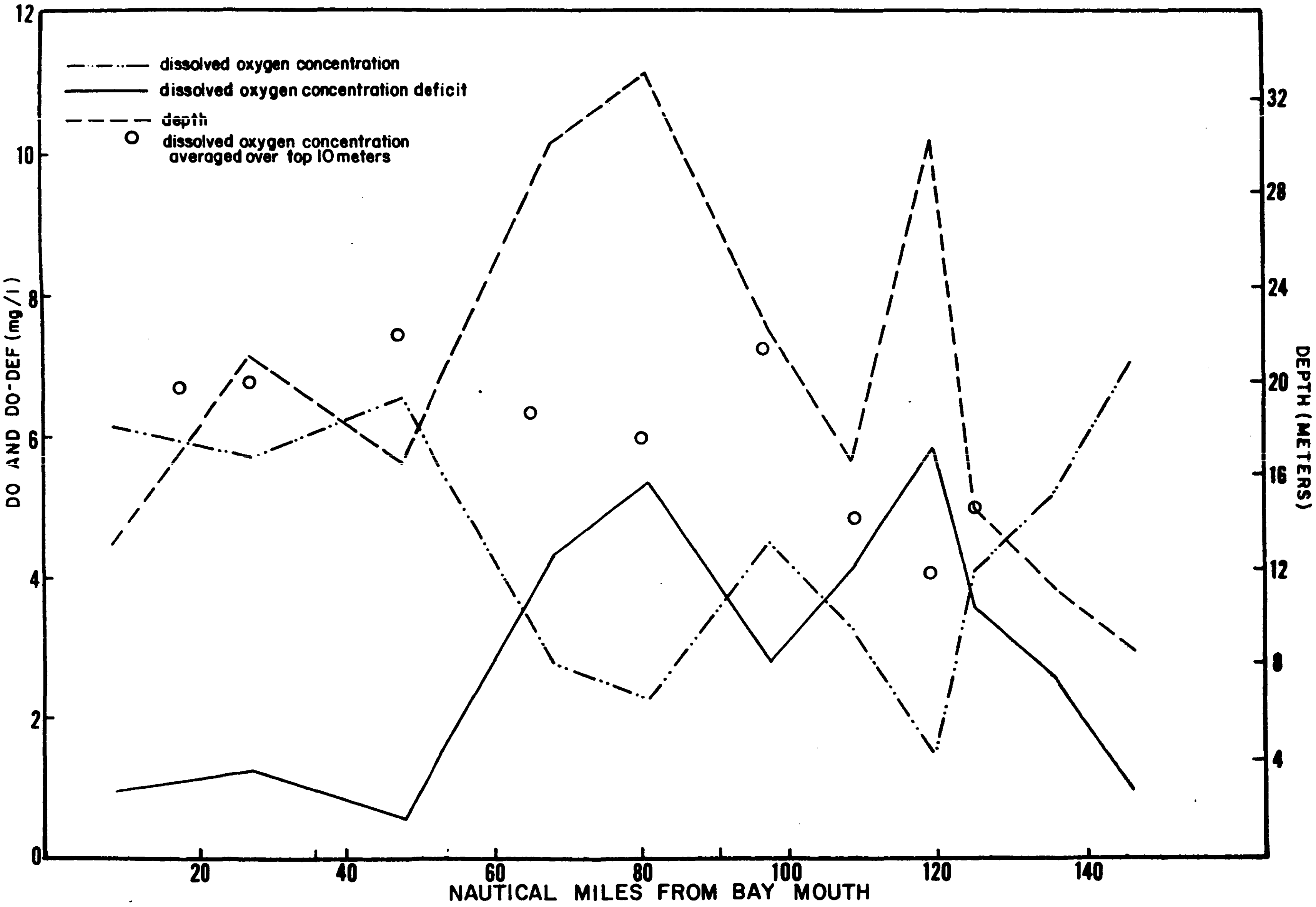


Figure III-18. Dissolved oxygen and oxygen deficit profiles for August 5-8, 1969.

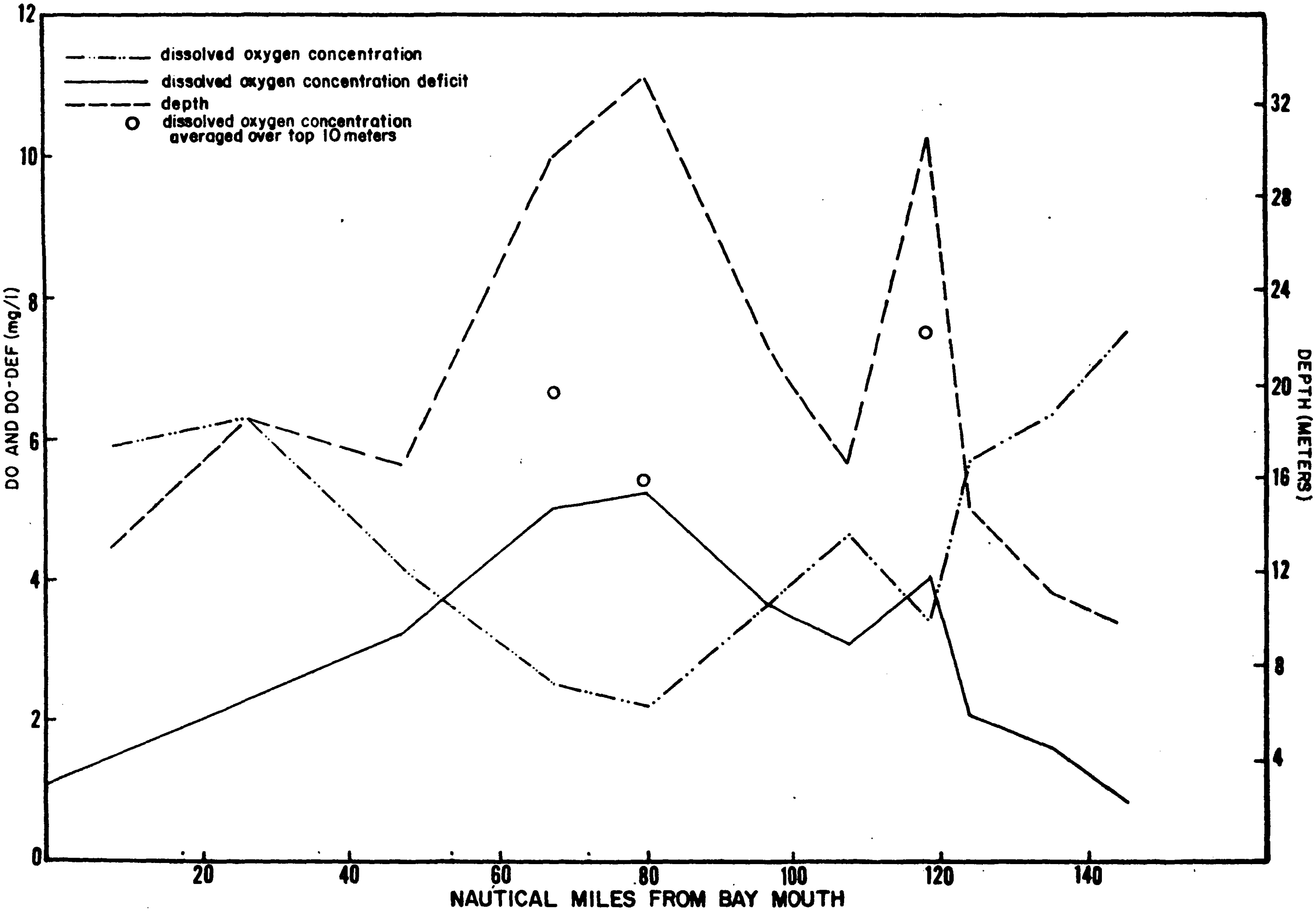


Figure III-19. Dissolved oxygen and oxygen deficit profiles for September 16-19, 1969.

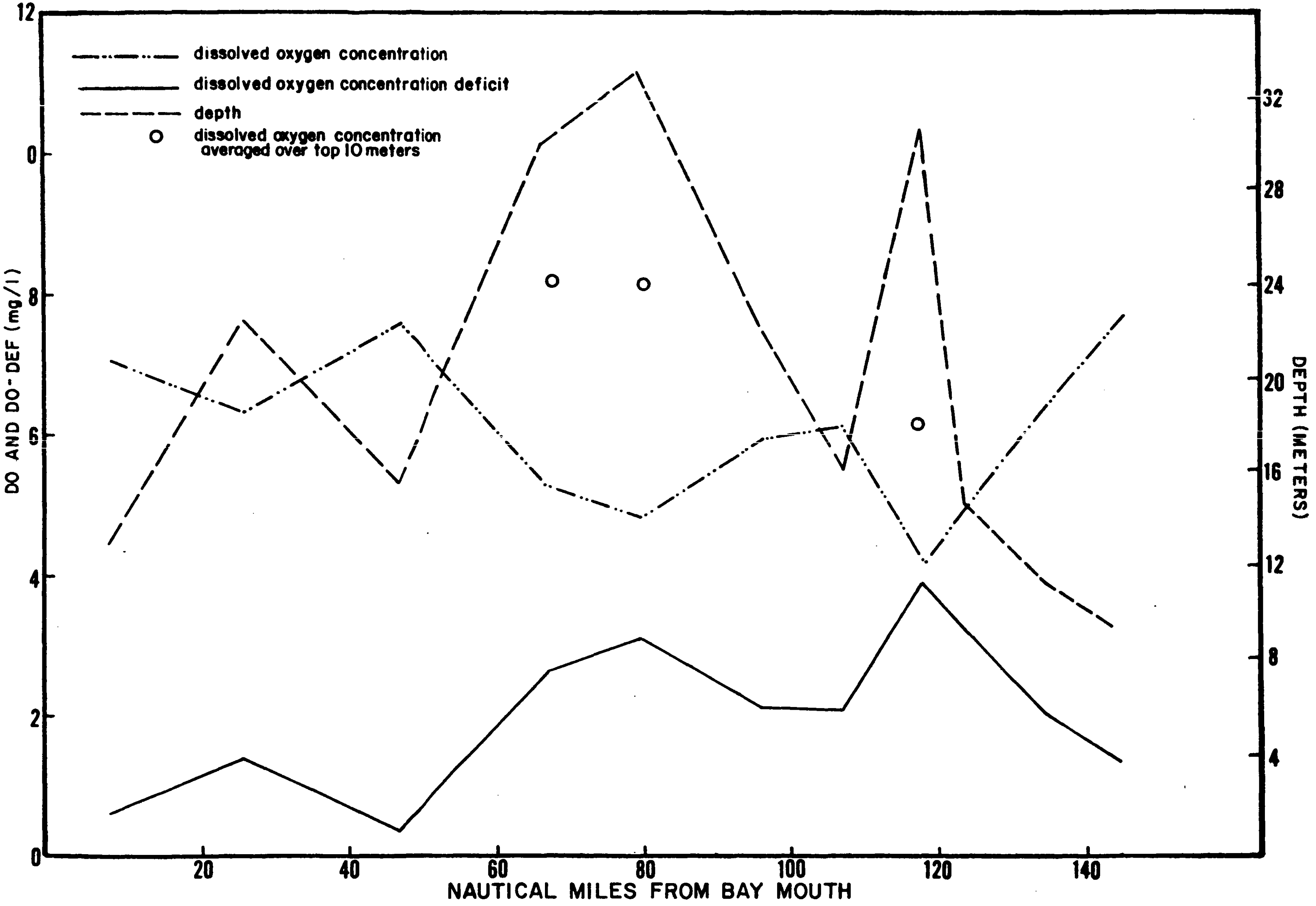


Figure III-20. Dissolved oxygen and oxygen deficit profiles for October 6-9, 1969.

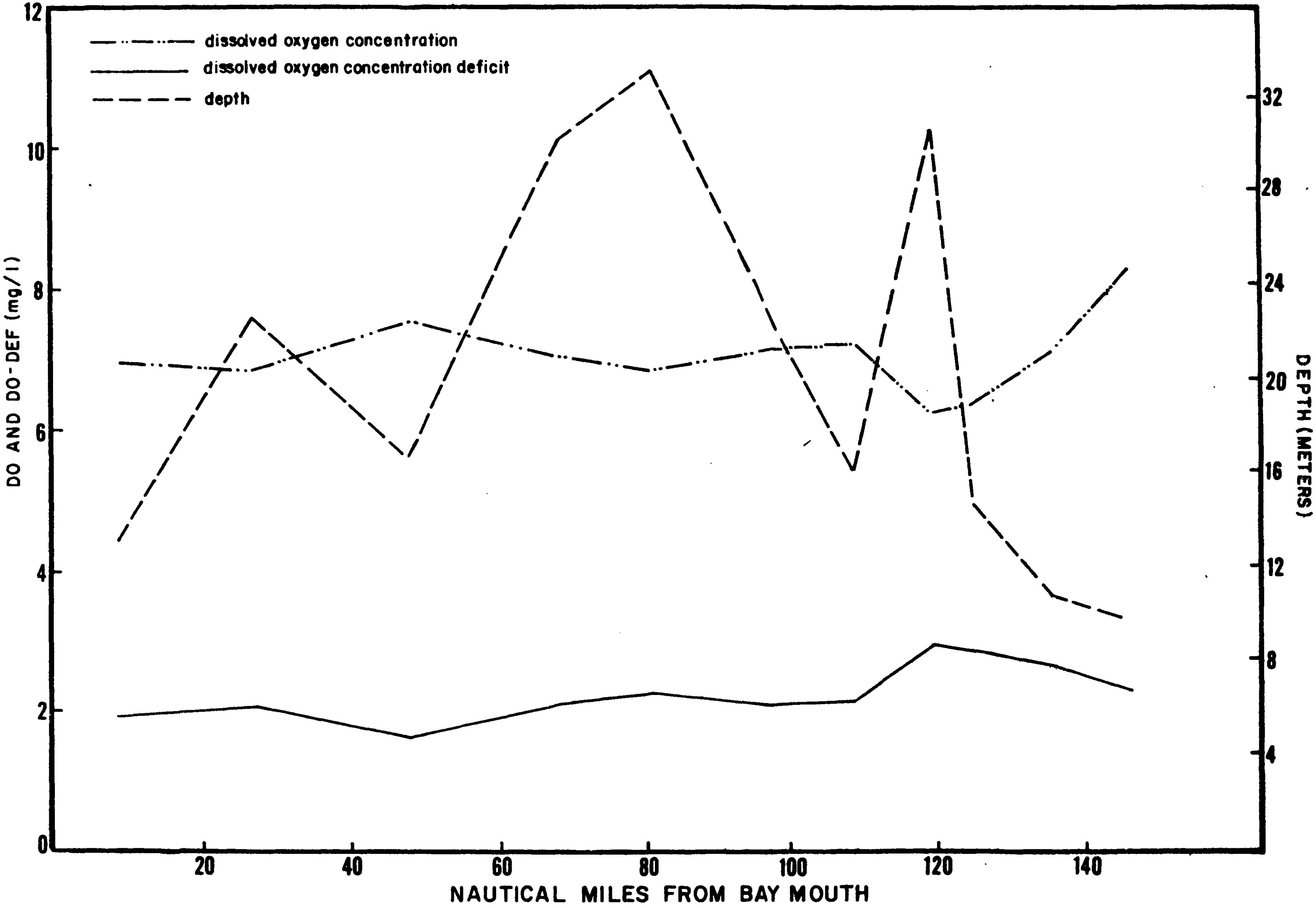


Figure III-21. Dissolved oxygen and oxygen deficit profiles for November 10-13, 1969.

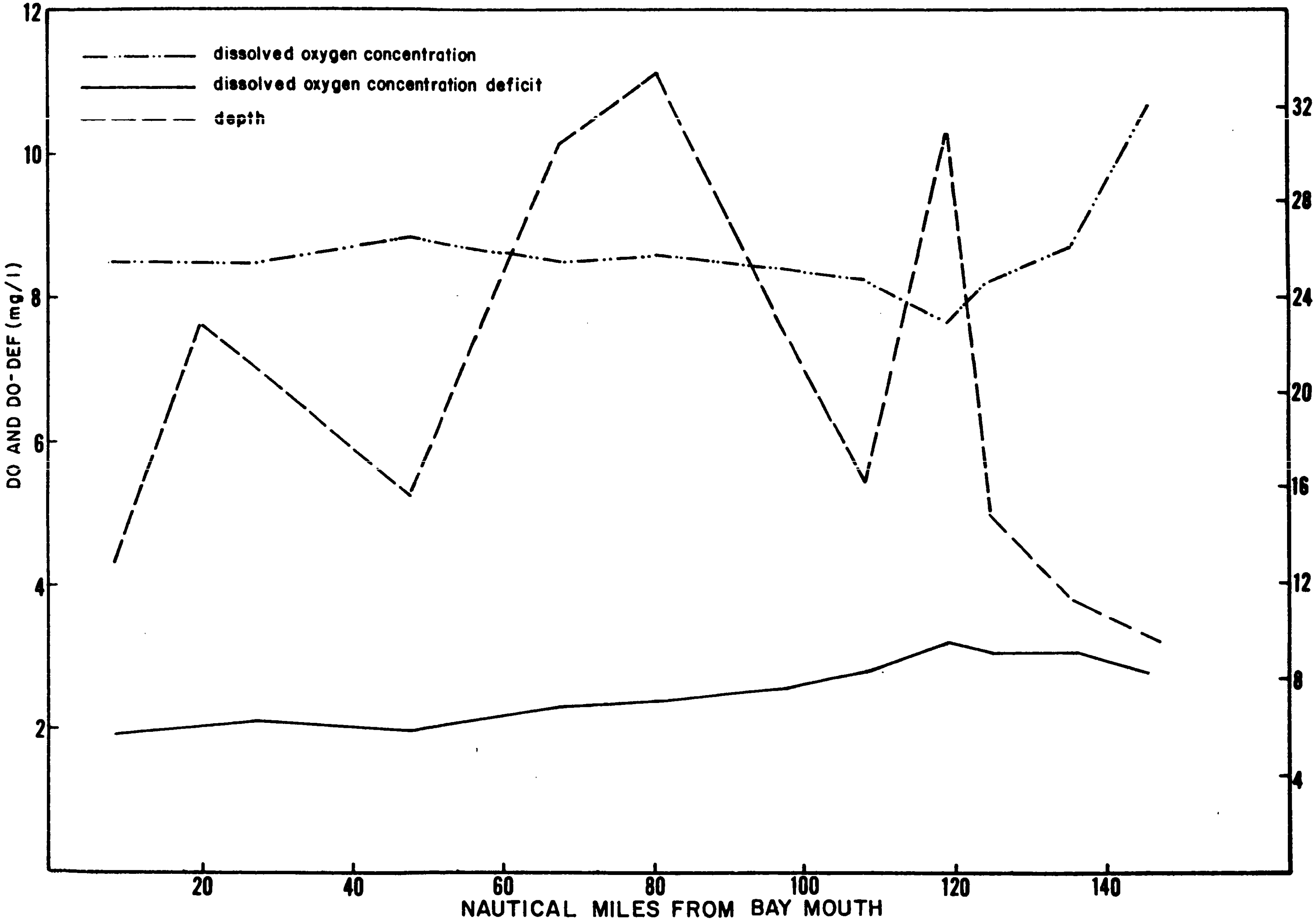


Figure III-22. Dissolved oxygen and oxygen deficit profiles for December 15-18, 1969.

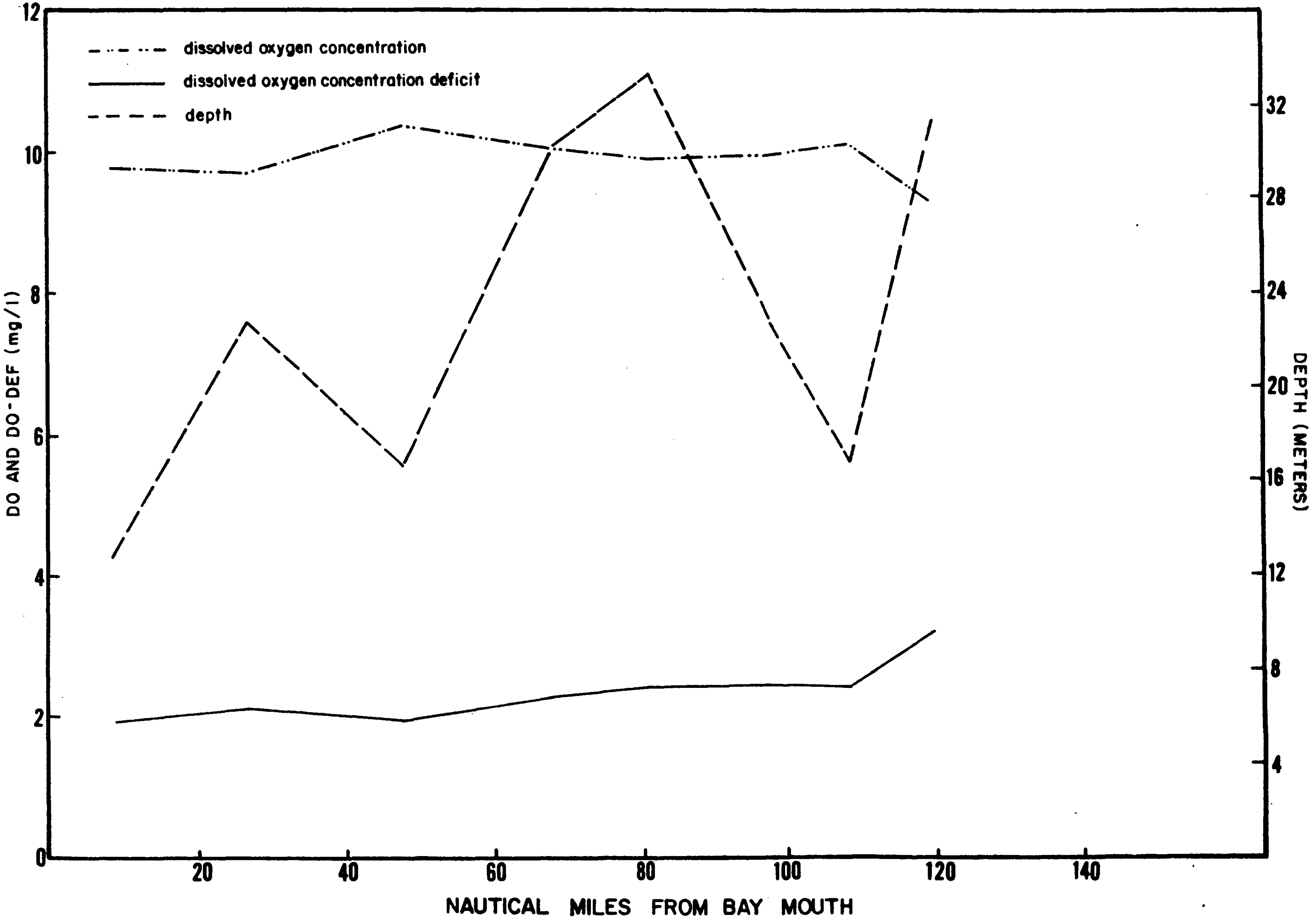


Figure III-23. Dissolved oxygen and oxygen deficit profiles for January 13-15, 1970.

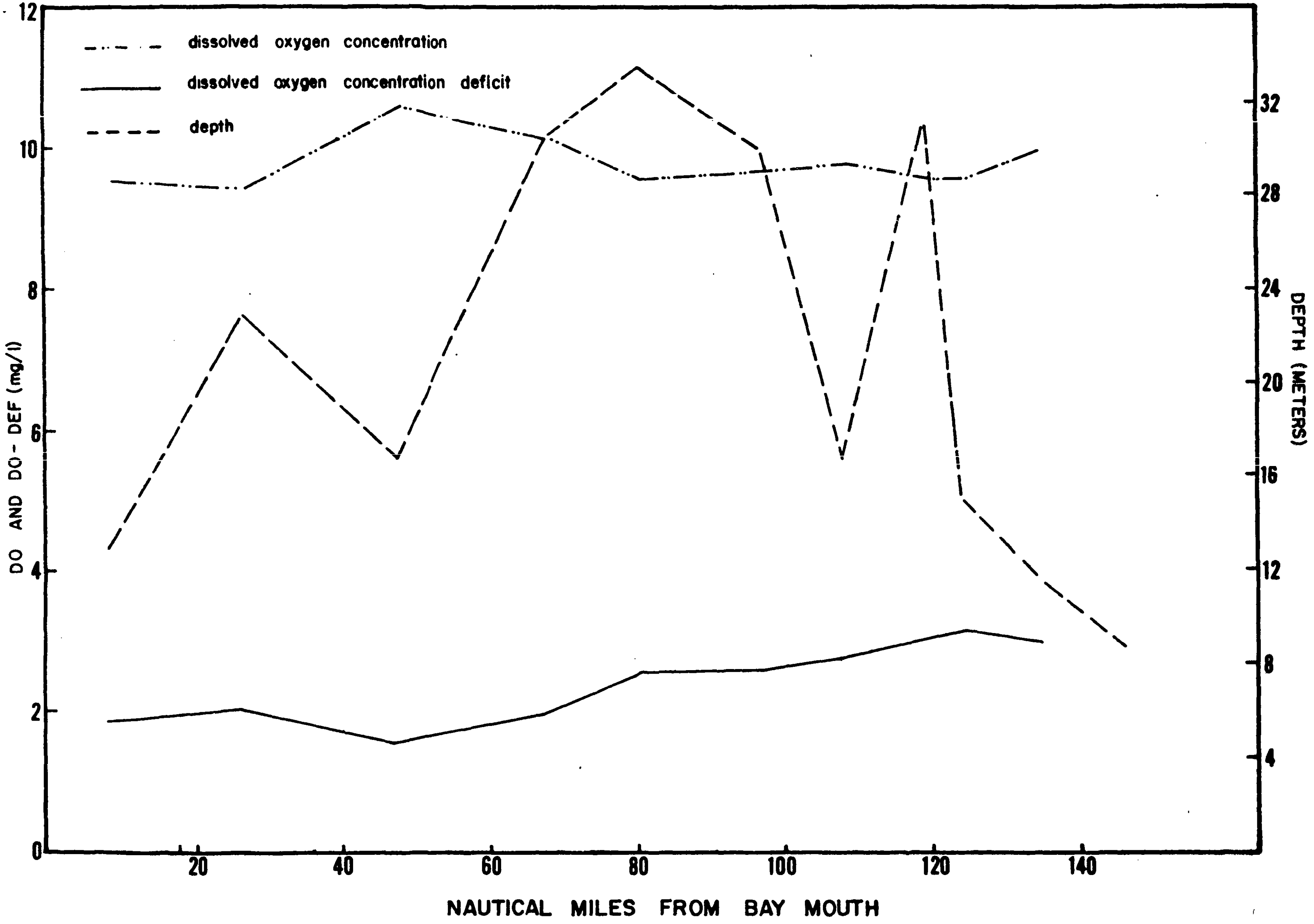


Figure III-24. Dissolved oxygen and oxygen deficit profiles for February 18-21, 1970.

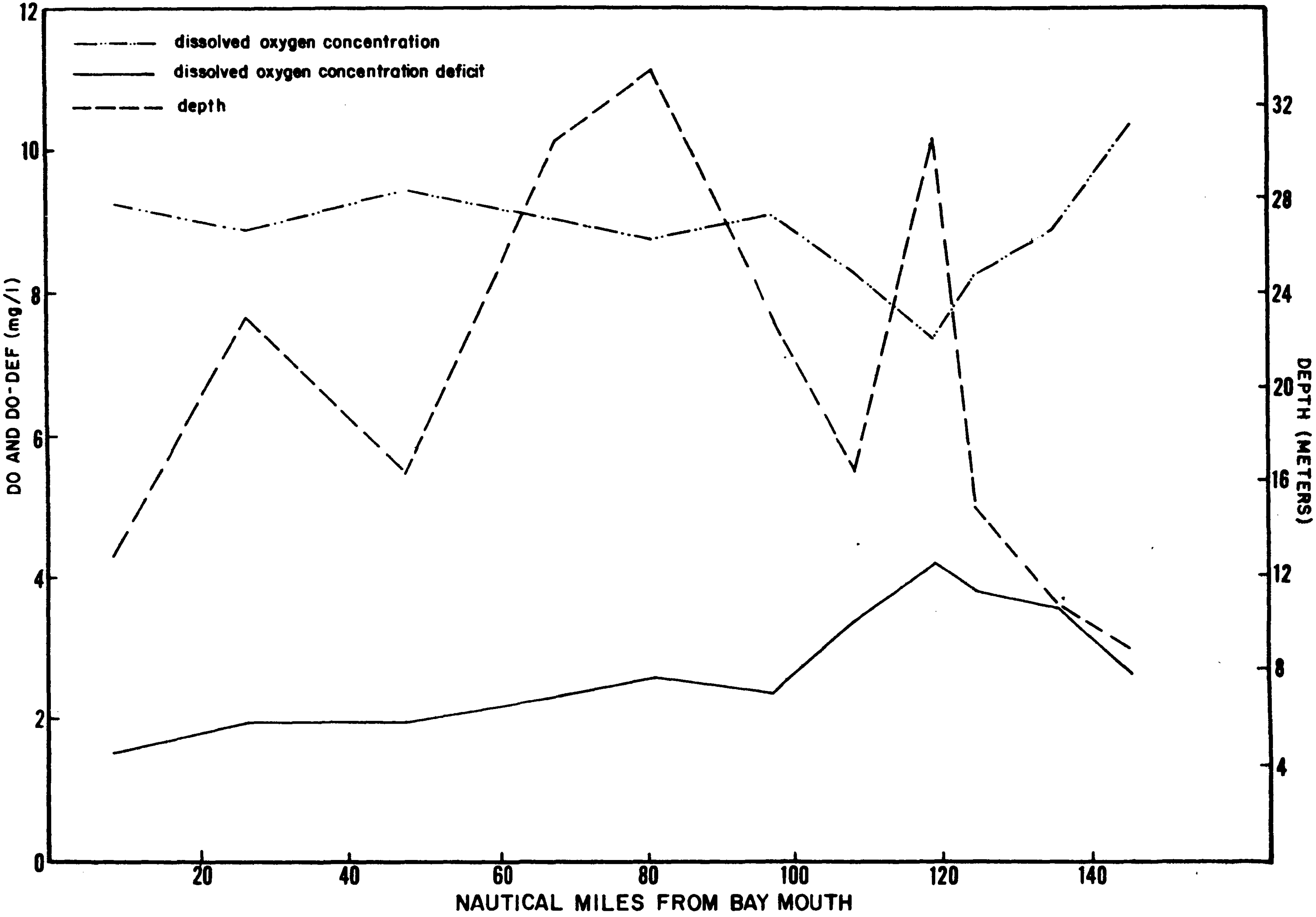


Figure III-25. Dissolved oxygen and oxygen deficit profiles for March 16-19, 1970.

Chesapeake Bay from April, 1969, to March, 1970. The dissolved oxygen concentration curves represent vertical averages at sampling stations and linear interpolations between the stations. The stations were located along the main channel at approximately 9, 26, 48, 67, 80, 97, 108, 120, 127, 137, and 145 nautical miles from the Bay mouth. The vertical averages based on field data collected by the Chesapeake Bay Institute (Taylor and Cronin 1974), were calculated by assuming linear variation in concentrations between sampling depths.

The oxygen deficit station values represent the differences between saturation concentrations and actual concentrations. The curves of oxygen deficit as well as those of depth, again were constructed on the basis of linear interpolations between stations.

The most significant factors affecting the vertical average oxygen deficits are probably reaeration rates, decay of waste loads (carbonaceous and nitrogenous biochemical oxygen demand - CBOD and NBOD) and photosynthetic activity. The reaeration rate is calculated from the formula

$$(k_2)_{20} = \frac{(D_c U)^{\frac{1}{2}}}{H^{3/2}}$$

where D_c is the molecular diffusivity of oxygen in water, U and H are the mean velocity and depth, respectively, and $(k_2)_{20}$ is the reaeration coefficient at 20°C (O'Connor and Dobbins 1956).

Assuming the temperature, velocity, photosynthetic activity and BOD decay rates at each station are relatively uniform, the oxygen deficit would be expected to vary from station to station directly with BOD concentrations and with the depth raised to the 3/2 power. A high correlation between the oxygen deficit and $H^{3/2}$ would therefore suggest that the DO distribution is dominated by the depth of the channel rather than the localized point sources or photosynthetic activity.

Table III-4 shows the linear correlation coefficients associated with the dissolved oxygen deficits and $H^{3/2}$ values for the sampled stations for each set of data. The first coefficient given corresponds to the stations located from 10 to 120 nautical miles from the mouth. The subscript indicates the number of stations sampled. The second coefficient corresponds to all the stations sampled.

For those months in which the water quality standard is violated (the high temperature, low flow summer season) significant correlations are found for the entire Bay in every case except July (when a smaller number of stations was sampled). In earlier months the correlation is significant for the section of the Bay below the Baltimore area but not above. These figures suggest that the DO profile in the Bay proper below Baltimore is dominated by the water depth. In the Bay proper above Baltimore, the pollutant loading from the Susquehanna River, and perhaps the seasonal phytoplankton activities, are also significant contributing factors to the DO profile.

Table III-4. **Relationships Between Dissolved Oxygen Concentration Deficits and $(\text{Depth})^{1.5}$**

Dates of Sampling	Linear Correlation Coefficients		Minimum Dissolved Oxygen Concentrations (mg/ℓ)
April 7-10, 1969	$r_8 = .858^{**}$	$r_{11} = .339$	9.80
May 1-4, 1969	$r_8 = .762^{*}$	$r_{11} = .279$	7.64
June 2-5, 1969	$r_8 = .709^{*}$	$r_{11} = .693^{*}$	3.06^{o}
July 7-9, 1969	$r_6 = .695$	$r_9 = .640$	1.39^{o}
August 5-8, 1969	$r_8 = .802^{*}$	$r_{11} = .743^{**}$	1.47^{o}
September 16-19, 1969	$r_8 = .829^{*}$	$r_{11} = .884^{**}$	2.18^{o}
October 6-9, 1969	$r_8 = .864^{**}$	$r_{11} = .641^{*}$	4.17^{o}
November 10-13, 1969	$r_8 = .636$	$r_{11} = .096$	6.27
December 15-18, 1969	$r_8 = .439$	$r_{11} = .049$	7.68
January 13-15, 1970	$r_8 = .614$		9.31
February 18-21, 1970	$r_8 = .497$	$r_{10} = .034$	9.45
March 16-19, 1970	$r_8 = .442$	$r_{11} = .064$	7.38

* Statistical significance at .05 level

** Statistical significance at .01 level

^{o} Violation of 5 mg/ℓ water quality standard

Figures III-14 to III-25 show that, during most times of the year, there are DO minima at miles 80 and 120, where the depths are greatest. With respect to vertical DO distributions, except in the winter months there are two distinct layers at most of the stations with depths greater than 10 meters. The DO concentrations decrease sharply below the depth of 10 meters. Since the deep channel is very narrow, the DO concentrations of the upper layer alone are more representative of cross-sectional average DO values. These upper layer average concentrations are also shown in the figures. At no time did the data for the upper 4 meters show an average DO concentration less than 5 mg/ℓ.

3. Nutrients

Total phosphorus (TP) and inorganic phosphorus (P_i) concentrations are considered, as well as concentrations of ammonia and organic nitrogen (TKN), ammonia (NH_3), nitrites and nitrates ($NO_2 + NO_3$).

Water flows from the Susquehanna, Potomac, and James River watersheds are the major sources of nutrients entering the Chesapeake Bay system. These three sources account for more than 80% of the freshwater inflow into the Bay, with the Susquehanna alone supplying more than 50% of the total freshwater inflow. The contributions of nutrients from these three tributaries expressed as percentage of total nontidal nutrient loading entering the Bay system (including tidal tributaries) are shown in Table III-5.

Table III-5. Tributary Nutrient Contributions (% of Total Load into Bay) (from Guide and Villa, Jr. 1972).

Source	TKN	$NO_2 + NO_3$	NH_3	TP	P_i
Susquehanna River	62	66	72	54	60
Potomac River	23	26	16	34	26
James River	10	5	9	7	8
Total	95	97	97	95	94

Nitrogen and phosphorus inputs to the Bay are presented graphically in Figures III-26 and III-27 respectively. Pentagons representing the input (as pounds/day) are proportional to the daily load carried by each tributary.

A direct correlation between river discharge and nutrient loadings has been demonstrated (Clark et al., 1973). Results of a regression analysis performed on 1969-1972 data relating Susquehanna River discharge to nutrient loads are presented in Table III-6. River discharge has a greater influence on nutrient input to the Bay than the river nutrient concentration. For example, the Patuxent River has greater average nutrient concentrations than any of the other tributaries but contributes only a minor nutrient load to the Bay because of its low river discharge.

The nutrient input to the Bay from the Susquehanna River at Conowingo, Maryland from June 1969 to August 1970 is presented in Table III-7. Daily and mean monthly river discharges during this period as shown in Figure III-28. Nutrient concentrations are shown in Figure III-29.

The increase in total and inorganic phosphorus concentrations from November 1969 to May 1970 were due to the high river discharge during this period. Periods of higher than normal flow result in increased non-point source loadings as well as reduced water retention time in the impoundment, resulting in less biological uptake of phosphorus compounds or deposition into sediments. The average reservoir retention time during periods of high

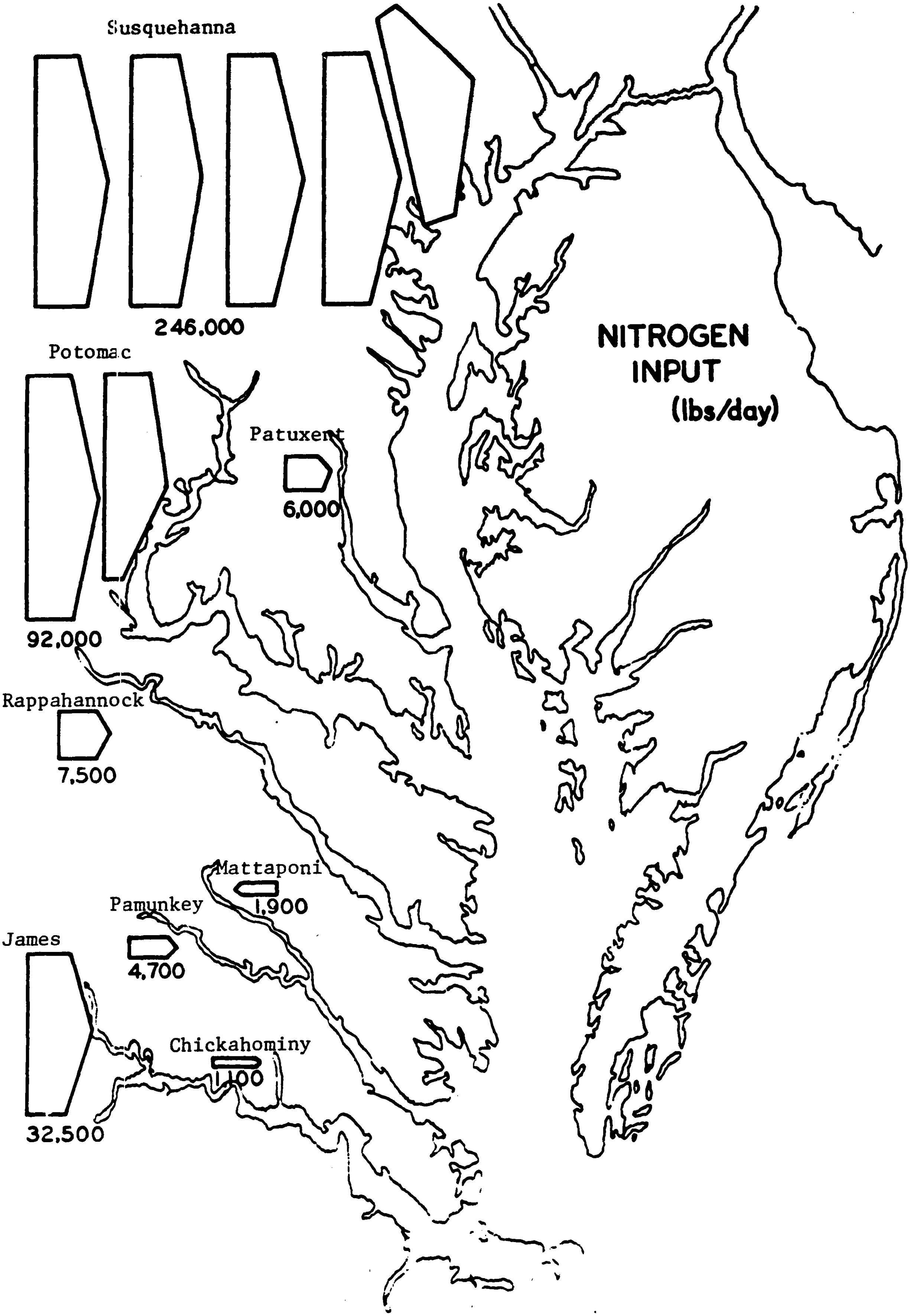


Figure III-26. Nitrogen input to Chesapeake Bay (From: Guide and Villa, Jr. 1972).

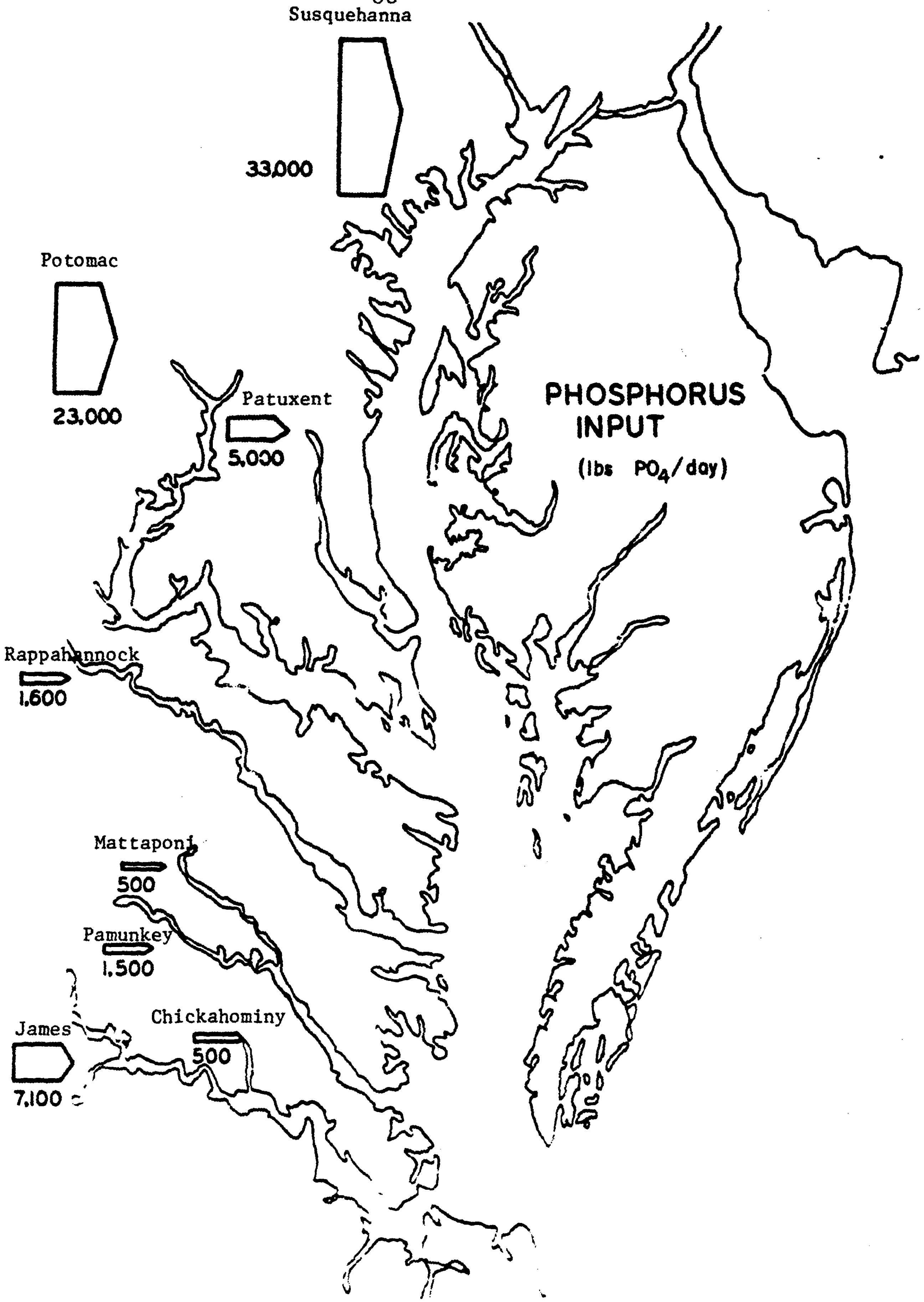


Figure III-27. Phosphorus input to Chesapeake Bay
(From: Guide and Villa, Jr. 1972).

Table III-6. Susquehanna River Nutrient Loads by River Discharge. (From: Clark, et al., 1973)

River Discharge	TKN	Inorganic N as N	NO_3 as N	TP as P	P_i as P
(cfs)	lbs/day				
10,000	80,000	58,000	40,000	2450	1150
50,000	400,000	300,000	250,000	16300	9800
100,000	800,000	600,000	530,000	39150	24500

Table III-7. Nutrient Input to the Chesapeake Bay from the Susquehanna River at Conowingo, Maryland. (From Guide and Villa, Jr. 1972).

Date	Total P as P	Inorganic P	TKN	$NO_2 + NO_3$ as N	NH_3 as N
	χ 1000 lb/day				
06/69	4.9	2.6	63	82	21
07/69	3.6	2.0	51	61	17
08/69	4.6	2.6	60	76	20
09/69	1.3	0.7	25	23	9
10/69	1.0	0.3	21	18	8
11/69	7.2	3.9	81	114	26
12/69	9.1	5.2	95	141	30
01/70	4.9	2.6	62	79	21
02/70	24.5	15.0	181	335	52
03/70	17.0	10.1	141	242	42
04/70	57.4	38.8	319	723	86
05/70	13.1	7.8	120	193	37
06/70	5.5	2.9	66	87	22
07/70	5.5	2.9	66	87	22
08/70	2.3	1.3	38	42	14
Avg. Mo.	10.8	6.5	93	153	29
Avg. Mo. Conc.	0.059	0.12mg/ℓ	0.67 mg/ℓ	0.91 mg/ℓ	0.23 mg/ℓ

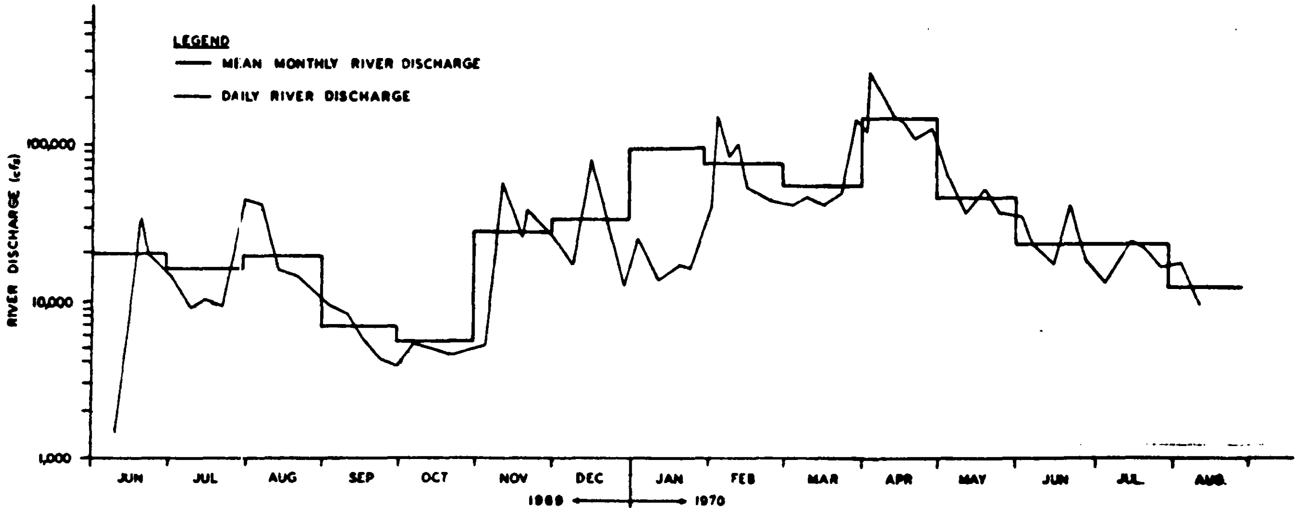


Figure III-28. Susquehanna River Discharge at Conowingo, Maryland (From Guide and Villa, Jr. 1972).

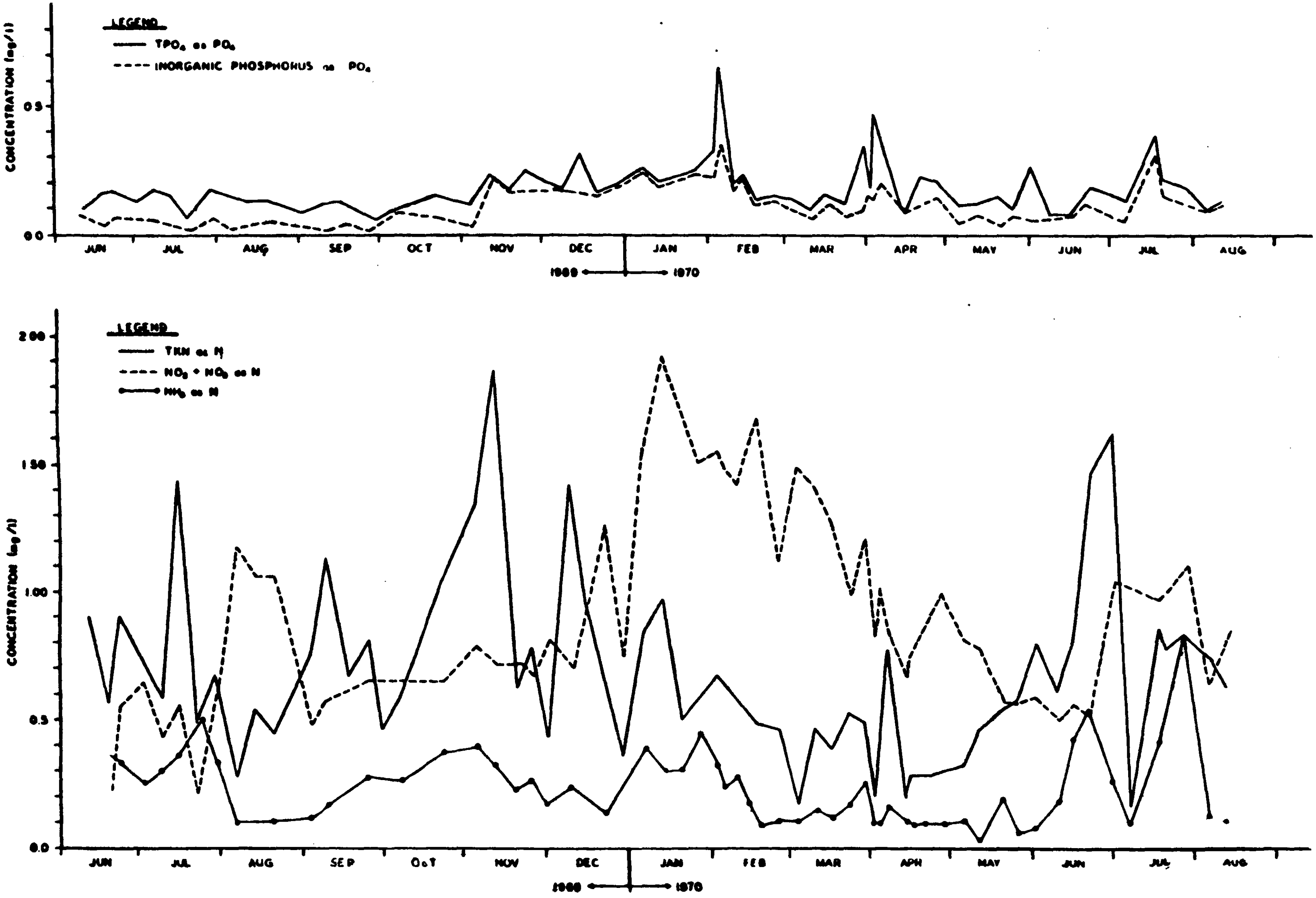


Figure III-29. Nutrient concentrations for Susquehanna River at Conowingo, Maryland (1969-1970). (From: Guide and Villa, Jr. 1972).

flow (October through May) is commonly less than 24 hours (Whaley 1960). Average residence time during slower flow periods (June-September) is 2 to 6 days, depending on the magnitude of the minimal flow.

Nitrite- and nitrate-nitrogen concentrations are directly related to water discharge, while total Kjeldahl-nitrogen (TKN) is indirectly related to water discharge. High nitrite and nitrate concentrations during the winter months must result from land runoff, since nitrification of ammonia to nitrate does not occur at temperatures below 10°C. A secondary reason for these high levels may be reduced detention times. (Guide and Villa, Jr. 1972). During the summer months nitrite-nitrate concentrations decrease and TKN concentrations increase as algal cells convert nitrate to TKN.

Relatively extensive nutrient data for the upper Bay, from nautical mile 120 to the Susquehanna River are available for the period 1969-1971. Data for 1969 and 1970 have been grouped within 2- to 5-mile segments of the Bay (Table III-8). In general, concentrations of TKN and NO_2 + NO_3 decreased with depth, inorganic P increased, total P was variable, and NH_3 was distributed fairly evenly throughout the water column. Average values for TKN and ammonia for the upper Bay (from the mouth of to 40 miles below the Susquehanna River) for 1968-1971 are presented in Figure III-30, those for nitrate-nitrogen in

Table III-8. **Average Nutrient Concentration in Bay (1969-1971)**

Date	**TKN** (mg N/ℓ)	**NO_2 + NO_3** (mg N/ℓ)	**NH_3** (mg N/ℓ)	**Tot. P** (mg PO_4/ℓ)	**Inorg. P** (mg PO_4/ℓ)
Bay Mile 120 - 125					
03-06-69	0.14	0.27	--	0.12	--
05-22-69	0.48	0.38	--	0.07	--
06-17-69	0.37	0.03	0.17	0.13	--
07-07-69	0.37	0.01	0.24	0.22	0.06
09-02-69	0.42	0.08	0.12	0.21	0.08
12-09-69	0.58	0.30	0.30	0.12	0.12
02-09-70	0.46	0.60	0.26	0.13	0.11
03-30-70	0.53	0.59	0.44	0.16	0.06
05-19-70	0.55	0.45	0.19	0.22	0.04
06-08-70	0.42	0.30	0.10	0.12	0.08
07-06-70	0.53	0.08	0.16	0.17	0.08
08-10-70	0.72	0.01	0.07	0.20	0.12
10-05-70	0.55	0.15	0.18	0.22	0.24
11-09-70	0.40	0.31	0.36	0.16	0.16

(1969 data is reduced from Marks et al. 1969 b;
1970 data is reduced from Marks et al. 1969 a.)

Bay Mile 125 - 130					
03-06-69	0.21	0.32	--	0.12	--
05-20-69	0.46	0.39	--	0.09	--
06-18-69	0.48	0.07	0.28	0.15	--
07-09-69	0.54	0.04	0.32	0.19	0.06

Table III-8. (Continued)
Bay Mile 125 - 130

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
09-03-69	0.54	0.08	0.10	0.21	0.09
12-17-69	0.24	0.31	0.29	0.13	0.12
02-18-70	0.48	0.48	0.24	0.17	0.14
03-31-70	0.47	0.61	0.28	0.14	0.06
05-19-70	0.53	0.42	0.18	0.12	0.03
06-11-70	0.18	0.27	0.11	0.14	0.06
07-07-70	0.53	0.04	0.24	0.19	0.11
08-10-70	0.49	0.004	0.09	0.20	0.19
10-06-70	0.58	0.26	0.59	0.29	0.17
11-11-70	0.48	0.46	0.37	0.20	0.17
12-02-70	0.64	0.42	0.20	0.15	0.12

(1969 data is reduced from Marks et al. 1969 b;- 1970 data is reduced from Marks et al. 1970 a.)

Bay Mile 130 - 135

06-18-69	0.54	0.13	0.26	0.17	--
07-09-69	0.59	0.06	0.28	0.22	.044
09-03-69	0.83	0.08	0.28	0.25	.07
05-20-70	0.53	0.57	0.38	0.18	0.06
06-11-70	0.52	0.30	0.24	0.16	0.09
07-07-70	0.72	0.09	0.07	0.19	0.08
10-06-70	0.81	0.53	1.29	0.14	0.05
11-11-70	0.56	0.55	0.58	0.17	0.10

(1969 data reduced from Marks et al. 1969 b; 1970 data reduced from Marks et al. 1970 a.)

Table III-8. (Continued)
Bay Mile 135 - 140

Date	TKN (mg N ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
06-24-69	0.73	0.14	0.03	0.18	0.02
07-14-69	0.47	0.10	0.14	0.18	0.01
09-08-69	0.61	0.03	0.09	0.24	0.02
05-20-70	0.48	0.64	0.07	0.13	0.06
06-15-70	0.44	0.37	0.05	0.11	0.10
07-08-70	0.50	0.15	0.03	0.20	0.10
11-12-70	0.36	0.41	0.32	0.13	0.12
05-17-71	0.21	0.48	0.18	0.10	0.04
06-21-71	0.73	0.12	0.04	0.16	0.04
07-12-71	0.54	0.31	0.13	0.17	0.06
08-17-71	0.55	0.03	0.06	0.19	0.08
(data reduced from Marks et al. 1971 a)					
Bay Mile 140 - 143					
04-12-71	0.73	0.88	0.18	0.19	0.12
06-22-71	0.58	0.10	0.04	0.10	0.05
(from Marks et al. 1971 b)					
Bay Mile 143 - 145					
06-24-69	0.49	0.24	0.04	0.15	0.03
07-14-69	0.43	0.18	0.11	0.16	0.001
09-08-69	0.63	0.10	0.10	0.18	0.003
05-20-70	0.47	0.67	0.14	0.11	0.02
06-15-70	0.43	0.44	0.001	0.5	0.10

Table III-8. (Continued)
Bay Mile 143 - 145

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
07-08-70	0.36	0.32	0.02	0.16	0.10
11-12-70	0.44	0.52	0.14	0.15	0.09
05-17-71	0.16	0.49	0.08	0.14	0.04
05-19-71	0.10	0.60	0.03	0.13	0.03
06-21-71	0.58	0.60	0.05	0.12	0.04
07-12-71	0.70	0.42	0.05	0.18	0.06
08-17-71	0.40	0.27	0.02	0.12	0.06

(data reduced from Marks et al. 1971 a)

Bay Mile 145 - 148

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
06-24-69	0.49	0.29	0.01	0.15	0.01
07-14-69	0.47	0.20	0.11	0.15	0.004
09-08-69	0.63	0.13	0.13	0.00	0.0
05-21-70	0.57	0.63	0.17	0.16	0.10
06-15-70	0.44	0.49	0.05	0.04	0.08
07-08-70	0.22	0.44	0.02	0.14	0.09
11-12-70	0.48	0.41	0.34	0.18	0.08
05-17-71	--	0.55	0.02	0.12	0.001
06-21-71	0.63	0.61	0.04	0.14	0.04
07-12-71	0.62	0.55	0.04	0.17	0.05
08-17-71	0.50	0.41	0.02	0.14	0.06

(Data reduced from Marks et al. 1971 a)

Table III-8. **(Continued)**
Also Bay Mile 145 - 148

Date	TKN (mg N/ℓ)	NO_2 + NO_3 (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
06-24-69	0.32	0.26	0.06	0.14	0.01
07-15-69	0.56	0.20	0.03	0.12	--
07-21-69	--	0.04	0.10	0.18	no
09-15-69	0.79	0.16	0.09	0.50	0.22
03-09-70	0.45	1.46	0.15	0.14	0.08
05-21-70	0.37	0.63	0.02	0.08	0.07
06-17-70	0.69	0.42	0.10	0.10	0.08
07-15-70	0.36	0.78	0.10	0.13	0.08
08-13-70	--	0.32	0.02	--	0.09
04-12-71	0.03	1.40	0.10	0.14	0.07
05-18-71	0.15	0.54	0.08	0.17	0.05
06-15-71	0.74	0.59	0.10	0.18	0.07
06-16-71[1]	0.75	0.60	0.14	0.10	0.05
06-29-71[1]	0.51	0.66	0.02	0.16	0.03
06-30-71[1]	0.52	0.65	0.02	0.12	0.04
08-23-71	0.89	0.19	0.03	0.24	0.05

(1969 data is reduced from Marks and Villa 1969;
remainder is reduced from Marks et al. 1971 c)

([1]) Only surface values obtained

Bay Mile 150 - 153

06-24-69	0.57	0.09	0.06	0.21	no
07-15-69	0.84	0.38	0.04	0.12	--

Table III-8. **(Continued)**
Bay Mile 150 - 153

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
09-15-69	0.64	0.14	0.01	0.18	.001
03-09-70	0.72	1.38	0.12	0.11	0.06
05-21-70	0.37	0.57	0.02	0.35	0.09
06-17-70	0.56	0.36	0.10	0.13	0.06
07-15-70	0.65	0.83	0.10	0.19	0.08
08-13-70	--	0.20	0.02	--	0.15
04-12-71	0.18	1.20	0.08	0.12	0.06
05-18-71	0.40	0.65	0.07	0.28	0.06
06-16-71[1]	0.70	0.70	0.08	0.17	0.04
08-17-71[1]	0.50	0.001	0.02	0.16	0.09
08-24-71	0.90	0.03	0.05	0.23	0.03

(1969 data is reduced from Marks and Villa 1969; remainder is reduced from Marks et al. 1971 c.)

(1) Only surface values obtained.

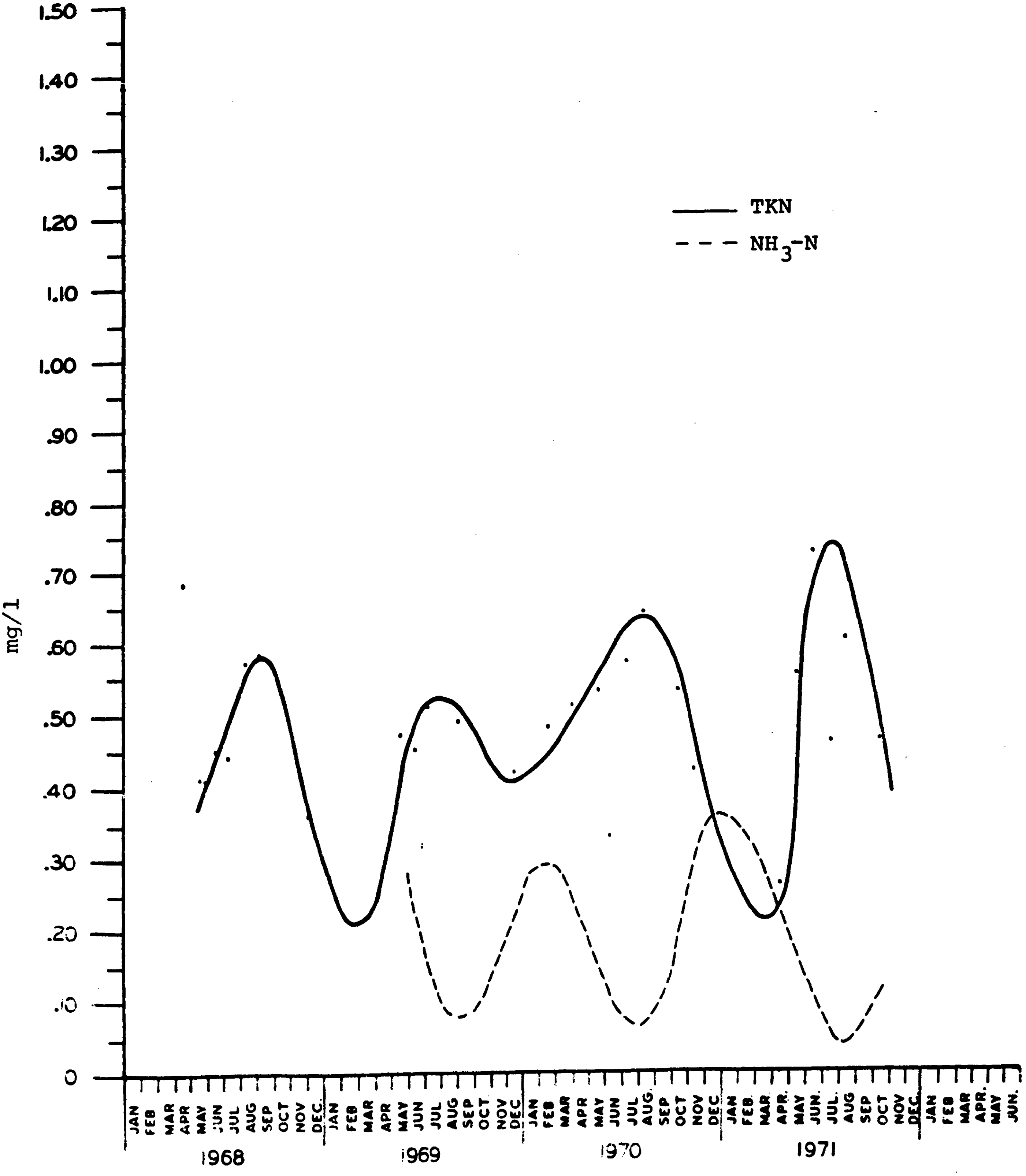


Figure III-30. Ammonia and total Kjeldahl nitrogen concentrations of Upper Chesapeake Bay (Average Data). (From: Clark, et al. 1973).

Figure III-31, and those for total and inorganic phosphorus in Figure III-32. The spatial distribution of inorganic nitrogen (NH_3 + NO_3) and phosphate from eight to thirty eight miles below the Susquehanna River are shown in Figures III-33 and III-34 respectively. The following general facts are derived from these data.

1) TKN ranged from a maximum 0.77 mg N/ℓ to a minimum 0.20 mg N/ℓ during the study period, with annual maximums in summer, annual minimums in winter.

2) NH_3 ranged from 0.05 mg N/ℓ to 0.37 mg N/ℓ over the three years reported, with annual summer minimums, and annual winter maximums.

3) Nitrate-nitrogen exhibited summer minimums of 0.01 - 0.03 mg N/ℓ, winter maximums from 0.38 - 0.72 mg N/ℓ during the four years reported.

4) No clearly defined increase in nitrogen concentration is evident from 1968 to 1971.

5) Total phosphorus exceeded 0.2 mg PO_4/ℓ during late summer and fall of 1969, 70, and 71. Minimum concentrations during spring were 0.08-0.12 mg PO_4/ℓ.

6) Inorganic phosphorus concentrations ranged from 0.04-0.18 mg PO_4/ℓ, with minima in spring, maxima in late summer and fall.

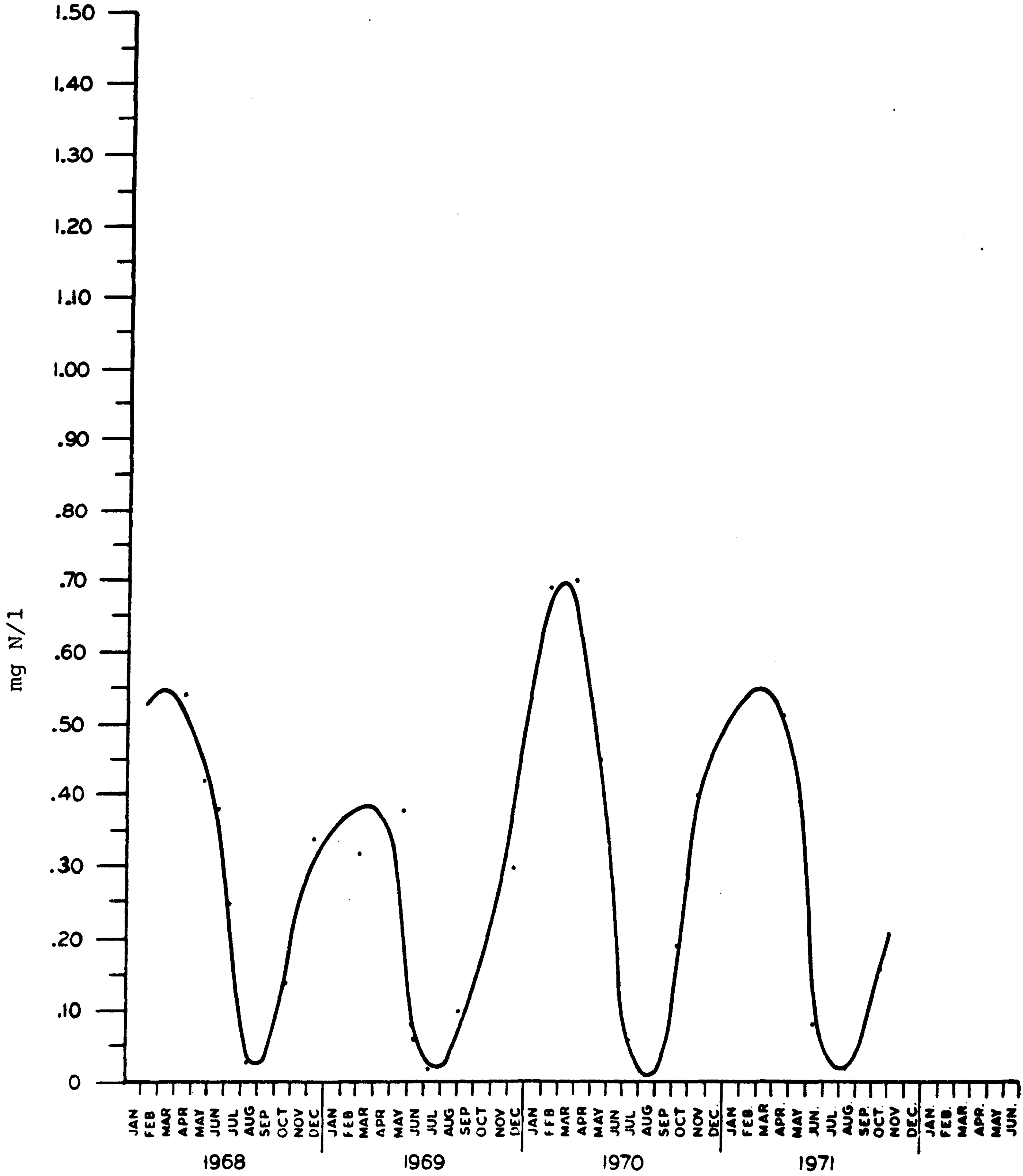


Figure III-31. Nitrate nitrogen concentrations of Upper Chesapeake Bay (Average Data). (From: Clark, et al. 1973).

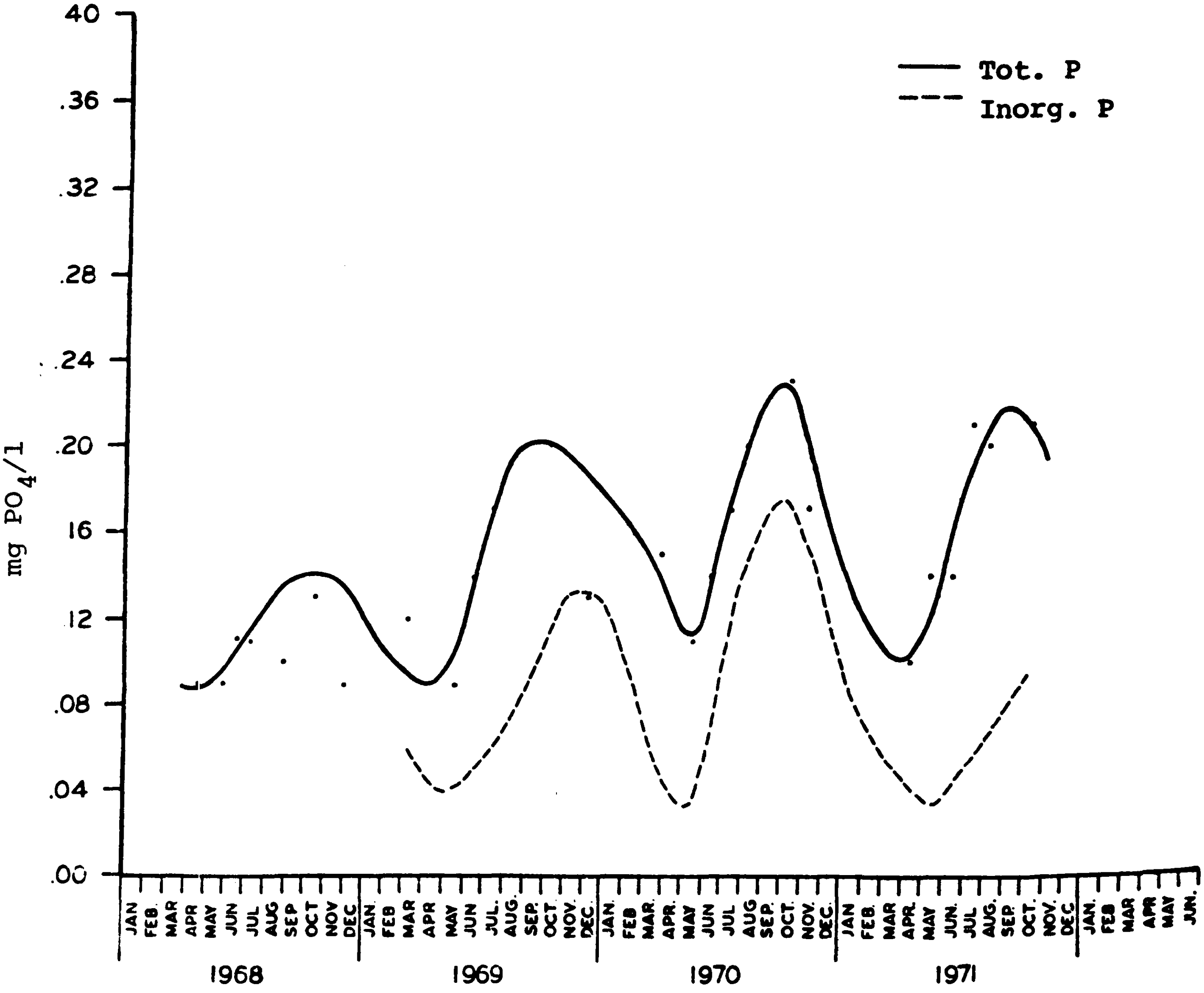


Figure III-32. Total phosphorus and inorganic phosphorus concentrations of Upper Chesapeake Bay. (From: Clark, et al. 1973).

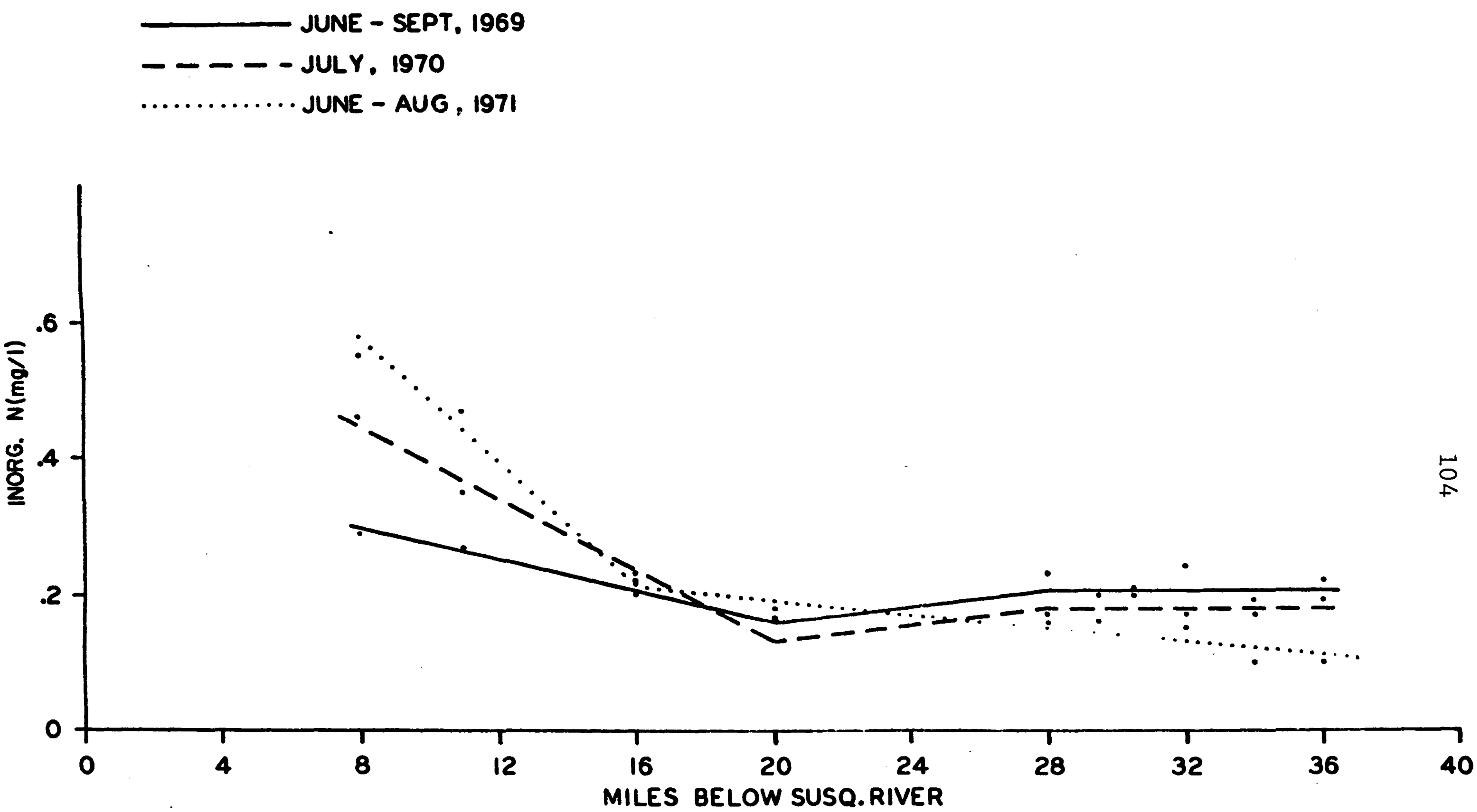


Figure III-33. Spatial inorganic nitrogen distribution of Upper Chesapeake Bay. (From: Clark, et al. 1973).

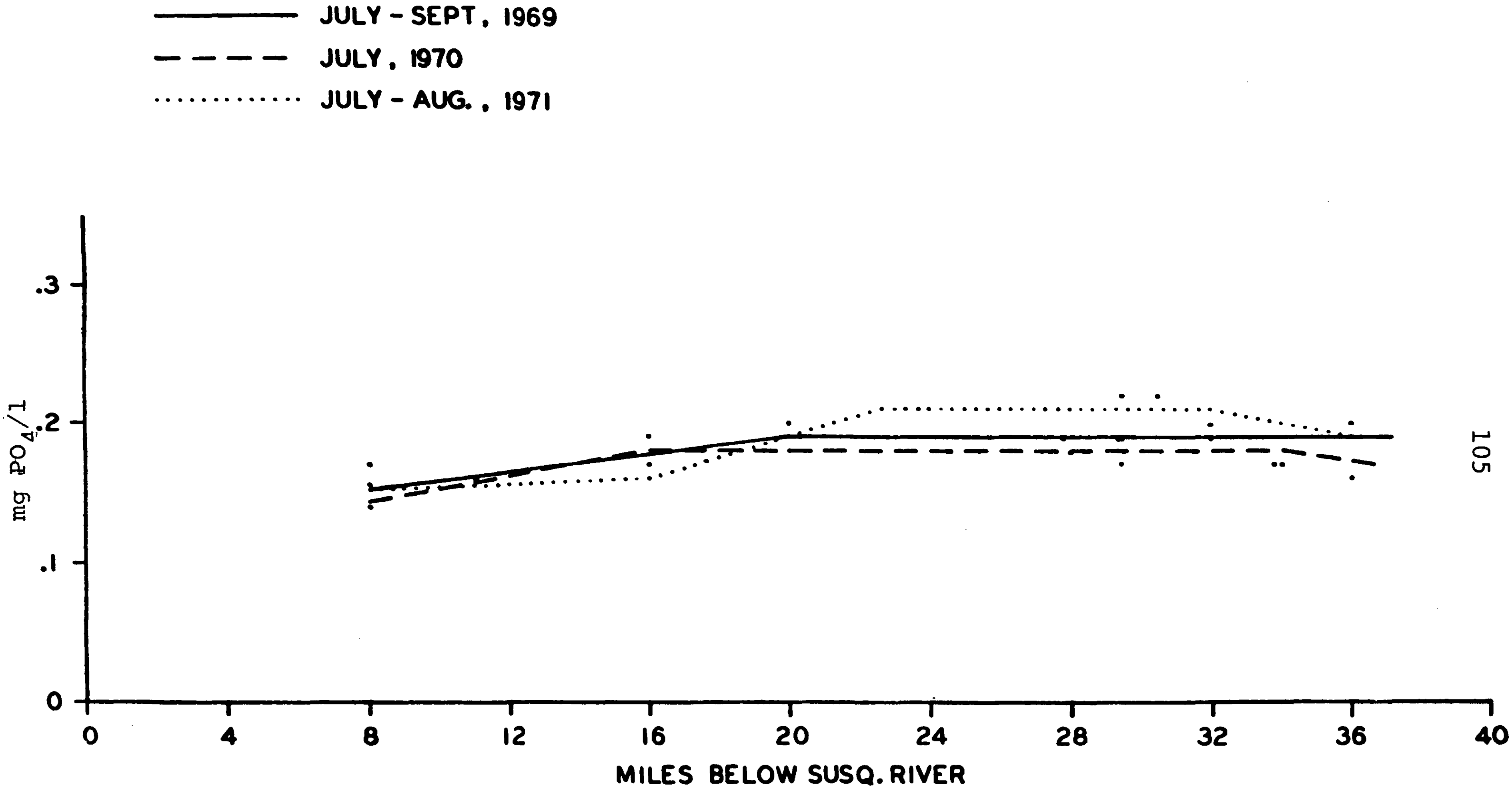


Figure III-34. Spatial phosphorus distributions of Upper Chesapeake Bay. (From: Clark, et al. 1973).

7) Both total and inorganic phosphorus concentrations increased steadily from 1969 to 1971. Furthermore, values reported for total phosphorus in 1969 are higher than those reported in 1968.

8) In the upper Bay, summer concentrations of inorganic nitrogen decrease rapidly with movement down the Bay to a point 20 miles below the Susquehanna. Further downstream relatively little change in concentration is observed.

During the summer growing season nutrient concentrations in the main channel of the Baltimore Harbor are greater than those in adjacent areas of the Bay (miles 130-135). Average total inorganic nitrogen (Figure III-35) and total phosphorus concentrations (Figure III-36) across the mouth of the harbor are at least 0.04 mg/ℓ higher than those in the adjacent Bay areas. Daily nutrient loading from the Baltimore metropolitan area has been reported as 40,000 pounds of total phosphorus (as PO_4), 75,000 pounds total nitrogen, and 60,000 pounds of inorganic nitrogen (Clark, et al. 1973).

Very little recent nutrient data has been obtained from the mid-Bay region. Data from near the Potomac River (Bay mile 65-70) and the Patuxent River (mile 80-85) are presented in Table III-9.

Information concerning nutrient conditions in the lower Bay is scattered. Zubkoff, et al. (1973) report data from June 1972 to August 1973 at a series of

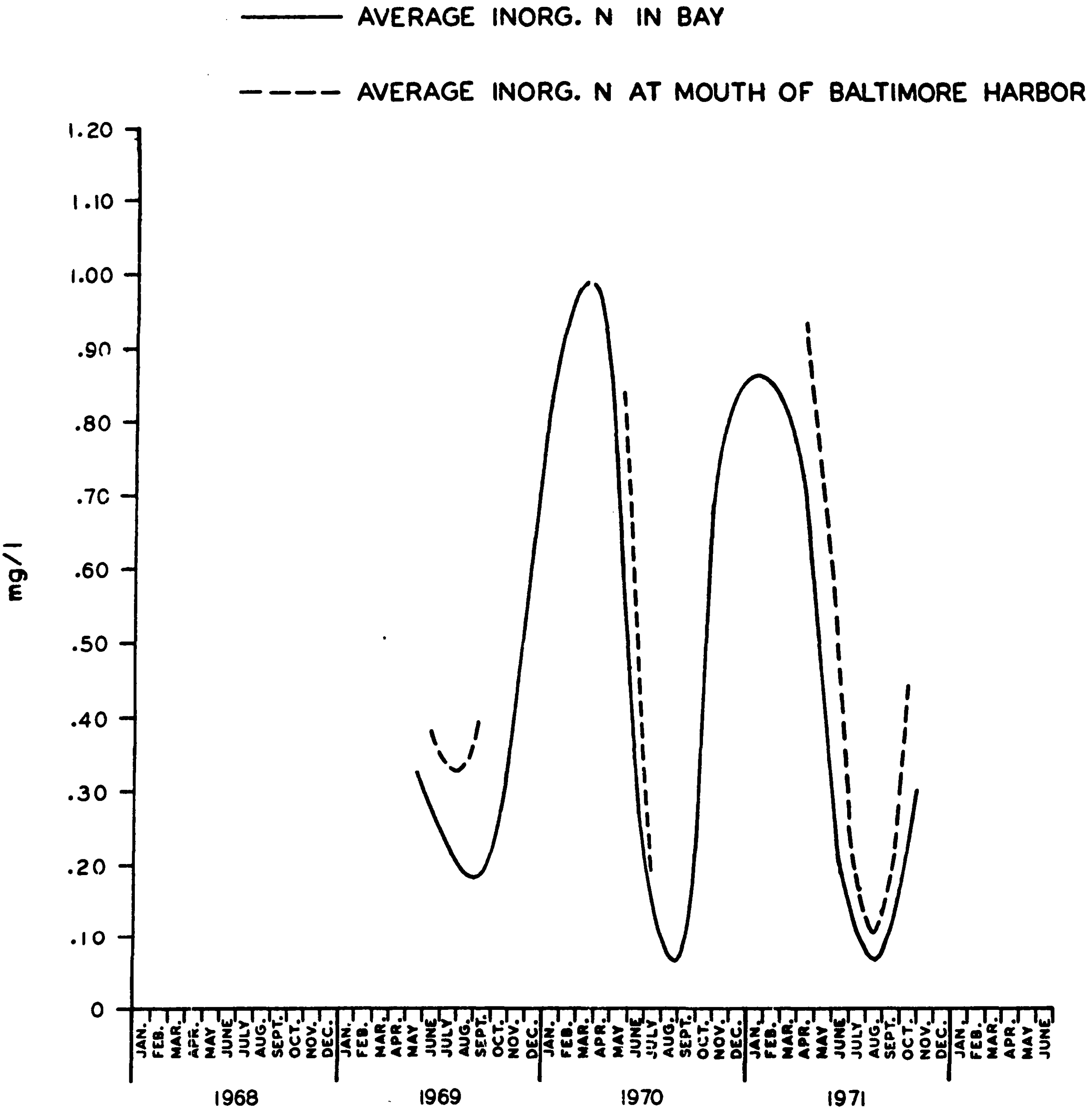


Figure III-35. Comparison of inorganic nitrogen concentrations in transects within Chesapeake Bay and transect across mouth of Baltimore Harbor. (From: Clark, et al. 1973).

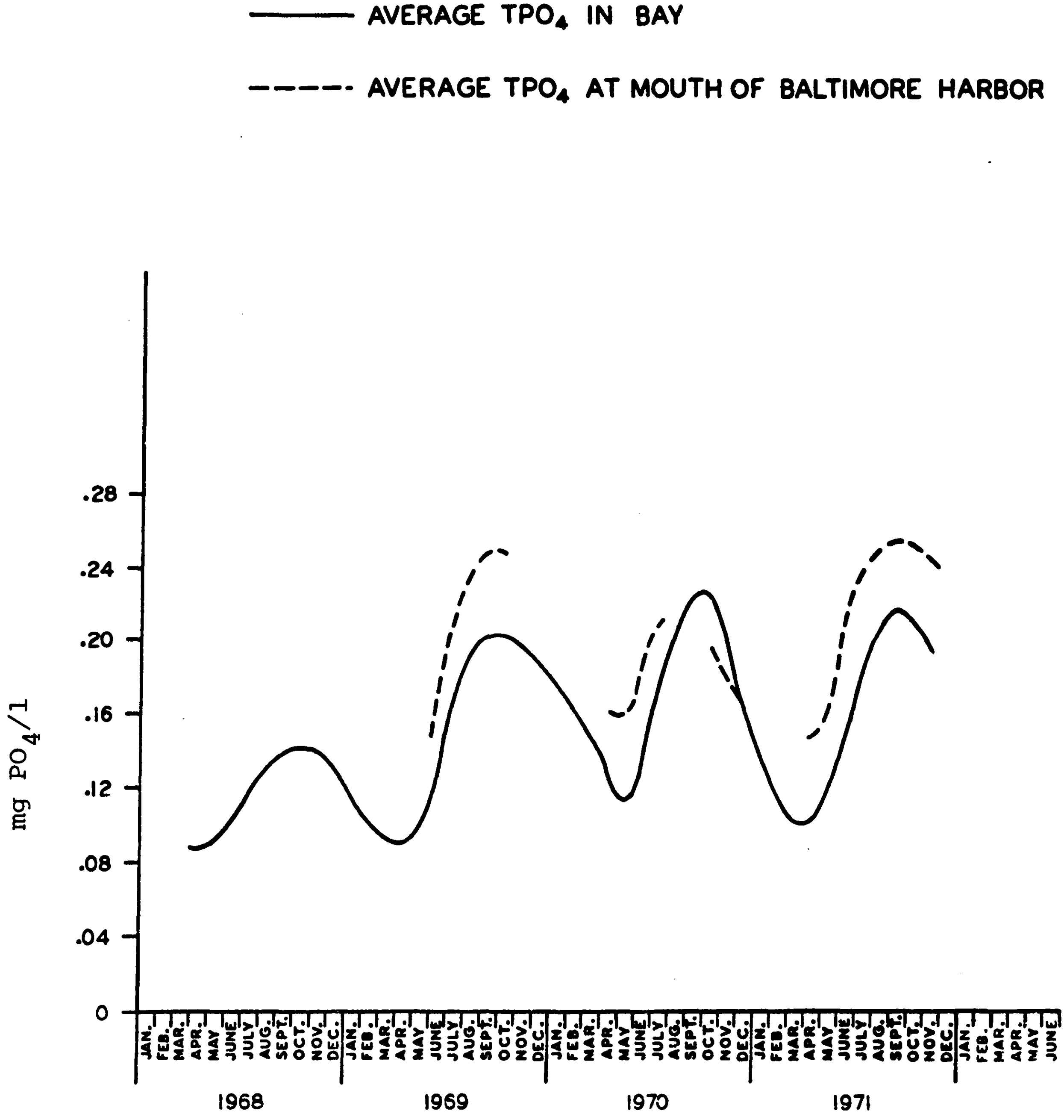


Figure III-36. Comparison of total phosphorus concentrations in transects within Chesapeake Bay and transect across mouth of Baltimore Harbor. (From Clark, et al. 1973).

Table III-9. Nutrient Concentrations in Bay

Bay Mile 65 - 70 (Near Potomac River)

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
07-18-69	0.73	0.07	.005	0.14	0.02
03-25-70	0.42	0.28	0.14	0.04	0.001
05-07-70	0.62	0.48	0.12	0.16	0.06
05-20-70	0.57	0.26	0.02	0.14	0.03
06-01-70	0.83	0.10	0.13	0.12	0.10
06-16-70	0.77	0.01	0.05	0.25	0.08
07-07-70	--	0.03	0.02	--	0.08
07-28-70	1.41	0.05	0.14	0.20	0.22
11-18-70	0.42	0.21	0.10	0.18	0.08

(1969 data from Marks et al. 1969 a; remainder from Marks et al. 1970 b.)

Bay Mile 80 - 85 (Near Patuxent River)

Date	TKN (mg N/ℓ)	$NO_2 + NO_3$ (mg N/ℓ)	NH_3 (mg N/ℓ)	Tot. P (mg PO_4/ℓ)	Inorg. P (mg PO_4/ℓ)
06-04-73	0.51	0.17	0.20	0.06	0.002
06-05-73	0.42	0.20	0.28	0.08	0.007
06-06-73	0.47	0.16	0.28	0.08	0.02
07-09-73	0.42	0.002	0.26	0.08	0.01
07-11-73	0.56	0.001	0.41	0.16	0.02
07-12-73	0.58	0.001	0.44	0.14	0.01

(From Pheiffer and Lovelace 1974)

stations in the lower Bay south of latitude 37°40'N (river mile 42.5). The accuracy of these values is open to question because the samples were preserved and stored for variable periods of time prior to analysis. The investigators believe that the data indicate correctly only the order of magnitude of concentrations.

The nutrient levels during this period were influenced by Tropical Storm Agnes, which occurred in June, 1972, and, therefore, may not be typical. The lower Bay was divided into 8 subareas for the purpose of the study on the basis of water depth and location (Figure III-37). Monthly averages for each subarea are shown in Tables III-10 through III-17. Nitrite-nitrogen values were generally low through the year. Nitrate-nitrogen levels in areas near the James River and just below the Potomac River were relatively high in June 1972, shortly after Tropical Storm Agnes, and fell only slightly during the remainder of the summer. Concentrations of nitrate-nitrogen increased in late fall, to peaks in winter or early spring in all subareas, and then declined to low levels more typical of the lower Bay during the following summer. Phosphate-phosphorus concentrations were generally low throughout the study period.

Other sources of data are too scattered and incomplete to do more than confirm the general trends of the above study and are hence not presented in detail.

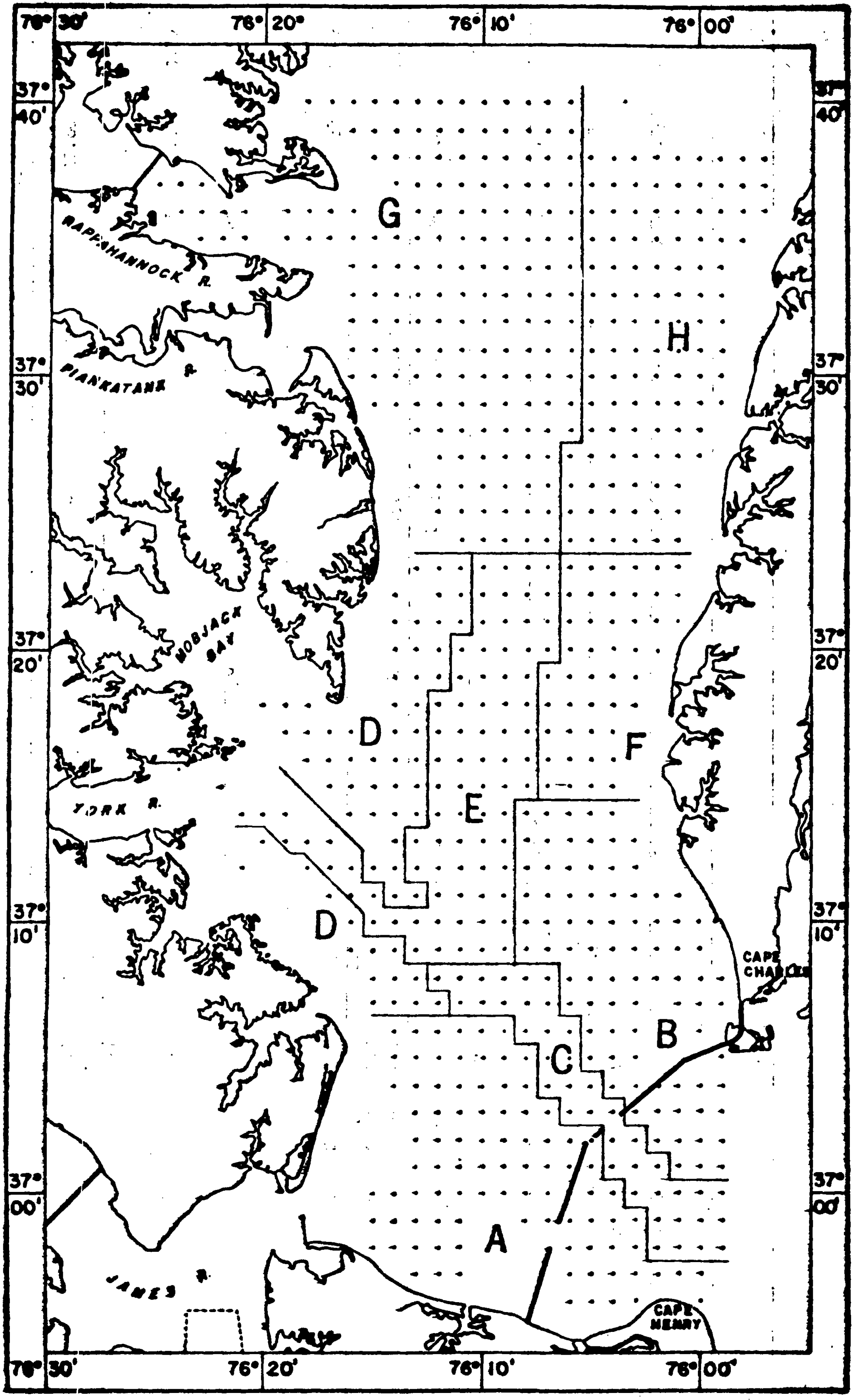


Figure III-37. Segmentation of lower Chesapeake Bay used for nutrient sampling. (From: Zubkoff, et al. 1973).

Table III-10. Nutrient Concentrations in Sub-area A of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	26.04	94.08	19.84
	July	6.16	34.72	15.19
	August	N.A.	N.A.	N.A.
	Sept.	1.68	3.78	3.41
	Oct.	16.1	28.28	15.5
	Nov.	6.72	22.12	13.33
	Dec.	8.4	92.96	11.16
1973	Jan.	8.82	96.88	9.92
	Feb.	5.18	147.84	6.82
	March	4.9	136.92	6.51
	April	5.18	169.82	5.58
	May	1.96	5.04	5.89
	June	1.54	2.8	9.61
	July	1.96	7.28	26.35
	Aug.	1.96	1.40	18.91

Table III-11. Nutrient Concentrations in Sub-area B of the Lower Chesapeake Bay

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	8.26	N.A.	14.26
	July	4.62	13.16	8.06
	Aug.	4.2	3.36	11.16
	Sept.	.56	2.66	7.13
	Oct.	N.A.	N.A.	N.A.
	Nov.	10.22	17.22	7.13
	Dec.	12.74	63.98	5.27
1973	Jan.	8.26	84.28	6.51
	Feb.	4.06	152.6	7.44
	March	4.34	162.96	4.34
	April	8.26	130.76	7.13
	May	3.22	5.74	6.82
	June	1.68	2.66	7.75
	July	2.10	7.84	24.18
	Aug.	2.24	.84	15.19

Table III-12. Nutrient Concentrations in Sub-area C of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	14.70	.28	9.61
	July	2.66	27.72	15.19
	Aug.	2.1	6.72	9.61
	Sept.	1.26	1.82	24.8
	Oct.	24.92	27.72	5.58
	Nov.	6.3	13.86	11.16
	Dec.	13.30	73.78	5.27
1973	Jan.	8.12	80.64	7.75
	Feb.	4.34	129.64	7.13
	March	3.5	51.24	6.2
	April	4.06	143.78	6.82
	May	2.24	3.08	4.96
	June	1.54	3.08	6.51
	July	1.96	2.94	17.98
	Aug.	2.8	1.96	17.98

Table III-13. Nutrient Concentrations in Sub-area D of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	10.08	.84	6.51
	July	9.52	72.1	13.33
	Aug.	3.64	17.08	8.37
	Sept.	7.42	6.44	8.06
	Oct.	17.5	15.96	3.72
	Nov.	15.96	35.98	9.61
	Dec.	14.98	74.34	7.44
1973	Jan.	11.2	136.08	16.43
	Feb.	4.2	216.72	6.2
	March	4.62	183.82	4.34
	April	5.04	178.08	5.58
	May	3.78	15.68	3.41
	June	1.4	4.2	7.75
	July	1.96	3.22	17.98
	Aug.	3.92	2.8	23.25

Table III-14. Nutrient Concentrations in Sub-area E of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	18.9	4.48	6.2
	July	8.68	96.32	12.4
	Aug.	2.38	2.10	8.68
	Sept.	.98	1.4	7.13
	Oct.	14.28	15.68	1.86
	Nov.	11.48	39.48	8.68
	Dec.	15.68	82.6	39.06
1973	Jan.	10.64	117.74	13.95
	Feb.	5.04	260.54	4.03
	March	4.76	209.02	3.41
	April	4.34	203.84	4.96
	May	4.62	20.44	5.27
	June	1.68	5.32	6.20
	July	1.82	2.38	13.02
	Aug.	3.64	1.82	22.32

Table III-15. Nutrient Concentrations in Sub-area F of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	12.04	14.70	10.54
	July	3.78	48.02	14.26
	Aug.	2.38	17.78	8.99
	Sept.	1.68	7.84	8.99
	Oct.	3.22	-	1.55
	Nov.	7.14	26.04	6.51
	Dec.	15.12	90.72	5.89
1973	Jan.	10.22	132.72	4.96
	Feb.	5.04	137.76	4.96
	March	5.46	195.16	13.02
	April	5.04	198.66	4.96
	May	5.46	15.40	6.2
	June	1.40	1.54	7.75
	July	2.10	1.96	16.74
	Aug.	2.10	1.96	15.81

Table III-16. Nutrient Concentrations in Sub-area G of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	-	-	-
	July	9.52	193.62	25.11
	Aug.	4.34	49.42	8.68
	Sept.	0.0	.70	8.99
	Oct.	15.82	6.44	2.48
	Nov.	-	-	-
	Dec.	16.66	141.54	.62
1973	Jan.	11.06	242.76	4.03
	Feb.	5.88	329.42	3.72
	March	-	-	-
	April	5.88	215.6	5.58
	May	8.54	159.18	3.41
	June	1.68	8.12	4.96
	July	1.82	1.4	14.88
	Aug.	-	-	-

Table III-17. Nutrient Concentrations in Sub-area H of the Lower Chesapeake Bay.

		NO_2-N (μg N/ℓ)	NO_3-N (μg N/ℓ)	PO_4-P (μg P/ℓ)
1972	June	-	-	-
	July	3.08	53.62	19.84
	Aug.	6.44	45.78	9.92
	Sept.	.28	1.96	7.44
	Oct.	11.48	10.36	3.10
	Nov.	-	-	-
	Dec.	14.14	71.54	.93
1973	Jan.	10.5	146.16	4.34
	Feb.	6.02	205.94	3.41
	March	5.88	198.94	5.89
	April	5.6	213.64	5.27
	May	6.16	55.44	5.27
	June	1.26	2.66	6.51
	July	2.10	3.08	12.09
	Aug.	-	-	-

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IV. Description of Pollutant Discharges

The salinity of the Chesapeake Bay waters precludes its use for irrigation; hence, there are no irrigation return flows. Any irrigation runoff entering the Bay system is included with non-point sources (Section E).

A. Data Sources and Limitations

Information on feedlots in the study area was not available.

The data on pollutant loads entering the Bay through Susquehanna River inflow were calculated from information developed at the Annapolis Field Office of the EPA. Potomac River data were calculated from EPA STORET information, and James River loadings from information collected by the Virginia Institute of Marine Science.

Data on actual outfall loads in Maryland (Table IV-6) was compiled from office files of the Maryland Water Resources Administration. Corresponding Virginia data were obtained from office files of the Kilmarnock, Virginia Beach, and Piedmont regional offices of the Commonwealth of Virginia Water Control Board.

Nitrogen and, therefore, nitrogenous biochemical oxygen demand loading information was available for very few outfalls. No nutrient or coliform data at all was available for Virginia outfalls. Few outfalls in either state were sampled every month for any parameters. The Maryland outfalls do appear, however, to have been sampled relatively regularly for coliforms. The specific data gaps in actual discharge information are apparent from inspection of Table IV-6.

The information on point source discharges used for the water quality model (Table IV-7) was obtained, where possible, from National Pollutant Discharge Elimination System (NPDES) permits. Few permits, however, specified nitrogen or phosphorus limits or flow rates; these were, therefore, estimated in many cases from generally accepted average pollutant concentrations for different treatment levels (American Chemical Society, 1969; Metcalf and Eddy, 1972). In some cases they were estimated from values in Table IV-6 or judged insignificant.

Data on non-point sources of pollutants were calculated primarily from information of the U. S. Army Corps of Engineers on land use patterns and from information of the Annapolis Field Office of the EPA on mass emission rates of pollutants for various land uses. The land utilization information was not "fine-grained" enough for our purpose and thereby made simplifying assumptions necessary. The yield rates, moreover, were developed only for a small area, the lower Susquehanna River basin. Application of these rates to the entire Bay area, as was done in this study, may not be warranted. Furthermore, since no rates at all were available for CBOD, very crude estimates were made. This is an area that calls for much further study.

B. Summary Description

Two groups of point sources were considered in this study. The major tributaries of the Bay - the Susquehanna, Potomac, and James Rivers - were considered point sources for the purposes of the model. In addition, all identifiable major (discharge $\geq$ 0.5 MGD; 3300 to 5000 population equivalents) municipal and industrial facilities discharging into the Bay or one of its tributaries at distances less than 10 nautical miles from the Bay were included. (A complete list of all identifiable discharges in the Bay system is presented in Appendix A). There were 21[*] such sources which may be classified as follows:

Federal Facilities	3
Municipal	13
Industrial	5
Maryland	13
Virginia	8

The reaches and their distances from the Bay mouth used in the model are shown in Table IV-1. The point sources and their corresponding reaches are listed in Table IV-2.

A ten nautical mile cut-off point for point sources entering tributaries was chosen since it was judged that the significance of loads traveling any further than this would be negligible because of decay of nonconservative substances and settling. No adjustment was made

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[*] Two Virginia Municipal STP's will be phased out by 1977

Table IV-1. Segmentation of the Bay

Reach Number	Nautical Miles from Bay Mouth (Cape Henry/Cape Charles)
1	160-161
2	159-160
3	158-159
4	157-158
5	156-157
6	153-156
7	150-153
8	148-150
9	145-148
10	143-145
11	140-143
12	135-140
13	130-135
14	125-130
15	120-125
16	115-120
17	110-115
18	105-110
19	100-105
20	95-100
21	90-95
22	85-90
23	80-85
24	75-80
25	70-75
26	65-70
27	60-65
28	55-60
29	50-55
30	45-50
31	40-45
32	35-40
33	30-35
34	25-30
35	20-25
36	15-20
37	10-15
38	5-10
39	0-5

Table IV-2. Major Point Sources of Pollutants on the Chesapeake Bay

Model Reach No.	Bay Mile (Nautical)	Point Source	Activity
1	161	Susquehanna River	Major Tributary
2	160	Bainbridge NTC	Federal Facility
5	156	Harve de Grace	Municipal
6	155	Perryville	Municipal
7	153	Aberdeen	Municipal
9	145	Sod Run	Municipal
10	144	Edgewood Arsenal	Federal Facility
11	142	Joppatown	Municipal
12	136	Back River	Municipal
13	130	Cox Creek	Municipal
13	130	Patapsco	Municipal
13	134	Bethlehem Steel	Metal Processing
15	118	Annapolis	Municipal
24	78	Pine Hill Run	Municipal
27	60	Potomac River	Major Tributary
29	50	Standard Products	Fish Processing
29	50	Haynie Products	Fish Processing
36	17	American Oil-Yorktown	Oil Refinery
36	17	VEPCO - Yorktown	Energy Production
36	17	Naval Mine Depot	Federal Facility
38	5	James River	Major Tributary
39	1	Birchwood Gardens*	Municipal
39	0	HRSD-Oceana Naval Air Station*	Municipal
39	3	HRSD-Chesapeake-Elizabeth	Municipal

* Phasing out anticipated by 1977

for distance of travel, however, for those sources falling within the ten nautical mile limit. Urban drainage, whether sewered or not, was included with non-point sources (see Section E). No provision was made for the irregular loadings associated with "combined sewers", since the water quality model deals only with equilibrium conditions.

C. Point Sources and Their Characteristics

1. Major Tributaries

a. Susquehanna River

The most upstream reach of the model is located at the head of tide in the Susquehanna River 5.8 miles (9.3 km) upstream from the mouth. The pollutant loadings from the Susquehanna River are specified in Table IV-3 in terms of concentration by freshwater discharge level. These concentrations serve as the boundary conditions of the mass balance equation. The concentrations of total phosphorus and total nitrogen were calculated from the results of regression analysis by Clark, et al. (1974) about the pollutant loadings at Conowingo Dam, Maryland. The nitrogenous BOD loadings were calculated from total Kjehldahl nitrogen (TKN) values by applying the 4.57 stoichiometric ratio of oxygen to ammonia nitrogen in the nitrification process. These concentrations result from loadings of both point sources and non-point sources on the lower Susquehanna. The estimated proportion of load attributable to point sources is also indicated in Table IV-3.

Table IV-3. Present Pollutant Loadings from the Susquehanna River

River Flow cfs	(cms)	Total-P mg/ℓ	(% From Point Sources)	Total-N mg/ℓ	(% From Point Sources)	NBOD mg/ℓ	(% From Point Sources)	CBOD mg/ℓ	(% From Point Sources)	DO* mg/ℓ
2700	(76.5)	.034	(100)	1.57	(25)	4.57	(69)	2.48	(0)	7.26
6400	(181.0)	.041	(85)	1.55	(19)	3.87	(61)	2.35	(0)	7.26
25100	(710.0)	.052	(44)	1.50	(11)	2.90	(45)	2.16	(0)	8.60
38600	(1090.0)	.055	(35)	1.48	(5)	2.58	(36)	2.10	(0)	10.20
70300	(1990.0)	.056	(21)	1.46	(3)	2.47	(17)	2.03	(0)	12.10

*assumed 90% of saturation concentration

There are no data regarding carbonaceous biochemical oxygen demand (CBOD) collected at Conowingo Dam. The regression analysis of total organic carbon (TOC) by Guide and Villa (1972) was used to estimate CBOD. The CBOD concentration at each flow condition was obtained by multiplying TOC concentration by the ratio of CBOD to TOC at the head of tidal Potomac (Clark and Jaworski, 1972). The point source contribution to the CBOD loading from the Susquehanna to the Bay was assumed negligible, due to decay and settlement behind the Conowingo Dam.

b. Potomac River

The pollutant loadings from the Potomac River were estimated from the EPA STORET data of pollutant concentrations at the river mouth. The 1973 average concentrations are:

Total-P:	0.117 mg/ℓ
Total-N:	0.73 mg/ℓ
NBOD:	2.33 mg/ℓ
CBOD:	2 mg/ℓ

The pollutant loadings listed in Table IV-4 were obtained by multiplying the concentrations with freshwater discharges.

Nearly all of the major point sources along the tidal Potomac are located in Metropolitan Washington, which is about 110 miles (177km) from the Bay. The results of the mathematical study by Clark, et al. (1973) indicates that these point sources contribute little to pollutant loads in the Bay. Therefore, all the loadings were assumed to have originated from non-point sources.

Table IV-4. Present Pollutant Loadings from the Potomac River

River Flows		Total - P	Total - N	NBOD	CBOD	DO*
cfs	(cms)	lb/day	lb/day	lb/day	lb/day	mg/ℓ
870	(25)	178	3,420	10,900	9,360	6.9
2100	(59)	430	8,250	26,300	22,600	6.9
7000	(198)	1430	27,500	87,800	75,300	8.2
13300	(376)	2720	52,200	166,800	143,100	9.65
23600	(668)	4820	92,700	296,000	254,000	11.5

* assume 90% of saturated oxygen concentration

c. James River

The present pollutant loadings from the James River were estimated from the field data of pollutant concentrations at the river mouth. Since the results of the regression analysis of the pollutant loadings from the Susquehanna River indicate that the pollutant concentrations vary little with freshwater flow, the reported data of pollutant concentrations at the James River mouth (Neilson, et al. 1975) were applied to all freshwater conditions. The data reported are:

CBOD:	2.0 mg/ℓ
Total-IN:	0.15 mg/ℓ
Total-P:	0.062 mg/ℓ

The present pollutant loadings under various flow conditions are listed in Table IV - 5. The value of inorganic nitrogen was used also for the total nitrogen and TKN.

Under the low flow conditions, it is expected that the pollutant loadings from non-point sources are negligible compared with those from point sources, primarily those in the Hampton Roads area. Under the high flow conditions it was assumed that 50% of pollutant loadings at the river mouth were contributed by point sources. The percentage-of-contribution values are also indicated in Table IV - 5. In view of the insignificant effects of the pollutant loadings from the James River on the water quality of the Bay as predicted by the model, the above assumptions are justifiable without more elaborated delineation

Table IV - 5. Present Pollutant Loadings from the James River

River Flow cfs	River Flow (cms)	Total-P lb/day	(% From Point Sources)	Total-N lb/day	(% From Point Sources)	NBOD lb/day	(% From Point Sources)	CBOD lb/day	(% From Point Sources)	DO* mg/ℓ
1020	(29)	340	(100)	825	(100)	3770	(100)	11000	(100)	6.55
1200	(34)	400	(100)	970	(100)	4430	(100)	13000	(100)	6.55
4800	(136)	1600	(100)	3880	(100)	17700	(100)	51600	(100)	7.76
12500	(354)	4170	(50)	10900	(50)	49800	(50)	134500	(50)	9.10
19300	(547)	6440	(50)	15800	(50)	72200	(50)	208000	(50)	10.8

* assumed 90% of saturated oxygen concentration

of point and non-point sources.

2. Other Point Sources

Figure IV-1 shows the locations of major point sources of pollutants within 10 nautical miles of the Bay. Table IV-6 presents 1973-1974 monthly average loadings, as available, of various pollutants discharged by these major municipal and industrial facilities. (A presentation of loadings from all major point sources in the Bay system is given in Appendix A) The distance from the Bay and the type of activity associated with each source are indicated in the table.

Loads of the various nutrients and BOD from Maryland outfalls were calculated on the basis of flows and effluent concentrations. The flows of the Maryland outfalls are given as a composite average rather than monthly averages.

The total and fecal coliform values are reported in units of most probable number per 100 milliliters (MPN). The monthly averages represent the geometric mean of all values reported for a month. Since samples were not taken on a regular basis and since 9999.0 is a ceiling value, these reported monthly averages may not be accurate reflections of the true monthly averages of coliform.

Nutrient and coliform information was not available for the Virginia outfalls. Generally, nutrient loadings have not been a problem in the Virginia portion of the Bay.

Figure IV-1. Locations of major municipal and industrial facilities discharging pollutants into the Chesapeake Bay.

Key

a) Bainbridge NTC
b) Havre deGrace STP
c) Perryville STP
d) Aberdeen STP
e) Sod Run STP
f) Edgewood Arsenal
g) Joppatown STP
h) Back River STP
i) Cox Creek STP
j) Potapsco STP
k) Bethlehem Steel Co.
l) Annapolis STP
m) Pine Hill Run STP
n) Standard Products
o) Haynie Products
p) American Oil Co. - Yorktown
q) VEPCO - Yorktown
r) Naval Mine Depot
s) Birchwood Gardens
t) HRSD - Oceana Naval Air Station
u) HRSD - Chesapeake Elizabeth

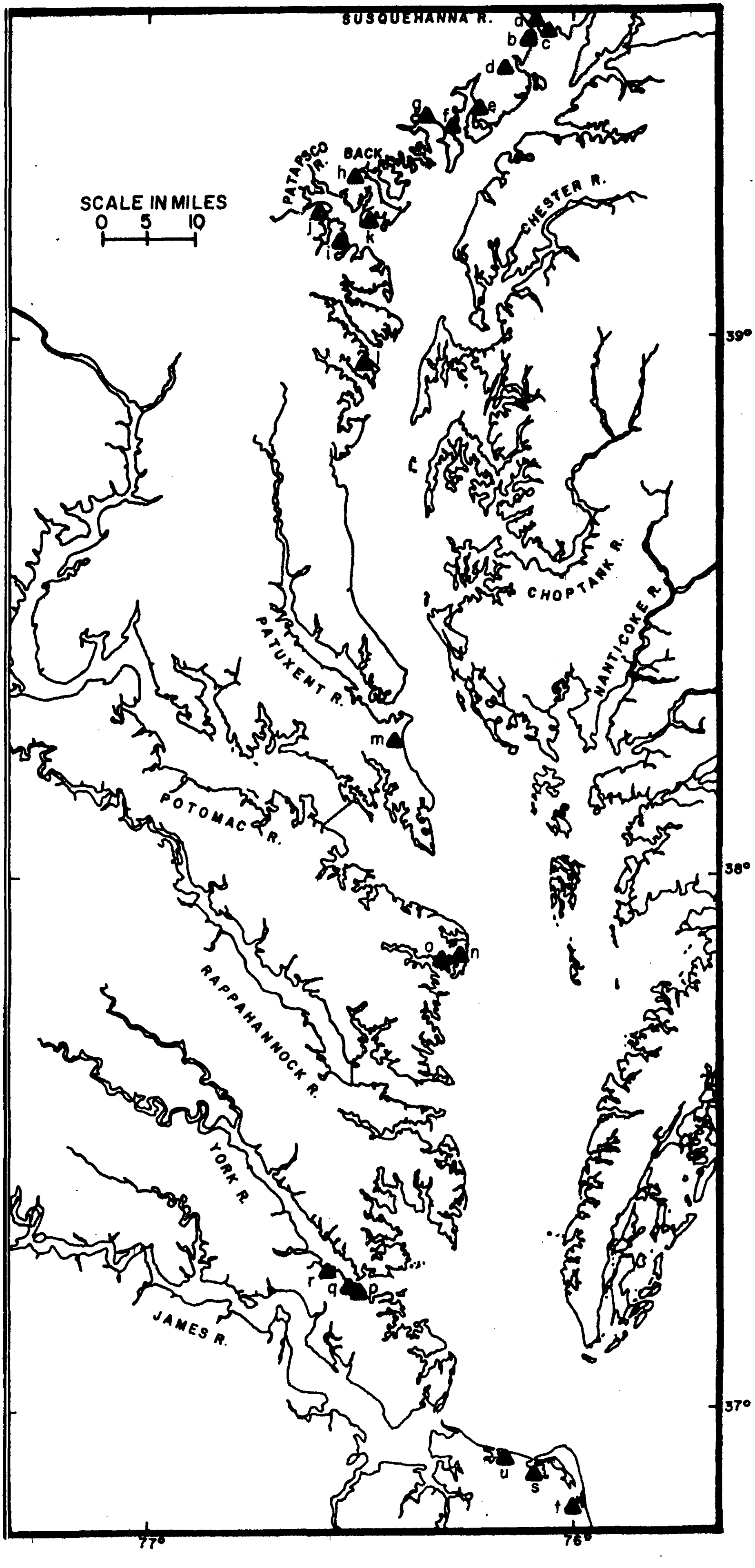
SUSQUEHANNA R.
a
b
c
d
e
f
g
PATAPSCO R.
BACK R.
h
j
i
k
SCALE IN MILES
0 5 10
CHESTER R.
39°
CHOPTANK R.
NANTICOKE R.
PATUXENT R.
m
POTOMAC R.
38°
o
n
RAPPAHANNOCK R.
YORK R.
r
q
p
JAMES R.
37°
u
s
t
77°
76°

Table IV - 6

MONTHLY AVERAGE LOADINGS FROM MAJOR (>0.5 MGD) POINT SOURCE EFFLUENTS

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
2	Bainbridge NTC	0.0	1973	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.6												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)				3.6	3.6	4300	3.6		131				
Fec. Col. (MPN)				3.0	3.0	930	3.0		26				

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
5	Havre de Grace	0.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.4												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)					43			58					
Fec. Col. (MPN)					3.6			8.3					

MONTHLY AVERAGE LOADINGS FROM MAJOR (>0.5 MGD) POINT SOURCE EFFLUENTS

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
2	Bainbridge NTC	0.0	1974	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.6								
DO (ppm)		8.1							
BOD_5 (lbs/day)		60							
P-ortho (lbs/day)		14							
P-poly (lbs/day)		2.5							
P-tot. (lbs/day)		16.5							
Tot. Col. (MPN)		20							
Fec. Col. (MPN)		3.3							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
5	Havre de Grace	0.0	Municipal

	Comp	Jan	Feb
Flow (MGD)	1.4		
DO (ppm)		7.45	9.00
BOD_5 (lbs/day)		619	537
P-ortho (lbs/day)		42	36
P-poly (lbs/day)		35	37
P-tot. (lbs/day)		77	74
Tot. Col. (MPN)			
Fec. Col. (MPN)			

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
6	Perryville	1.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.0												
DO (ppm)												2.95	
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)			23	430	3	9300	1500	4300	1500			1500	
Fec. Col. (MPN)			3.6	43	3	430	43	2300	430			150	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
7	Aberdeen	3.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.1												
DO (ppm)												5.0	
BOD_5 (lbs/day)												119	
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day													
Tot. Col. (MPN)					9999		93	2738	632				
Fec. Col. (MPN)					669		3	200	46				

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
9	Sod Run	<2	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	3.2												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)					9999			9999	656				
Fec. Col. (MPN)					430			9999	190				

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
6	Perryville	1.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	1.0								
DO (ppm)		8.0	7.87						
BOD_5 (lbs/day)		255	325						
P-ortho (lbs/day)		23	28						
P-poly (lbs/day)		13	9						
P-tot. (lbs/day)		35	36						
Tot. Col. (MPN)		4625							
Fec. Col. (MPN)		525							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
7	Aberdeen	3.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	1.1								
DO (ppm)		6.7							
BOD_5 (lbs/day)		257							
P-ortho (lbs/day)		42							
P-poly (lbs/day)		6							
P-tot. (lbs/day)		48							
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
9	Sod Run	<2	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	3.2								
DO (ppm)		8	7.9						
BOD_5 (lbs/day)		668	721						
P-ortho (lbs/day)		179	179						
P-poly (lbs/day)		29	37						
P-tot. (lbs/day)		208	216						
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source		Nautical Miles from Bay Reach							Activity			
10	Edgewood Arsenal			3.25				1973			Federal		
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Flow (MGD)	0.6												
	DO (ppm)													9.8
	BOD_5 (lbs/day)													15
	Tot. Col. (MPN)													3.6
	Fec. Col. (MPN)													3.0
11	Joppatown 1&2			8.0							Municipal			
	Flow (MGD)	.65												
	DO (ppm)											3.95	3.4	8.4
	BOD_5 (lbs/day)											57		22
	NH_3-N											37		
	NO_3-N											27		
	NO_2-N											4		
	P-ortho (lbs/day)											62		
	P-poly (lbs/day)											4		
	P-tot. (lbs/day)											66		
	Tot. Col. (MPN)			230	930			93	462	656		727	3.6	
	Fec. Col. (MPN)			43	3.0			3.6	3.0	99		93	3.0	
12	Back River			9.0							Municipal			
	Flow (MGD)	70												
	DO (ppm)											3.7		
	BOD_5 (lbs/day)											5266		
	Tot. Col. (MPN)											737	9999	1516
	Fec. Col. (MPN)											136	6557	373

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
10	Edgewood Arsenal	3.25	1974	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.6								
DO (ppm)									
BOD$_5$ (lbs/day)									
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
11	Joppatown 1&2	8.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	.65								
DO (ppm)		4.2	4.1						
BOD$_5$ (lbs/day)		168	112						
NH_3-N									
NO_3-N									
NO_2-N									
P-ortho (lbs/day)		48	55						
P-poly (lbs/day)		8	6.5						
P-tot. (lbs/day)		56	61						
Tot. Col. (MPN)		2300							
Fec. Col. (MPN)		30							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
12	Back River	9.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	70								
DO (ppm)									
BOD$_5$ (lbs/day)									
Tot. Col. (MPN)		1085							
Fec. Col. (MPN)		136							

Reach No.	Point Source			Nautical Miles from Bay Reach							Activity			
13	Cox Creek			4.3				1973			Municipal			
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Flow (MGD)	8.5												
	DO (ppm)											6.5		5.4
	BOD_5 (lbs/day)											425.6		893.8
	NH_3-N													915.0
	NO_3-N													730.6
	NO_2-N													.709
	Chloride													3638.8
	P-ortho (lbs/day)													295.1
	P-poly (lbs/day)													26.2
	P-tot. (lbs/day)													319.0
	Tot. Col. (MPN)				9999							43.0		
	Fec. Col. (MPN)				9990							23.0		
13	Patapsco			7.4							Municipal			
	Flow	17												
	DO (ppm)										2.9	4.1		
13	Bethlehem Steel			5.2							Metal Processing			
	Flow (MGD)	120												
	DO (ppm)											3.7		
	BOD_5 (lbs/day)											8990		
	Tot. Col. (MPN)											737	9999	1516
	Fec. Col. (MPN)											136	6557	373

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
13	Cox Creek	4.3	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	8.5								
DO (ppm)		2.68	3.8						
BOD$_5$ (lbs/day)		1950.6	2184.7						
NH$_3$-N		1035.6	1021.4						
NO$_3$-N									
NO$_2$-N		.709	.851						
Chloride		3674.3	3064.3						
P-ortho (lbs/day)		523.5	610.0						
P-poly (lbs/day)		58.1	38.3						
P-tot. (lbs/day)		581.3	645.1						
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Patapsco	7.4	Municipal

	Comp	Jan	Feb
Flow	17		
DO (ppm)			

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Bethlehem Steel	5.2	Metal Processing

	Comp	Jan	Feb
Flow (MGD)	120		
DO (ppm)			
BOD$_5$ (lbs/day)			
Tot. Col. (MPN)		1085	
Fec. Col. (MPN)		136	

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
15	Annapolis	2.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	4.9												
DO (ppm)											2.34		
BOD_5 (lbs/day)											2167		
NH_3-N											654.2	572.5	
NO_3-N													
NO_2-N											.82	.82	
Chloride											12880.5	11040	
P-ortho (lbs/day)											200.4	134.9	
P-poly (lbs/day)											45.0	8.2	
P-tot. (lbs/day)											245.3	143.1	
Tot. Col. (MPN)				21.0	20	118	150	192	99	227	880	9.1	63
Fec. Col. (MPN)				7.3	3.0	3.0	9.1	27	29	72	188	3.0	18.3

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
24	Pine Hill Run	0.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	2.1												
DO (ppm)										7.6		8.7	
BOD_5 (lbs/day)										350.5		350.5	
Tot. Col. (MPN)				29	750	75	9999		2300	230	93		686
Fec. Col. (MPN)				9	15.0	3.6	9999		36	3.0	3.0		69

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
15	Annapolis	2.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	4.9								
DO (ppm)			3.55						
BOD_5 (lbs/day)			4089.1						
NH_3-N		572.5	572.5						
NO_3-N		5.32	6.5						
NO_2-N		.82	.82						
Chloride		5683.8	8259.9						
P-ortho (lbs/day)		49.1	167.7						
P-poly (lbs/day)		12.3	8.2						
P-tot. (lbs/day)		61.3	175.8						
Tot. Col. (MPN)		49							
Fec. Col. (MPN)		12							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
24	Pine Hill Run	0.0	Municipal

	Comp	Jan
Flow (MGD)	2.1	
DO (ppm)		
BOD_5 (lbs/day)		
Tot. Col. (MPN)		430
Fec. Col. (MPN)		19

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Activity
29	Standard Products	<3							1973							Fish Processing
	Flow (MGD)												3.9	0	0	
	BOD_5 (lbs/day)												3990		0	
29	Haynie Products	<3														Fish Processing
	Flow (MGD)												11.2		0	
	BOD_5 (lbs/day)												7937		0	
36	American Oil - Yorktown 1&2	4														Refinery
	Flow (MGD)							52								
	BOD_5 (lbs/day)							2393								
36	VEPCO - Yorktown	7														Energy Production
36	Navy Mine Depot	7.87														Mine Depot
39	Birchwood Gardens	4.3														Municipal
	Flow (MGD)															
	BOD_5 (lbs/day)															
39	HRSD - Oceana Naval Air St.	0.0														Municipal
	Flow (MGD)			.9	.9	.9	1.1	1.07	1.0	.8	1.1	1.3	1.3	1.4	1.5	
	BOD_5 (lbs/day)			83	180	98	183	214	92	160	404	542	651	1005	826	

Reach No.	Point Source	Nautical Miles from Bay Reach										Activity
29	Standard Products	<3							1974			Fish Processing
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)			0	0	0	0	0.7	1.7	3.8	4.1	
	BOD_5 (lbs/day)			0	0	0	0	577	2390	3793	2490	
29	Haynie Products	<3										Fish Processing
	Flow (MGD)			0	0	0	0	1.3	8.1	6.6	4.8	
	BOD_5 (lbs/day)			0	0	0	0	119	848	941	682	
36	American Oil - Yorktown 1&2	4										Refinery
	Flow (MGD)											
	BOD_5 (lbs/day)											
36	VEPCO - Yorktown	7										Energy Production
36	Navy Mine Depot	7.87										Mine Depot
39	Birchwood Gardens	4.3										Municipal
	Flow (MGD)			.55								
	BOD_5 (lbs/day)			161	163	142	163	164	173	147	151	
39	HRSD - Oceana Naval Air St.	0.0										Municipal
	Flow (MGD)											
	BOD_5 (lbs/day)			921	340	411	638	531	445	320	73	

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
39	HRSD Chesapeake-Elizabeth	0.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)		12.5	14.0	14.8	13.7	12.1	12.2	12.5	12.6	10.1	11.1	8.2	9.6
BO$_5$ (lbs/day)		4796	6422	8887	9141	7266	7529	7506	9043	9271	7684	5543	6489

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
39	HRSD Chesapeake-Elizabeth	0.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)		11.5							
BOD_5 (lbs/day)		8728							

The values presented for Bethlehem Steel Co. discharge are actually based on the Back River STP data since Bethlehem Steel reuses approximately 120 MGD of Back River STP effluent. It was assumed that Bethlehem's activities do not alter the concentrations of the parameters included in this table (BOD$_5$, total and fecal coliform).

D. Summary Comparison of Point Sources and Values Used in Water Quality Model

1. Summary

a) Reaches 1-5 (Lower Susquehanna River): This portion of the Bay contains no large population centers and only scattered industry. Of the two "major" outfalls in this section, only Havre de Grace yields any appreciable loading. Sources upstream of our area of interest on the Susquehanna may have a more significant impact.

b) Reaches 6-11 (Chesapeake Bay above the Baltimore Area): Again there are no large population centers or industrial outfalls. Although some high bacterial counts are reported for effluents of the larger sources, the total BOD$_5$ loading from these sources is less than 1500 lbs/day.

c) Reaches 12-13 (Baltimore Area): While there are a multitude of industrial sources in this area of those not connected to the city's wastewater system, only Bethlehem Steel Company is very large. Some portion of the effluent of the municipal outfalls are generated, however, by industrial activities. Also, as pointed out above, approximately 120 MGD of the treated effluent of the Back River STP is reused by Bethlehem Steel in their processing before discharge into the Patapsco River.

The high bacterial counts and high BOD_5 loadings from the plants (greater than 15,000 lbs/day) may have some degree of influence on the Bay. Actually, the BOD loads are expected to be quite a bit higher than indicated there. The Back River and, therefore, Bethlehem Steel BOD_5 discharge levels in Table IV-6 are based on a single sample. The National Pollution Discharge Eliminination System (NPDES) permit for Back River effluent indicates a 7-fold higher weekly average effluent concentration for a combined allowable BOD_5 discharge of 98745 lbs/day (excluding overflows). This corresponds to 148118 lbs CBOD/day assuming a decay rate of .22 day^{-1} (base e). Moreover, the Patapsco STP NPDES permit allows another 51040 lbs BOD_5/day or 76,560 lbs CBOD/day. Combining these figures with the 4785 lbs CBOD/day allowed by the Cox Creek NPDES permit leads to a total allowed weekly average CBOD discharge from this area of 229463 lbs/day.

d) Reaches 14-26 (Chesapeake Bay between Baltimore and the Potomac River): There is little industry in this area. The most significant source is the city of Annapolis which is relatively small compared to Baltimore dischargers. The larger sources in the Patuxent Basin are too far upstream (50 nautical miles or more) to have much impact on the Bay. Cambridge, on the Choptank, is also rather far upstream to influence the Bay.

e) Reach 27 (The Potomac River): As pointed out in Section C, these loads are generated primarily from non-point sources. Moreover, while the pollutant loads appear rather large at the two higher flow conditions, their relative significance is rather small due to a high degree of dilution on entering the Bay.

f) Reaches 29-35 (Chesapeake Bay between the Potomac and York Rivers): The most important sources are the two fish processing plants that discharge seasonally from May through October. Since their discharge season includes the critical low flow period their effluents might be significant locally (in the immediate vicinity of the outfall) but would not be easily detectable when mixed over the entire 5-mile reach.

No major sources on the Rappahannock appear to be far enough downstream to influence the Bay.

g) Reaches 36-37 (York River area): The American Oil Co. BOD discharge is the most significant in this area, since the Chesapeake Corp. is too far upstream to influence the Bay. The non-point sources near the mouth of the York, however, dominate the BOD profile.

h) Reach 38 (James River): As in the case of the Potomac River, these loads, even smaller and subject to greater dilution than those of the Potomac, have little impact on pollutant concentrations in the Bay.

i) Reach 39: These municipal discharges are rather small and their effluents are subject to a high degree of dilution once they enter the Bay. Moreover, Birchwood Gardens and HRSD-Oceana are expected to phased out by 1977.

j) Conclusion: The dominant point sources of BOD for the Chesapeake Bay are the municipal and industrial facilities of the Baltimore area. The loads from the Potomac and James Rivers have little effect on the Bay, since they are smaller and undergo greater dilution on entry to the Bay. (The Potomac loads, moreover, arise primarily from non-point sources). Other sources, such as Annapolis or the seasonal fish processors below the Potomac mouth, may have impact in the immediate vicinity of their outfalls, but not on the Bay as a whole, again due to dilution.

2. Values Used in Water Quality Model

The point source inputs to the mathematical water quality model used to simulate present water quality conditions are listed in Table IV-7.

Since actual effluent discharge information was scant (See Table IV-6) and its accurate representation of typical values is questionable (see previous discussion of Baltimore point sources in this section), where possible NPDES permit limitations for the 1974 period were used. In most cases permit limits existed only for BOD_5 discharges. (In Maryland these figures are maximum weekly averages; in Virginia maximum daily averages). These maximum limits may overestimate (or possibly underestimate) actual loads. Overflow discharges noted on certain permits (i.e. Havre de Grace, Back River), however, were not included since they are necessarily intermittent.

a) Ultimate Carbonaceous Oxygen Demand (CBOD) BOD_5 mass emission rates used to calculate CBOD rates in Table IV-7 were obtained from NPDES permits covering the 1974 period for all sources except the following;

(1) Federal facilities (Bainbridge NTC, Edgewood Arsenal, and Naval Mine Depot) were assumed to be meeting the 1977 standards of secondary treatment (concentration of BOD_5 = 30 mg/ℓ) in 1974. The mass emission rates were calculated based on this figure and the design flow rates.

Table IV-7. Estimated Chesapeake Bay Point Source Average Mass Emission Rates for 1974 (lbs/day)

Model Reach #	Source	Flow Rate (MGD)	CBOD	TKN	NBOD	NO_2NO_3-N	TN	TP
2	Bainbridge NTC	.7	263	105	480	22	127	19
5	Havre de Grace	1.5	2664	434	1983	0	434	81
6	Perryville	1.0	410	290	1325	0	290	36
7	Aberdeen	1.13	425	170	777	35	205	49
9	Sod Run	4.0	2250	1158	5292	0	1158	33
10	Edgewood Arsenal	3.0	1125	451	1061	93	544	205
11	Joppatown	0.75	375	113	516	23	136	71
12	Back River	65.0	52041	18822	86017	0	18822	5695
13	Cox Creek	8.5	4785	2461	11247	0	2461	518
	Patapsco	18.0	76560	5212	23819	0	5212	1577
	Bethlehem Steel	120.0	96077	62226	284373	0	62226	10515
15	Annapolis	6.0	10125	1737	7938	0	1737	190
24	Pine Hill Run	3.0	1703	869	3971	0	869	263
29	Standard Products	4.4	9428	0	0	0	0	0
	Haynie Products	8.64	14931	0	0	0	0	0
36	American Oil (Yorktown)		5259	1314	6005	0	1314	0
	VEPCO (Yorktown)		0	0	0	0	0	0
	Naval Mine Depot	0.52	126	78	357	22	100	36
39	Birchwood Gardens	0.8	218	120	548	25	145	55
	HRSD- Oceana	0.5	609	145	663	0	145	44
	HRSD- Chesapeake Elizabeth	13.0	6509	3764	17201	0	3764	1139

Since all except Edgewood Arsenal are rather small, this is probably not critical.

(2) Aberdeen STP was assumed to be meeting 1977 standards of secondary treatment in 1974. This is reasonable based on actual recorded effluent concentrations. The mass emission rate was calculated based on this figure and the design flow rate.

(3) Effluent from Bethlehem Steel at Sparrows Point was assumed to have the same BOD_5 concentration as that from the Back River STP, the source of their water. That is, it was assumed that Bethlehem Steel's activities neither add nor remove BOD_5 to the water. Further, the diversion of Back River effluent to Bethlehem Steel was assumed to be 120 MGD out of 185 MGD.

(4) Birchwood Gardens and HRSD - Oceana Naval Station values were obtained from the average of their actual 1974 monthly discharges.

CBOD rates were calculated from BOD_5 values assuming BOD_5 is composed totally of carbonaceous matter and the decay rate is .22 day^{-1} (base e).

b. Flow Rates

Since no flow rates were specified on the NPDES permits, indirect determinations were made. If a BOD_5 effluent concentration limit as well as a mass emission rate limit was specified in the permit, the flow rate value was calculated on the basis of these two figures. Otherwise the design flow rate was used. Since these flow rates are hopefully maximums they may overestimate the actual flow rates.

c. Total Kjeldahl Nitrogen (TKN), Nitrogenous BOD (NBOD) and Nitrite/Nitrate Nitrogen (NO_2 &NO_3-N)

TKN mass emission rates for municipal STP's and Federal facilities were calculated from flow rates on the basis of concentrations of 18 mg/ℓ for secondary treatment and 34.7 mg/ℓ for primary treatment. 18 mg/ℓ is a standard municipal secondary effluent TKN concentration. Assuming total nitrogen (TKN + NO_2 &NO_3-N) reduction rates of 20% and 50% for primary and secondary municipal treatment, respectively, (Amer. Chem. Soc. 1969) and 0.0 and 3.7 mg/ℓ NO_2 &NO_3-N concentrations for primary and secondary municipal effluent, respectively, (Metcalf and Eddy 1972; Amer. Chem. Soc. 1969), a 34.7 mg/ℓ TKN concentration was calculated for primary municipal effluent.

The American Oil TKN (NH_3 and organic -N) mass emission rate was determined from the NPDES permit limitations for ammonia nitrogen. That is, organic nitrogen discharges were assumed to be negligible.

Bethlehem Steel's NPDES ammonia nitrogen limitations for 1974 was added to the 1974 influent TKN (from Back River STP effluent) to obtain TKN emission rates.

Since neither the NPDES permits nor the EPA Effluent Guidelines and Standards specified TKN discharge rates, no TKN discharge was assumed from Standard Products (fish processing), Haynie Products (fish processing), or VEPCO.

NBOD mass emission rates were calculated from TKN rates on the basis of the stoichiometric ratio 4.57 of oxygen to ammonia nitrogen in the nitrification equation;

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$$

As mentioned above NO_2 &NO_3-N concentrations were assumed to be 0.0 and 3.7 mg/ℓ for primary and secondary municipal effluent, respectively. The same NO_2 &NO_3-N concentrations used for the Back River STP was used for Bethlehem Steel effluent. Again, no NO_2 NO_3 discharge was assumed for Standard Products, Haynie Products or VEPCO.

These concentrations were combined with the flow rates to yield mass emission rates.

d. Total Phosphorus (TP)

Total phosphorus emissions were calculated in Table IV-7 on the basis of average actual measured concentrations for 1973-1974 where available. Where not available, concentrations of 10.5 and 8.2 mg/ℓ for primary and secondary municipal effluents, respectively, (Amer. Chem. Soc. 1969) were used.

Bethlehem Steel effluent concentration was assumed to be the same as Back River STP. As in the case of TKN and NO_2 &NO_3-N, Standard Products, Haynie Products, American Oil, and Vepco were assumed to have no phosphorus discharge.

The mass emission rates of total phosphorus were calculated from the concentrations and the flow rates.

E. Non-Point Sources of Pollutants

The non-point sources of pollutants considered in the model consisted of runoff from (a) undeveloped land (forest, park, open), (b) agricultural land, (c) urban land, (d) suburban land, and (e) marshland draining into the Bay, from distances less than 10 nautical miles, either directly or through a tributary. The 10 nautical mile cut-off point was chosen since it was judged that the significance of loads traveling any further than this would be negligible due to decay of non-conservative substances and settling.

The acreages (within 10 nautical miles of the Bay) devoted to each of the first four types of land use that drain into each model reach were estimated in the following manner.

1. The proportion of land in each relevant county devoted to the land use categories of (a) undeveloped (woodland, park, open), (b) agricultural, and (c) metropolitan (residential, commercial, industrial, public) was ascertained (Dept. of the Army 1973). The last category was further divided into urban and suburban according to the following formulae:

   Urban acreage = (Industrial acreage + commercial acreage)/.35

Suburban acreage = (Metropolitan acreage) - (Urban acreage) 0.35 was chosen as the proportion of a totally urban area devoted to industrial and commercial activities since this was the proportion in the city of Baltimore.

2. The proportion of land of each county within 10 nautical miles of each model reach of the Bay was estimated based on maps of the area.
3. Assuming that land uses are distributed in the 10 nautical mile belt as they are throughout the county, the data obtained in steps 1 and 2 were combined to give acreages of each type of land draining into each reach.

Statute miles of marsh shoreline for each reach were estimated from maps (Lippson, 1973; G. Silberhorn and G. Dawes {VIMS}, unpublished).

Yield rates corresponding to different Susquehanna flow conditions used for each type of land use are shown in Tables IV-8 through IV-12.

The values given in Tables IV-8 through IV-10 are logarithmic interpolations and extrapolations of coefficients developed from regression analyses of data from the lower Susquehanna River basin (Clark, et al., 1974). Urban and suburban runoff was considered to be negligible for Susquehanna flows of less than 37,400 cfs since such usually associated with storms. Shoreline marsh scouring was also assumed to be negligible under such flow conditions, although this assumption may not be warrented in

Table IV-8 Estimated Yield Rates of Total Phosphorus for Various Land Uses Under Different Flow Conditions

Susquehanna River Flow at Conowingo, Md. (cfs)

Land Use	2700	6400	25100	38600	70300
Undeveloped(lbs/acre/day)	0	.000033	.000228	.000294	.000326
Agricultural (lbs/acre/day)	0	.000326	.001860	.002382	.002937
Urban (lbs/acre/day)	0	0	0	.001468	.007832
Suburban (lbs/acre/day)	0	0	0	.000815	.003916
Marsh (lbs/statute mi/day)	0	0	0	24.6	97.2

Table IV-9 Estimated Yield Rates of Nitrite and Nitrate Nitrogen for Various Land Uses Under Different Flow Conditions

Susquehanna River Flow at Conowingo, Md. (cfs)

Land Use	2700	6400	25100	38600	70300
Undeveloped (lbs/acre/day)	0	0	.0018	.0020	.0030
Agricultural (lbs/acre/day)	.0060	.0260	.0570	.0670	.0800
Urban (lbs/acre/day)	0	0	0	.0065	.0190
Suburban (lbs/acre/day)	0	0	0	.0042	.0125
Marsh (lbs/statute mi/day)	0	0	0	0	0

Table IV-10 Estimated Yield Rates of Total Kjehldahl Nitrogen for Various Land Uses Under Different Flow Conditions

Susquehanna River Flow at Conowingo, Md. (cfs)

Land Use	2700	6400	25100	38600	70300
Undeveloped (lbs/acre/day)	0	.0005	.0028	.0035	.0042
Agricultural (lbs/acre/day)	0	.0015	.0080	.0100	.0132
Urban (lbs/ acre/day)	0	0	0	.0140	.0380
Suburban (lbs/ acre/day)	0	0	0	.0070	.0188
Marsh (lbs/ statute mi/day)	0	0	0	110.	623.

Table IV-11 Estimated Yield Rates of Nitrogenous BOD for Various Land Uses Under Different Flow Conditions

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Uses	2700	6400	25100	38600	70300
Undeveloped (lbs/acre/day)	0	.0023	.0128	.0160	.0192
Agricultural (lbs/acre/day)	0	.0069	.0366	.0457	.0603
Urban (lbs/acre/day)	0	0	0	.0640	.1737
Suburban (lbs/acre/day)	0	0	0	.0320	.0859
Marsh (lbs/statute mi/day)	0	0	0	502.7	2847.1

Table IV-12 Estimated Yield Rates of Ultimate Carbonaceous BOD for Various Land Uses Under Different Flow Conditions

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Use	2700	6400	25100	38600	70300
Undeveloped (lbs/acre/day)	0	.00366	.02035	.02544	.03053
Agricultural (lbs/acre/day)	0	.01097	.05819	.07266	.09588
Urban (lbs/acre/day)	0	0	0	.19968	.54194
Suburban (lbs/acre/day)	0	0	0	.09984	.26801
Marsh (lbs/statute mi/day)	0	0	0	799.3	4526.9

the case of tidal marshes. Marsh yields of nitrogen derived from the literature were expressed in terms of total nitrogen. It was therefore assumed that all nitrogen yielded from marshland was TKN. In fact, a study of two salt marshes on the York River (Axelrad 1974) showed this to be the case on the basis of annual net flux. The monthly net export of NO_2&NO_3-N never exceeded 11% of the total dissolved nitrogen export in these marshes.

The nitrogenous BOD (NBOD) values in Table IV-11 were calculated from the TKN coefficients on the basis of the stoichiometric ratio 4.57 of oxygen to ammonia nitrogen in the nitrification equation:

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$$

The ultimate carbonaceous BOD (CBOD) values were calculated for undeveloped, agricultural and marsh land on the basis of an average annual BOD_5 concentration of 7 mg/ℓ in agricultural runoff (Loehr 1974). Assuming this figure corresponds to an intermediate Susquehanna flow condition of 37,400 cfs and assuming an annual rainfall of 30 inches with a .37 runoff coefficient, the calculated yield rate of .04824 lbs BOD_5/acre/day has a ratio of 1.06 to the agricultural land NBOD yield at 37,400 cfs. This ratio was then applied to the NBOD coefficients for undeveloped, agricultural and marsh land at all flow conditions to obtain corresponding BOD_5 yield rates.

Similarly, a BOD_5 to NBOD coefficient ratio of 2.08 was calculated for urban runoff at 37,400 cfs on the basis of a 27,000 lbs $BOD_5/mi^2/yr$ annual yield rate (American Chemical Society, 1969; Loehr, 1974). This ratio was then applied to the NBOD coefficients for urban and suburban land at all flow conditions to obtain corresponding BOD_5 yield rates.

The CBOD yield rates were calculated from the BOD_5 rates assuming BOD_5 is composed entirely of carbonaceous matter and the dacay rate is .22 day^{-1} (base e).

Finally, the yield rates were combined with the acreages relevant to each Bay reach to obtain the mass emission rates of non-point source pollutants for each Susquehanna River flow condition as shown in Tables IV-13 through IV-17.

Tables IV-18 through IV-21 show the relative contributions of the various land uses to non-point source pollutant loads in the Bay as a whole at different Susquehanna flow levels. The values were calculated from the yield rates and relevant acreages. The non-point sources included in the Susquehanna, Potomac and James River discharge calculations were not included in Tables IV-18 through IV-21. In the cases of total phosphorus, NBOD and CBOD marshes appear to be the dominant non-point sources at the higher flow levels. In the total nitrogen case, both marshes and agricultural land appear significant

Table IV-13 Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 2700 cfs at Conowingo, Md.

(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
1-5	0	0	0	0	0	0
6	0	0	132	132	0	0
7	0	0	0	0	0	0
8	0	0	99	99	0	0
9	0	0	103	103	0	0
10	0	0	159	159	0	0
11	0	0	87	87	0	0
12	0	0	69	69	0	0
13	0	0	110	110	0	0
14	0	0	175	175	0	0
15	0	0	86	86	0	0
16	0	0	69	69	0	0
17	0	0	221	221	0	0
18	0	0	46	46	0	0
19	0	0	122	122	0	0
20	0	0	23	23	0	0
21	0	0	57	57	0	0
22	0	0	57	57	0	0
23	0	0	55	55	0	0
24	0	0	34	34	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	50	50	0	0
30	0	0	164	164	0	0
31	0	0	7	7	0	0
32	0	0	94	94	0	0
33	0	0	56	56	0	0
34	0	0	40	40	0	0
35	0	0	40	40	0	0

Table IV-13 (cont'd)

Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 2700 cfs at Conowingo, Md.

(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
36	0	0	133	133	0	0
37	0	0	49	49	0	0
38	0	0	3	3	0	0
39	0	0	0	0	0	0

Table IV-14 Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 6400 cfs at Conowingo, Md. (lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
1-5	0	0	0	0	0	0
6	8	43	574	617	196	311
7	0	0	0	0	0	0
8	6	32	430	462	147	233
9	6	31	446	477	140	223
10	10	55	691	746	250	265
11	3	26	379	405	120	191
12	4	21	300	321	94	149
13	7	47	478	526	216	344
14	10	54	756	810	245	390
15	6	39	371	410	179	284
16	5	31	297	328	143	227
17	13	76	957	1032	346	550
18	3	21	198	219	96	151
19	7	41	529	570	188	299
20	2	10	100	110	47	75
21	4	23	249	271	104	165
22	4	23	249	271	104	165
23	4	24	236	261	111	176
24	2	12	149	161	56	90
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	3	22	219	241	101	160
30	10	62	711	773	285	452
31	1	3	3	6	14	23
32	7	45	409	454	206	327
33	4	30	245	275	136	327
34	2	14	172	186	63	101
35	2	14	172	186	63	101

Table IV-14 (Cont'd)
Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 6400 cfs at Conowingo, Md.
(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
36	9	64	577	642	294	468
37	3	20	211	230	88	139
38	0	4	13	93	19	30
39	0	0	0	0	0	0

Table IV-15 Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 25100 cfs at Conowingo, Md. (lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
1-5	0	0	0	0	0	0
6	46	231	1293	1524	1055	1678
7	0	0	0	0	0	0
8	34	173	970	1143	792	1258
9	34	165	996	1161	754	1198
10	56	296	1569	1864	1352	2149
11	29	141	847	988	645	1026
12	23	110	669	779	505	802
13	43	258	1119	1377	1177	1871
14	59	289	1694	1983	1321	2100
15	35	213	877	1091	974	1548
16	28	170	702	872	779	1238
17	79	409	2197	2606	1870	2973
18	19	113	468	581	518	824
19	43	223	1198	1421	1017	1617
20	9	56	235	291	258	409
21	22	123	575	698	562	894
22	56	723	575	698	562	894
23	22	132	557	689	605	961
24	12	67	340	407	305	485
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	20	120	514	634	550	874
30	61	338	1635	1973	1544	2454
31	3	61	71	132	279	124
32	39	246	974	1220	1125	1788
33	25	163	594	757	746	1788
34	14	75	391	466	342	544
35	14	75	391	466	342	544

Table IV-15 (cont'd)

Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 25100 cfs at Conowingo, Md.
(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
36	56	352	1377	1729	1608	2557
37	18	104	488	592	476	757
38	3	23	41	64	105	166
39	0	0	0	0	0	0

Table IV-16 Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 38,6000 cfs at Conowingo, Md.
(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
1-5	0	0	0	0	0	0
6	112	551	1539	2090	2518	4306
7	46	247	38	285	1129	2365
8	676	3162	1253	4413	14450	24344
9	577	2697	1277	3974	12325	20859
10	565	2614	1867	4481	11946	19303
11	630	2878	1026	3904	13152	21349
12	193	892	806	1698	4076	6747
13	250	1560	1637	3197	7129	16114
14	251	1172	2011	3183	5356	8807
15	172	922	1111	2103	4214	7814
16	294	1441	889	2330	6585	11366
17	431	2073	2616	4689	9474	15986
18	373	1788	583	2371	8171	13160
19	794	3641	1439	5080	16639	26894
20	232	1064	277	1341	4862	7760
21	394	1810	678	2488	8272	13206
22	126	601	651	1252	2747	4414
23	310	1444	659	2103	6599	10575
24	748	3386	401	3787	15474	24629
25	171	770	0	770	3519	5595
26	171	770	0	770	3519	5595
27	171	770	0	770	3519	5595
28	141	638	0	638	2916	4636
29	194	914	604	1518	4177	6674
30	673	3129	1944	5073	14300	23048
31	243	1100	84	1184	5027	7997
32	261	1262	1144	2406	5767	9230
33	216	1039	699	1738	4748	7605
34	187	855	460	1315	3907	6224
35	90	415	460	875	1897	3027

Table IV-16 (cont'd)

Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 38,600 cfs at Conowingo, Md. (lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
36	707	3615	1653	5268	16521	26775
37	422	1950	600	2550	8912	14507
38	7	65	67	132	295	721
39	0	0	0	0	0	0

Table IV-17 Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 70,300 at Conowingo, Md.
(lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
1-5	0	0	0	0	0	0
6	289	1735	1888	3623	7929	13409
7	191	1156	111	1267	5283	9955
8	2592	16381	1708	18088	74861	122700
9	2196	13836	1721	15557	63231	103927
10	2056	13054	2294	15348	59657	95819
11	2413	15349	1285	16634	70145	112699
12	689	4333	1001	5334	19802	32213
13	936	6383	2544	7927	29170	52108
14	795	4941	2451	7392	22580	36674
15	580	3572	1495	5067	16324	28978
16	1086	6845	1196	8041	31282	52155
17	1459	9113	3269	12382	41646	68703
18	1426	9079	768	9847	41491	67216
19	3017	19217	1789	21006	87822	140819
20	891	5706	340	6047	26076	41534
21	1495	8960	826	10386	40947	69592
22	426	2707	826	3533	12371	19797
23	1158	7408	812	8220	33854	54067
24	2930	18805	486	19291	85939	136701
25	680	4361	0	4361	19930	31688
26	680	4361	0	4361	19930	31688
27	680	4361	0	4361	19930	31688
28	564	3613	0	3613	16511	26256
29	704	4502	738	5240	20574	32798
30	2471	15736	2395	18131	71914	115177
31	957	6134	102	6236	28032	44583
32	901	5769	1401	7170	26364	42073
33	771	4953	863	5815	22635	38013
34	694	4424	33	4457	20218	32186
35	305	1932	556	2488	8829	14079

Table IV-17 (cont'd)

Estimated Non-Point Source Pollutant Loads By Bay Reach for Susquehanna River Flow Rate of 70,300 at Conowingo, Md. (lbs/day)

Reach #	TP	TKN	NO_2&NO_3-N	TN	NBOD	CBOD
36	2887	18319	2086	20405	83718	134478
37	1620	10327	774	11101	47194	75950
38	24	132	120	252	603	1636
39	0	0	0	0	0	0

Table IV-18. Composition of Non-Point Source Total Phosphorus Loads Contributed to Chesapeake Bay by Lands in Various Uses

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Use	2700	6400	25100	38600	70300
Undeveloped	-	13	16	2	<1
Agricultural	-	87	84	8	3
Urban	-	0	0	1	2
Suburban	-	0	0	1	1
Marsh	-	0	0	88	94

Table IV-19. Composition of Non-Point Source Total Nitrogen Loads Contributed to Chesapeake Bay by Lands in Various Uses

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Use	2700	6400	25100	38600	70300
Undeveloped	0	3	10	4	1
Agricultural	100	97	90	38	12
Urban	0	0	0	2	2
Suburban	0	0	0	2	1
Marsh	0	0	0	54	83

Table IV-20. Composition of Non-Point Source NBOD Loads Contributed to Chesapeake Bay by Lands in Various Uses

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Use	2700	6400	25100	38600	70300
Undeveloped	-	34	35	4	1
Agricultural	-	66	65	8	2
Urban	-	0	0	2	1
Suburban	-	0	0	2	1
Marsh	-	0	0	84	95

Table IV-21. Composition of Non-Point Source CBOD Loads Contributed to Chesapeake Bay by Lands in Various Uses

	Susquehanna River Flow at Conowingo, Md. (cfs)				
Land Use	2700	6400	25100	38600	70300
Undeveloped	-	34	35	4	1
Agricultural	-	66	65	7	2
Urban	-	0	0	5	2
Suburban	-	0	0	3	2
Marsh	-	0	0	81	93

at these higher flow levels, with the marshes contributing TKN and agricultural land contributing primarily nitrite and nitrate nitrogen.

F. Comparison of Point and Non-Point Sources

Table IV-22 shows the relative significance of point and non-point sources to the pollutant loadings in the Bay as a whole for different flow conditions. Both point and non-point source loads entering the Bay through the Susquehanna, Potomac and James Rivers as delineated in Tables IV-3 through IV-5 were included in calculations for Table IV-22. The magnitudes of the point source discharges vary with freshwater flow level. This phenomenon is due to the inclusion of the point source contributions associated with the major tributaries. The absolute levels of these contributions vary with freshwater flow level due to decay of non-conservative substances, settling, and settling rate variations. Thus, the amount of the pollutant that has decayed and/or settled between the point source outfall and the tributary mouth will vary with freshwater flow level.

The values in the table apply to the Bay as a whole. The distribution of the pollutant loads, however, is as significant a factor as the overall magnitude in determining the impact on water quality in the Bay, a relatively large body of water. More than half of the point source load in each category is concentrated in the Baltimore area, while more than half the non-point source load of total nitrogen is generated upstream of the Bay on the lower Susquehanna River. These concentrated effluents strain the assimilative capacity of the Bay to a greater extent than would more evenly distributed pollutants. Moreover, the upstream reaches of the Bay, where the high loads occur contain smaller water volumes than those downstream and thus have lower assimilative capacities. The percentages indicated in Table IV-22, therefore, may not accurately reflect the relative significance of point and non-point sources with regard to water quality but only the relative overall magnitudes.

Table IV-22. Comparison of Point and Non-Point Sources of Pollutants on the Chesapeake Bay

	2700	6400	25100	38600	70300
Total Phosphorus					
Point Sources (lbs/day)	21359	22123	25208	26598	28182
%	99	97	80	54	30
Non-Point Sources (lbs/day)	178	788	6215	23068	65154
%	1	3	20	46	70
Total Nitrogen					
Point Sources (lbs/day)	106201	110773	125793	120466	124112
%	82	64	35	22	12
Non-Point Sources (lbs/day)	22822	52403	235448	428820	928041
%	18	36	65	78	88
NBOD					
Point Sources (lbs/day)	503029	539076	647042	670856	648074
%	94	87	67	47	22
Non-Point Sources (lbs/day)	31426	82210	324612	768900	2284236
%	6	13	33	53	78
CBOD					
Point Sources (lbs/day)	296883	298883	337483	353133	389883
%	87	73	46	26	12
Non-Point Sources (lbs/day)	45291	109800	401179	1031566	2937867
%	13	27	54	74	88

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V. Selection of Hydrological Conditions for Projections

A. Data Sources and Limitations. See Chapter III.

B. Rationale and Selection

The water quality model for the Chesapeake Bay requires the freshwater discharges from the Susquehanna, Potomac and James as input data. These three rivers contribute about 83% of the total freshwater input to the Bay. The flows from other tributaries are estimated in the model by applying to the Susquehanna discharge the ratio of the tributary discharge area to the Susquehanna drainage. Therefore, in selecting the hydrologic conditions, the flow rates from the three major tributaries must be determined.

1. 7-Day 10-Year Low Flow

Data in Table III-2 were used as the basis for these estimates. The flow rates estimated at the gauging stations were adjusted to the flow rates at the river mouths in proportion to drainage areas.

2. Seasonal Flows for the Lower Quartile Year

Figure III-2 shows that the monthly flow variation for the lower quartile year (1968) does not follow the monthly variation of the 23 year average flow. The 23 year average flow reaches its maximum in early spring (March), then decreases monotonically and reaches its minimum in early fall (September). At the midpoints between times of maximum and minimum flows, the flows are roughly equal to the yearly average. The 1968 hydrograph shows a dip in April and a peak in September; it further shows an unusual high flow in June.

Of the years ranked adjacent to the lower quartile year (1954 and 1964), it is concluded that the 1954 hydrograph most resembles the 23-year average hydrograph in terms of seasonal variation. The 1954 monthly average flows from the Susquehanna, Potomac and James are provided in Table V-1. The four flow conditions selected to represent seasonal variation are underlined.

Table V-2 summarizes the five freshwater flow conditions with typical water temperatures of the seasons. The gauging records have been adjusted to the flow rates at the river mouths in proportion to drainage area.

Table V-1. 1954 Hydrograph

	Mouth of Susquehanna	Potomac River at Washington D. C.	James River at Richmond
Jan.	15,200	4,110	5,993
Feb.	46,400	4,540	5,282
Mar.	70,300	19,570	12,839
Apr.	57,200	8,560	7,439
May	62,800	8,304	6,842
June	25,100	5,813	3,186
July	7,600	2,144	2,294
Aug.	5,500	2,213	1,169
Sept.	6,400	1,753	802
Oct.	12,400	10,180	4,739
Nov.	21,400	8,389	5,783
Dec.	38,600	11,080	8,298

Table V-2. Seasonal Freshwater Discharges and Water Temperature Used for Model Simulation.

Season	Susquehanna River cfs	Potomac River cfs	James River cfs	Temperature $^{\circ}C$
7/Q/10	2,700	870	1020	27
Feb - Mar	70,300	23,600	19,300	3
May - June	25,100	7,000	4,800	18
Aug - Sept	6,400	2,100	1,200	27
Nov - Dec	38,600	13,300	12,500	10

VI. Water Quality Model

A Mathematical model was used to project the water quality in the Chesapeake Bay. The model is a one-dimensional tidal-time model, which has been successfully applied to the tidal portion of the James River (Fang, et al. 1973).

A. Basic Principle of the Model

The model is based on the equation describing the mass-balance of a dissolved or suspended substance in a water body. To facilitate the numerical computation, the Bay is divided into a number of volume elements, called reaches, by a series of lateral transects perpendicular to its axis. The concentration of a substance is represented by an average value within the volume element. Changes in the amounts of a substance with respect to time in a particular reach may be due to:

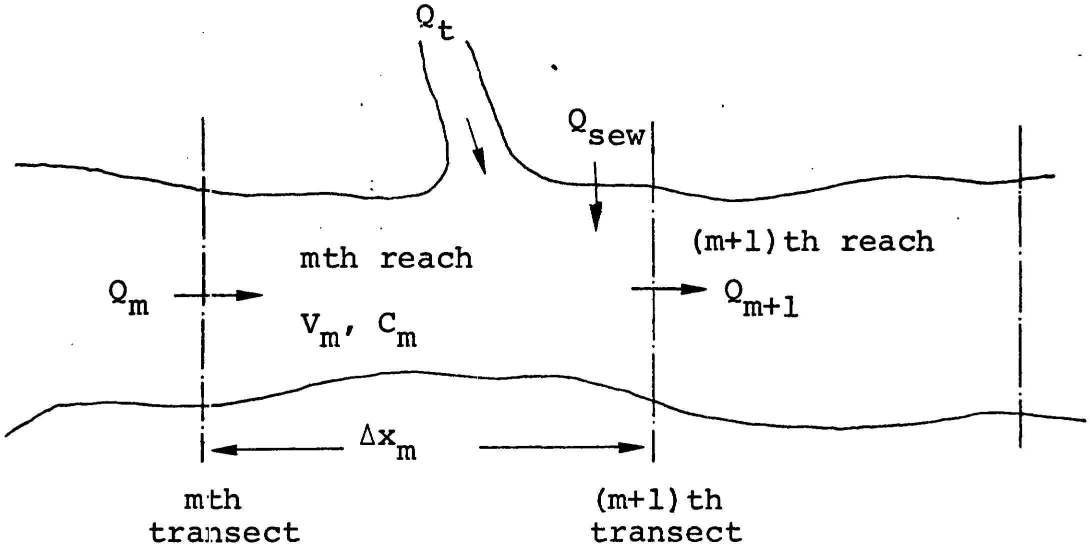
(1) advection and dispersion which physically transport materials into or out of the reach through the bounding transects,

(2) biochemical decay or creation of the substance within the reach,

(3) addition or removal of the substance due to external sources or sinks.

These mechanisms may be expressed mathematically to formulate a mass-balance equation for substances such as sea salt, oxygen, biochemically degradable material, or any form of nutrients.

Considering the mth reach of the Bay bounded by the mth and (m+1)th transects as shown in the sketch below:



the time rate of change of the total amount of a particular substance within the reach may be expressed as:

$$\frac{\partial}{\partial t}(C_m V_m) = Q_m C_m^{*} - Q_{m+1} C_{m+1}^{*} + \left(EA\frac{\partial C}{\partial x}\right)_{m+1} - \left(EA\frac{\partial C}{\partial x}\right)_m + SO_m \qquad (1)$$

where

t = time,

x = the distance along the Bay axis,

C_m = the volume average concentration of the mth reach,

V_m = the volume of the mth reach,

Q_m = the flow rate of water through the mth transect,

C_m^{*} = the concentration of the water, flowing through the mth transect,

E_m = dispersion coefficient at the mth transect,

A_m = the cross-sectional area of the mth transect,

SO_m = external sources or sinks.

Of the terms on the right hand side of the equation (1), the first two represent advective transport, the next two represent dispersive transport, the last represents the internal decay and creation, plus the external addition and removal. Mathematical expressions for the last term are different for different substances.

The time rate of change of water volume may be expressed as

$$\frac{\partial V_m}{\partial t} = Q_m - Q_{m+1} + Q_\ell \tag{2}$$

where $Q_\ell = Q_t + Q_{sew}$, and

Q_t = discharge from tributaries,

Q_{sew} = discharge from human activities such as sewage flow.

Substituting equation (2) into equation (1) and dividing the resulting equation by V_m, one obtains

$$\frac{\partial C_m}{\partial t} = \frac{Q_m}{V_m}(C_m{}^* - C_m) - \frac{Q_{m+1}}{V_m}(C_{m+1}{}^* - C_m) + \frac{1}{V_m}\left(EA\frac{\partial C}{\partial x}\right)_{m+1} - \frac{1}{V_m}\left(EA\frac{\partial C}{\partial x}\right)_m + \frac{1}{V_m}(SO_m - Q_\ell C_m) \tag{3}$$

B. Finite Difference Approximation in Time Domain

With proper initial and boundary conditions, equation (3) may be integrated with respect to time to obtain the temporal variations of concentration within each reach of the Bay proper. To solve the equation with a digital computer, it is integrated numerically over successive finite time intervals. At each integration step over a time increment, the various parameters, such as flow rates, dispersion coefficients, etc., should assume representative values during this particular time interval. An implicit scheme is used to formulate the finite difference equation, i.e., the concentration at the end of the time step as well as that at the beginning of the time step is used to express the right hand side of equation (3).

Equation (3) is approximated by the following finite difference form,

$$\begin{aligned}\frac{C'_m - C_m}{\Delta t} = {} & \frac{1}{2}\left\{\frac{Q'_m}{V'_m}(C^{*\prime}_m - C'_m) + \frac{Q_m}{V_m}(C^{*}_m - C_m)\right\} \\ & - \frac{1}{2}\left\{\frac{Q'_{m+1}}{V'_m}(C^{*\prime}_{m+1} - C'_m) + \frac{Q_{m+1}}{V_m}(C_{m+1} - C_m)\right\} \\ & + \frac{E'_{m+1}A'_{m+1}}{V'_m}\,\frac{C'_{m+1} - C'_m}{\Delta x_m + \Delta x_{m+1}} + \frac{E_{m+1}A_{m+1}}{V_m}\,\frac{C_{m+1} - C_m}{\Delta x_m + \Delta x_{m+1}} \\ & - \left(\frac{E'_mA'_m}{V'_m}\,\frac{C'_m - C'_{m-1}}{\Delta x_m + \Delta x_{m-1}} + \frac{E_mA_m}{V_m}\,\frac{C_m - C_{m-1}}{\Delta x_m + \Delta x_{m-1}}\right) \\ & + \overline{\frac{1}{V_m}(SO_m - Q_\ell C_m)} \qquad (4)\end{aligned}$$

where Δt is the time increment. The primed and unprimed variables designate the parameters evaluated at the end and beginning of time interval respectively, and the over bar represents the average value over the time interval.

The concentration, C^*_m, of the water flowing through the mth transect is calculated as a weighted average of the concentrations in the adjacent reaches, C_{m-1} and C_m. Thus

$$C^*_m = \alpha\, C_{m-1} + (1-\alpha)C_m \qquad (5)$$

$$C^{*\prime}_m = \alpha' C'_{m-1} + (1-\alpha')C'_m \qquad (6)$$

where the weighting factors α and α' depend on the direction of flow through the transect,

$$0.5 \le \alpha \le 1 \qquad \text{if } Q_m \ge 0$$

$$0 \le \alpha \le 0.5 \qquad \text{if } Q_m < 0$$

and

$$0.5 \le \alpha' \le 1 \qquad \text{if } Q_m' > 0$$

$$0 \le \alpha' \le 0.5 \qquad \text{if } Q_m' < 0$$

Similarly,

$$C^*_{m+1} = \alpha_2 C_{m+1} + (1-\alpha_2) C_m \tag{7}$$

$$C^{*\prime}_{m+1} = \alpha_2' C'_{m+1} + (1-\alpha_2') C_m' \tag{8}$$

and

$$0.5 \le \alpha_2 \le 1 \qquad \text{if } Q_{m+1} < 0$$

$$0 \le \alpha_2 \le 0.5 \qquad \text{if } Q_{m+1} \ge 0$$

$$0.5 \le \alpha_2' \le 1 \qquad \text{if } Q'_{m+1} < 0$$

$$0 \le \alpha_2' \le 0.5 \qquad \text{if } Q'_{m+1} \ge 0$$

Substituting equations (5), (6), (7) and (8) into equation (4), it is obtained that

$$\begin{aligned}
C_m' - C_m = {} & \frac{\Delta t}{2} \left\{ \frac{Q_m'}{V_m'} \alpha' (C'_{m-1} - C_m') + \frac{Q_m}{V_m} \alpha (C_{m-1} - C_m) \right\} \\
& - \frac{\Delta t}{2} \left\{ \frac{Q'_{m+1}}{V_m'} \alpha_2' (C'_{m+1} - C_m') + \frac{Q_{m+1}}{V_m} \alpha_2 (C_{m+1} - C_m) \right\} \\
& + \frac{E'_{m+1} A'_{m+1}}{V_m'} \frac{\Delta t}{\Delta x_m + \Delta x_{m+1}} (C'_{m+1} - C_m') \\
& + \frac{E_{m+1} \cdot A_{m+1}}{V_m} \cdot \frac{\Delta t}{\Delta x_m + \Delta x_{m+1}} (C_{m+1} - C_m) \\
& + \frac{E_m' \cdot A_m'}{V_m'} \cdot \frac{\Delta t}{\Delta x_m + \Delta x_{m-1}} (C_m' - C'_{m-1}) \\
& + \frac{E_m \cdot A_m}{V_m} \cdot \frac{\Delta t}{\Delta x_m + \Delta x_{m-1}} (C_m - C_{m-1}) + \frac{\Delta t}{V_m} (SO_m - Q_\ell C_m)
\end{aligned} \tag{9}$$

Defining

$$ADV_m = \frac{\Delta t}{2} \cdot \frac{AC_m}{V_m}$$

$$ADV2_m = \frac{\Delta t}{2} \quad \frac{AC_{m+1}}{V_m}$$

$$DIF_m = \frac{\Delta t}{\Delta x_m + \Delta x_{m-1}} \cdot \frac{E_m \cdot A_m}{V_m}$$

$$DIF2_m = \frac{\Delta t}{\Delta x_m + \Delta x_{m+1}} \cdot \frac{E_{m+1} \cdot A_{m+1}}{V_m}$$

$Q_m = AC_m \cdot U_m$

$Q_{m+1} = AC_{m+1} \cdot U_{m+1}$

U_m = advective velocity

AC_m = conveyancy cross-sectional area

and similarly for the primed variables, equation (9) becomes

$$\begin{aligned}
& C'_m \; (1-\alpha'_2 U'_{m+1} \cdot ADV2'_m + \alpha' U'_m \cdot ADV'_m + DIF'_m + DIF2'_m) \\
= \; & C'_{m+1} \; (-\alpha'_2 U'_{m+1} \cdot ADV2'_m + DIF2_m) + C'_{m-1} (\alpha' U'_m \cdot ADV'_m \\
& + DIF'_m) + C_m (1+\alpha_2 U_{m+1} \cdot ADV2_m - \alpha U_m \cdot ADV_m \\
& - DIF2_m - DIF_m) + C_{m+1} (-\alpha_2 U_{m+1} \cdot ADV2_m + \\
& DIF2_m) + C_{m-1} (\alpha U_m \cdot ADV_m + DIF_m) \\
& + \frac{\Delta t}{V_m} (SO_m - Q_\ell C_m) \qquad (10)
\end{aligned}$$

Equation (10) is further simplified to

$$\begin{aligned}
& (1+COE_m) C'_m = COE2_m \cdot C'_{m+1} + COE1_m \cdot C'_{m-1} \\
& + CON_m \cdot C_m + CON2_m \cdot C_{m+1} + CON1_m \cdot C_{m-1} \\
& + \frac{\Delta t}{V_m} (SO_m - Q_\ell C_m) \qquad (11)
\end{aligned}$$

where

$COE_m = \alpha' U'_m \cdot ADV'_m - \alpha'_2 U'_{m+1} \cdot ADV2'_m + DIF'_m + DIF2'_m$

$COE1_m = \alpha' U'_m \cdot ADV'_m + DIF'_m$

$$\mathrm{COE2}_m = -\alpha_2'U'_{m+1} \cdot \mathrm{ADV2}'_m + \mathrm{DIF2}'_m$$

$$\mathrm{CON}_m = 1 - \alpha U_m \cdot \mathrm{ADV}_m + \alpha_2 U_{m+1} \cdot \mathrm{ADV2}_m - \mathrm{DIF}_m - \mathrm{DIF2}_m$$

$$\mathrm{CON1}_m = \alpha U_m \cdot \mathrm{ADV}_m + \mathrm{DIF}_m$$

$$\mathrm{CON2}_m = -\alpha_2 U_{m+1} \cdot \mathrm{ADV2}_m + \mathrm{DIF2}_m$$

C. Application to Water Quality Parameters

Equation (11) may be applied to any dissolved or suspended substance which is of interest in the problem of water quality. The following paragraphs describe the application to some of the most important water quality parameters.

1. Salinity, S

$$SO_m = Q_t S_t + Q_{sew} \cdot S_{sew}$$

where S_t and S_{sew} are salinities of tributary inflow and point source discharge respectively. Therefore:

$$SO_m - Q_\ell S_m = Q_t\ (S_t - S_m) + Q_{sew}\ (S_{sew} - S_m)$$

In a tidal estuary, the tributary inflow may be positive or negative, depending on the phase of tide, with an average value over tidal cycle Q_f, the freshwater inflow of the tributary. Without the detailed information about the time variation of Q_t over a tidal cycle, the net effect of tributary inflow may be approximated as the dilution of salt water in the reach by the freshwater inflow Q_f. Therefore, the last term of equation (11) becomes

$$\frac{\Delta t}{V_m} \{- Q_f S_m + Q_{sew}\ (S_{sew} - S_m)\}$$

and equation (11) becomes

$$S'_m = a_m S'_{m+1} + b_m\ S'_{m-1} + c_m \qquad (12)$$

where

$$a_m = \frac{COE2_m}{1+COE_m}$$

$$b_m = \frac{COE1_m}{1+COE_m}$$

$$c_m = \{S_m(CON_m - \frac{Q_{sew} + Q_f}{V_m} \cdot \Delta t) + S_{m+1} \cdot CON2_m$$

$$+ S_{m-1}\ CON1_m + \frac{\Delta t}{V_m} \cdot Q_{sew} \cdot S_{sew})\}/(1 + COE_m)$$

2. Substances with First Order Decay

e.g. CBOD = carbonaceous biochemical oxygen demand

NBOD = nitrogenous biochemical oxygen demand

$$SO_m = - k_c \cdot CBOD_m \cdot V_m + CBODP_m + CBODNP_m$$

$$+ Q_t \cdot CBOD_t$$

where k_c is the decay rate, $CBODP_m$ and $CBODNP_m$ are the point source and non-point source respectively, and $CBOD_t$ is the concentration of tributary inflow. The net effect of tributary inflow resulting from the freshwater input may be estimated in the same way as the case of salinity, and thus,

$$\frac{\Delta t}{V_m} (\overline{SO_m - Q_\ell \cdot CBOD_m}) = - \frac{\Delta t}{2} k_c (CBOD'_m + CBOD_m)$$

$$+ \frac{\Delta t}{V_m} \{(CBODP_m + CBODNP_m) + Q_f(CBODBG - CBOD_m)$$

$$- Q_{sew} \cdot CBOD_m\}$$

where CBODBG is the concentration of CBOD in the freshwater input. Thus, equation (11) becomes

$$CBOD'_m = a_m \cdot CBOD'_{m+1} + b_m \cdot CBOD'_{m-1} + c'_m \qquad (13)$$

where

$$a_m = \frac{COE2_m}{1+COE_m+\frac{\Delta t}{2}\, k_c}$$

$$b_m = \frac{COE1_m}{1+COE_m+\frac{\Delta t}{2}\, k_c}$$

$$c_m = \{CBOD_m\ (CON_m - \frac{\Delta t}{2}\, k_c - \frac{Q_f + Q_{sew}}{V_m} \cdot \Delta t)$$

$$+ CBOD_{m+1} \cdot CON2_m + CBOD_{m-1} \cdot CON1_m$$

$$+ \frac{\Delta t}{V_m} \cdot Q_f \cdot CBODBG + \frac{\Delta t}{V_m}(CBODP_m + CBODNP_m)\}/$$

$$(1 + COE_m + \frac{\Delta t}{2}\, k_c)$$

3. Dissolved Oxygen, D.O.

$$SO_m = - k_c \cdot CBOD_m \cdot V_m - k_n \cdot NBOD_m \cdot V_m + f \cdot Ah_m \cdot$$

$$(DOS_m - DO_m) - BEN_m + PHOTO_m + Q_t \cdot DO_t + Q_{sew} \cdot DO_{sew}$$

where

k_n = decay rate of NBOD,

f = oxygen exchange coefficient,

Ah_m = total surface area of the reach,

DOS_m = saturated oxygen content,

BEN_m = benthic demand,

PHOTO = net addition of oxygen due to photosynthesis and respiration,

DO_t = oxygen content of tributary inflow,

DO_{sew} = oxygen content of point source discharge.

The net effect of tributary inflow resulting from the freshwater input may be estimated with the same way as salinity and, thus

$$\frac{\Delta t}{V_m}(SO_m - Q_\ell \cdot DO_m) = -k_c \cdot \Delta t \cdot CBOD_m - k_n \cdot \Delta t \cdot NBOD_m$$

$$+ \frac{\Delta t}{2}\ \frac{Ah_m}{V_m}\{f(DOS_m - DO_m) + f'\ (DOS'_m - DO'_m)\}$$

$$- \frac{\Delta t}{V_m}(BEN_m - PHOTO_m) + \frac{\Delta t}{V_m}\{Q_f(DOBGD - DO_m)$$

$$+ Q_{sew}\ (DO_{sew} - DO_m)\}$$

where DOBGD is the DO content of freshwater inflow from tributary. Thus, equation (11) becomes

$$DO'_m = a_m \cdot DO'_{m+1} + b_m \cdot DO'_{m-1} + c_m \tag{14}$$

where

$$a_m = \frac{COE2_m}{1 + COE_m + \frac{\Delta t}{2} k'_2}$$

$$b_m = \frac{COE1_m}{1 + COE_m + \frac{\Delta t}{2} k'_2}$$

$$c_m = \{DO_m(CON_m - \frac{\Delta t}{2} k_2 - \frac{Q_f + Q_{sew}}{V_m} \cdot \Delta t)$$

$$+ DO_{m+1} \cdot CON2_m + DO_{m-1} \cdot CON1_m$$

$$+ \frac{\Delta t}{V_m}(Q_f \cdot DOBGD + Q_{sew} \cdot DO_{sew})$$

$$- k_c \cdot \Delta t \cdot CBOD_m - k_m \cdot \Delta t \cdot NBOD_m$$

$$+ \frac{\Delta t}{2} k_2 \cdot DOS_m + \frac{\Delta t}{2} k'_2 \cdot DOS'_m$$

$$- \frac{\Delta t}{2} \cdot BEN_m + \frac{\Delta t}{V_m} \cdot PHOTO_m\}/(1+COE_m + \frac{\Delta t}{2} k'_2\ )$$

$k_2 = \frac{f}{V_m} \cdot Ah_m$, the reaeration coefficient.

D. Method of Solution

Because of advective and dispersive transport across the transects bounding each end of a particular reach of the estuary, the concentration of a substance in one reach will depend on the concentrations in two adjacent reaches. This interdependence of concentrations at neighboring reaches is manifested in equation (12), (13), and (14). Therefore, the equation cannot be solved for the concentration at the mth reach by itself. Equations must be written for every reach of the estuary and solved for the concentrations in every reach simultaneously.

Suppose that the total length of the estuary to be modeled is divided into N reaches. (N-2) equations will be obtained by writing equation (12), (13), or (14) for $m = ML+1$ to $m = MU-1$, where the MLth and MUth reaches are the most upstream and downstream ones, respectively. Since there are (N-2) equations for N unknowns, two boundary conditions must be specified. The principal operation of numerical computations in the model is then to compute the concentrations in each reach at time $t_o + \Delta t$ with a given initial concentration field at time t_o and appropriate boundary conditions. The computed concentration field at $t_o + \Delta t$ will then be used as the initial condition to compute the concentration field at time $t_o + 2\Delta t$, and so forth. Each computation cycle will advance the time by the increment of Δt. Within each computation cycle, the (N-2) simultaneous equations are solved by an elimination method.

Taking the equation for salinity as an example, S'_{ML+1} may be expressed in terms of S'_{ML+2} through equation (12) with m = ML+1, and boundary condition S'_{ML} given, i.e.

$$S'_{ML+1} = a_{ML+1}S'_{ML+2} + b_{ML+1}S'_{ML} + c_{ML+1} \tag{15}$$

where the only unknown on the right hand side of the equation is S'_{ML+2}. Equation (15) may, in turn, be substituted back into equation (12) with m = ML+2, and thus one arrives at an expression for S'_{ML+2} in terms of S'_{ML+3}. In general, there exists the following relation

$$S'_m = P_m S'_{m+1} + O_m \tag{16}$$

where the recursion coefficients P_m and O_m may be calculated from the upstream boundary condition S'_{ML}.

With subscript m-1, equation (16) becomes

$$S'_{m-1} = P_{m-1}S'_m + O_{m-1}$$

Substituting this expression for S'_{m-1} in equation (12), it becomes

$$S'_m = a_m S'_{m+1} + b_m\ (P_{m-1}S'_m + O_{m-1}) + c_m$$

or

$$S'_m = \frac{a_m}{1 - b_m \cdot P_{m-1}}\ S'_{m+1} + \frac{b_m O_{m-1} + c_m}{1 - b_m \cdot P_{m-1}} \tag{17}$$

The comparison between equations (16) and (17) gives

$$\left.\begin{aligned} P_m &= \frac{a_m}{1 - b_m \cdot P_{m-1}} \\ O_m &= \frac{b_m \cdot O_{m-1} + c_m}{1 - b_m \cdot P_{m-1}} \end{aligned}\right\} \tag{18}$$

Since S'_{ML} is a known quantity, the comparison between equation (15) and (16) with m = ML+1 gives

$$P_{ML+1} = a_{ML+1}$$

$$O_{ML+1} = b_{ML+1} \cdot S'_{ML} + c_{ML+1}$$

and thus

$$P_{ML} = 0, \; O_{ML} = S'_{ML}$$

In summary, the recursion coefficients and equation are

$$\left.\begin{aligned} & P_{ML} = 0, \; O_{ML} = S'_{ML} \\ & P_m = \frac{a_m}{1 - b_m \cdot P_{m-1}} \\ & O_m = \frac{c_m + b_m \cdot O_{m-1}}{1 - b_m \cdot P_{m-1}} \end{aligned}\right\} \qquad (18)$$

and

$$S'_m = P_m S'_{m+1} + O_m, \qquad (16)$$

with m = ML+1, ML+2, ---, ML+(MU-ML-1) or m = ML+1, ML+2, ---, MU-1.

Then, the order of numerical computations is (1) calculate the recursion coefficients by applying equations (18) repeatedly with m = ML+1, ML+2, ---, MU-1, and (2) with S'_{MU} given as the downstream boundary condition, calculate the salinity of the interior reaches by applying equation (16) repeatedly with m = MU-1, MU-2, ---, ML+1.

E. Evaluation of Parameters

1. Velocity U: In an estuary, the current velocity may be divided into two parts,

$$U_m(t) = UF_m + Ut_m(t) \tag{19}$$

where UF is the non-tidal component generated by freshwater discharge and Ut is the oscillating tidal component. In this model, the tidal current is approximated by a sinusoidal function of time with period T and phase ϕ

$$Ut_m(t) = UT_m \sin\{\frac{2\pi}{T} t + \phi_m\} \tag{20}$$

where UT is the amplitude. UT_m and ϕ_m are obtained from tidal prism and phase data compiled by Cronin (1971). The non-tidal component UF is calculated by the equation

$$UF_m = \frac{Q_m}{AC_m} \tag{21}$$

where Q_m is the freshwater discharge from a drainage area upstream of the mth transect; Q_m is estimated from the record of a stream gauge station located upstream of the tidal limit, with freshwater discharge assumed to be proportional to drainage area.

2. Dispersion Coefficient E: The dominant mechanism of longitudinal dispersion is the interaction between turbulent diffusion and shearing current. Taylor's (1954) formulation of one-dimensional dispersion has been successfully modified and extended to homogeneous estuaries (Holley, et.al. 1970; Harleman 1971). The dispersion coefficient in the freshwater portion of a tidal estuary may be expressed as

$$E = \nu n|U|R^{5/6} \tag{22}$$

where n is Manning's friction coefficient, $|U|$ is the absolute value of velocity, R is hydraulic radius, and ν is a constant on the order of 100. It is known that the presence of density stratification due to salinity intrusion enhances the vertical shear while suppressing the turbulence, and therefore, increases the dispersion coefficient. Equation (22) is modified to

$$E = \nu n|U|R^{5/6}(1 + \nu' S) + \nu'' \frac{\partial S}{\partial x} \tag{23}$$

where ν' and ν'' are constants, S is the salinity and $\frac{\partial S}{\partial x}$ is the salinity gradient. ν' and ν'' are determined by the model calibration, i.e. adjusting ν' and ν'' until the model results agree satisfactorily with the salinity distribution measured in the field.

3. Reaeration Coefficient k_2: O'Connor and Dobbins (1956) presented a theoretical derivation of the reaeration coefficient, in which fundamental turbulence parameters were taken into account. They derived the following formula

$$(k_2)_{20} = \frac{(D_c U)^{1/2}}{H^{3/2}} \tag{24}$$

where D_c is the molecular diffusivity of oxygen in water, U and H are the cross-sectional mean velocity and depth respectively, and $(k_2)_{20}$ is the reaeration coefficient at 20°C. This formula has been shown to give a satisfactory estimate of k_2 for a reach of river with cross-sectional mean depth and velocity more or less uniform throughout the reach. If the cross-section varies appreciably within a single reach, there is no reason to expect a satisfactory estimate from the formula by using the values of U and H at the two bounding transects of the reach. Therefore, equation

(24) is modified as stated in the following paragraph.

Assuming that the O'Connor and Dobbins formula is valid locally then

$$f = k_2 h = \frac{(D_c u)^{1/2}}{h^{1/2}} \tag{25}$$

where f is the exchange coefficient, i.e., the exchange rate of oxygen through unit water surface area, u is the local depth-mean velocity and h is local depth. M, the exchange rate of oxygen through the water surface over an entire reach is

$$M = \int_{Ah} f\ (DOS - DO)\, dAh \tag{26}$$

where Ah is the total surface area over a reach. By definition of k_2,

$$M = (k_2)_{20}\ V(DOS - DO) \tag{27}$$

thus,

$$(k_2)_{20} = \frac{D_c^{1/2}}{V} \int_{Ah} \frac{u^{1/2}}{h^{1/2}}\, dAh = D_c^{1/2} \left\langle \frac{u^{1/2}}{h^{1/2}} \right\rangle \frac{Ah}{V}$$

$$= D_c^{1/2} \left\langle \frac{u^{1/2}}{h^{1/2}} \right\rangle \frac{1}{\langle h \rangle} \tag{28}$$

where < > indicates the average over the surface area Ah, and <h> is the mean depth of the reach. Since the velocity data are available only at the end transects of a reach, no true $\left\langle \frac{u^{1/2}}{h^{1/2}} \right\rangle$ may be estimated. In this model, the average value $\frac{U^{1/2}}{H^{1/2}}$ at the two end-transects is used.

To adjust k_2 for temperatures other than 20°C, Elmore and West's (1961) formula is used

$$k_2 = (k_2)_{20} \cdot 1.024^{(\theta-20)} \tag{29}$$

where θ is the water temperature in centigrade degrees.

4. Photosynthesis and Respiration, PHOTO: The amount of oxygen produced by photosynthesis varies with the intensity of sunlight, the turbidity of water and the density of plant population. Moreover, the same plants extract oxygen from the water for respiration. This combined oxygen source and sink is assumed constant with respect to time. The magnitude is allowed to vary from reach to reach and an array for input data in mg/ℓ/day is provided in the computer program. If more complete information is available, the time varying functional form of this oxygen source and sink may be specified.

5. BOD Decay Rates: k_c and k_n

The decay rates of CBOD (carbonaceous biochemical oxygen demand) and NBOD (nitrogenous biochemical oxygen demand) are normally determined by the model calibration, i.e., adjustment of decay rates until the model results agree satisfactorily with the CBOD and NBOD distribution measured in the field. Because of the lack of CBOD and NBOD data, the decay rates and the following temperature dependence formulae used by Clark and Jaworski (1972) for the Potomac Estuary are adopted.

$$k_c = (k_c)_{20} \cdot 1.047^{(\theta-20)}$$

$$k_n = (k_n)_{20} \cdot 1.160^{(\theta-20)}$$

where k_c and k_n are decay rates of CBOD and NBOD; respectively θ is the temperature in centigrade.

6. Saturated Oxygen Content, DOS

The saturation concentration of dissolved oxygen depends on temperature and salinity. From tables of saturation concentration (Carritt and Green 1967) a polynomial equation was determined by a least-squares method.

$$\begin{aligned} DOS = 14.6244 - 0.367134\theta + 0.0044972\theta^2 \\ - 0.0966S + 0.002050\theta S + 0.0002739S^2 \end{aligned}$$

where S is salinity in parts per thousand, θ is temperature in degrees centigrade, and DOS is in mg/liter.

F. Segmentation of the Bay

The Bay is divided into 39 reaches. Except those reaches near the head of the Bay, the reaches are 5 nautical miles in length. Table IV-1 lists the reach numbers and their locations measured in distance from Bay mouth.

G. Coefficients in the Model Equations

1. CBOD - NBOD - DO Simulation

In addition to the physical transport by advection and dispersion, the dissolved oxygen concentration may be affected by the oxidation of carbonaceous and nitrogenous components of biochemical degradable materials, by the uptake of benthic organisms, by algal photosynthesis and respiration, and by reaeration. The decay rates of 0.17/day and 0.084/day at 20°C (base e) were used for carbonaceous and nitrogenous BOD respectively.

No benthic oxygen demand data is available for the Chesapeake Bay proper. A value of 1.0 gms/m^2-day at 20°C, typical for estuaries, was assumed for reaches north of the Potomac River mouth (reaches 1 to 28) except reaches 13, 14 and 15. Reaches 13, 14 and 15 cover the 15 nautical miles (27.8 km) segment around and to the south of Baltimore; a benthic demand of 2.0 gms/m^2-day at 20°C was assumed for these three reaches. For reaches to the south of the Potomac River mouth, no benthic oxygen demand was assumed. The temperature effect was approximated (Thomann, 1972) by

$$B = (B)_{20} \cdot 1.065^{(\Theta-20)}$$

where B is benthic demand. While there are provisions in the model to handle the algal photosynthesis and respiration, their effect was assumed zero in all the simulation runs, due to lack of data.

2. Total-P and Total-N Simulation

The distribution of total phosphorus and total nitrogen were simulated by the model with first order kinetics. Clark, et al. (1973) reported that the loss or uptake rate of total phosphorus in the upper Chesapeake Bay increased from 0.008/day to 0.015/day as the Susquehanna River flow increased from 10,000 cfs (283 cms) to 50,000 cfs (1415 cms). These values were used to estimate the loss rates for other freshwater flow conditions. The values used are listed below:

Susquehanna Flow (cfs)	Loss Rate (1/day)
2700	0.00225
6400	0.006
25,100	0.012
38,600	0.0138
70,300	0.0165

Clark, et al. (1973) also reported that the loss or uptake rate of total inorganic nitrogen was highly dependent on the existing chlorophyll level. The reported low value, 0.01/day, was used for the loss rate of total nitrogen under all freshwater flow conditions.

H. Model Calibration

The model was calibrated with salinity data collected by the Chesapeake Bay Institute of Johns Hopkins University (Seitz 1971). The salinity distributions on three different days - April 11, 1968; October 24, 1968; November 21, 1968 - representing three different freshwater flow conditions were used.

Actual cross-sectional average salinities at sampling stations were calculated according to the following assumptions:

1) Uniform cross-sectional width at all depths.
2) Uniform lateral salinity distribution.
3) The last depth sampled was the channel bottom.
4) Linear variation in salinity between sampling depths.

Freshwater flow at the upper end of the Bay (five nautical miles upstream from the mouth of the Susquehanna River) was estimated by averaging the daily discharges at Conowingo, Maryland for approximately 20 days preceding the day of interest.

The Potomac and James Rivers freshwater inputs were entered as point sources. Their magnitudes were estimated by the average discharge at the fall line for the preceding 20 days, adjusted by the ratio of the total river drainage area to the drainage area above the fall line.

Similarly, freshwater input to the Bay from all other runoff is calculated in the model relative to the Susquehanna discharge according to the ratio of drainage areas.

Calibration consisted of adjusting the empirical parameters AK and TK for the different flow conditions so that the resulting model salinity distribution closely resembled the distribution determined from the field data. The model relates AK and TK to the dispersion coefficient according to the following equation:

$$E_K = \left\{FC \times (H1_K)^{0.833} \times UEF_K \times (1 + AK \times (S_K + S_{K+1}))\right\} + \left\{TK \times \left| \frac{(S_{K+1} - S_K)}{(D_K - D_{K+1})} \right|\right\}$$

Where

E_K = dispersion coefficient at transect K

FC = 77 x Manning friction coefficient

$H1_K$ = water depth of transect K

UEF_K = average speed of current determined by the freshwater and tidal velocities at a particular transect

S_K = the salinity in reach K

D_K = distance of midpoint of reach K from mouth

or

$$E_K = \{FC \times (H1_K)^{0.833} \times UEF_K \times (1 + AK \cdot 2 \times SAL_K)\} + (TK \times SALG_K)$$

where

SAL_K = salinity at transect K

$SALG_K$ = salinity gradient at transect K

Table VI-1 shows the freshwater discharge levels used for different model runs and the corresponding AK and TK values. Figures VI-1 - VI-3 show the model results compared to the field data.

Table VI-1

Model Freshwater Flows (cfs)

Date of Field Sampling	James	Potomac	Susquehanna	AK	TK
October 24, 1968	3080[1]	2031[1]	6945[3]	3	0
November 21, 1968	4616[1]	6944[1]	38739[3]	5	0
April 11, 1968	11050[2]	22800[2]	84300[3]	20	15000

[1] Data reduced from U.S. Dept. of Interior Geol. Survey (1969)

[2] Data reduced from U.S. Dept. of Interior Geol. Survey (1968)

[3] Data reduced from U.S. Dept. of Interior Geol. Survey (1972)

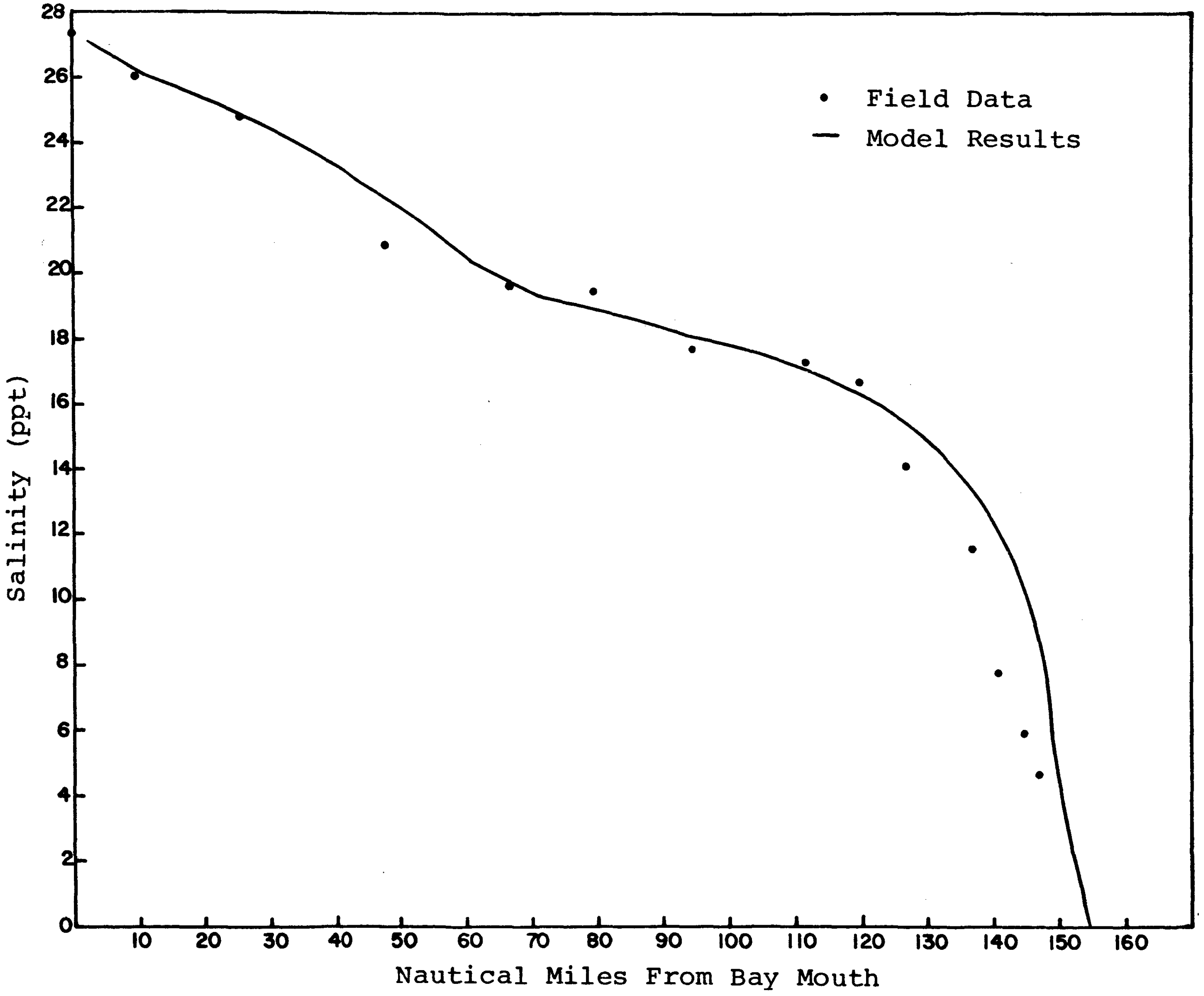


Figure VI- 1. Results of salinity calibration for Susquehanna River flow of 6945 cfs. (The field data are cross-sectional average values at slack before flood on October 24, 1968. The model results are tidal minimum values).

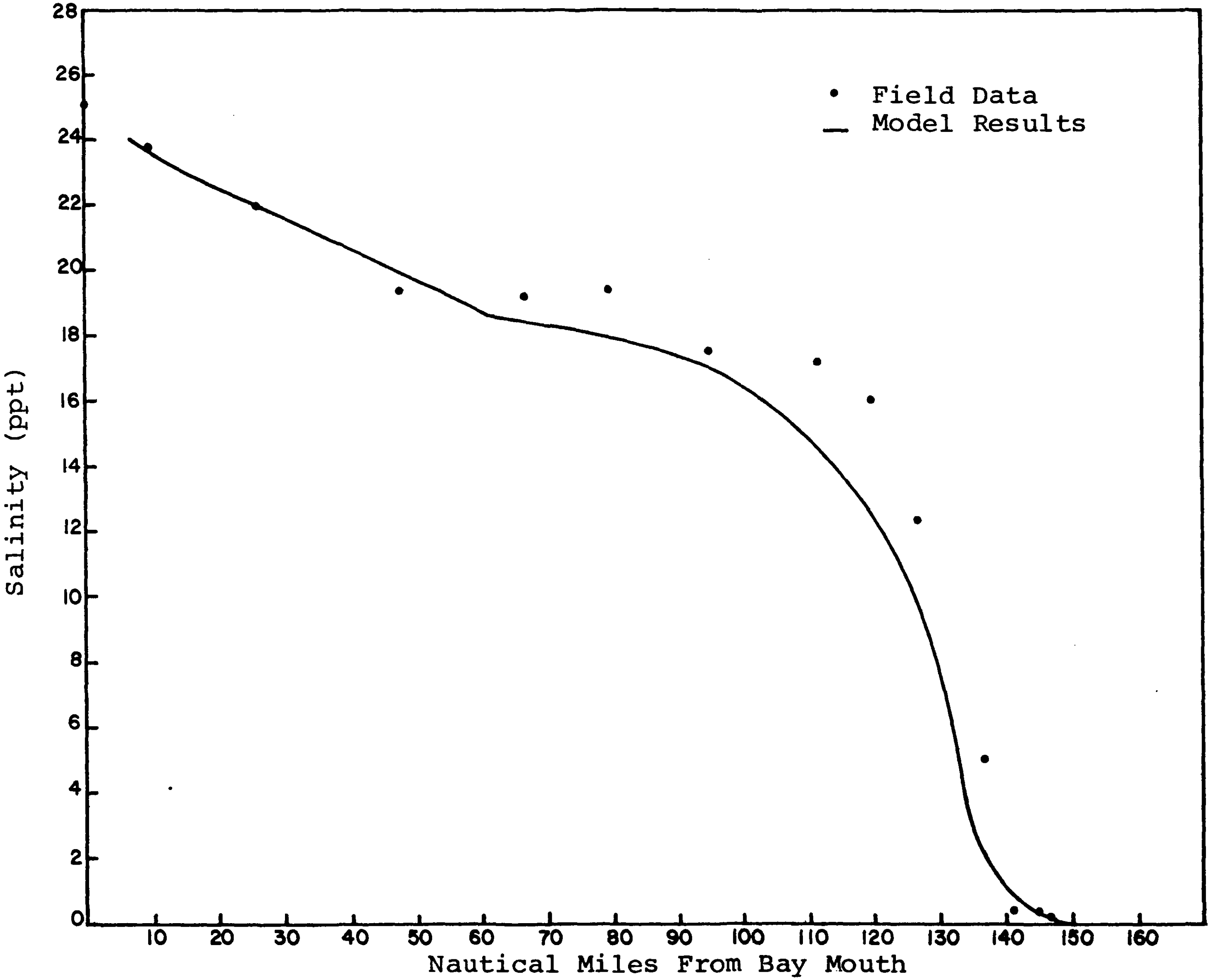


Figure VI - 2. Results of salinity calibration for Susquehanna River flow of 38,739 cfs. (The field data are cross-sectional average values at slack before flood on November 21, 1968. The model results are tidal minimum values).

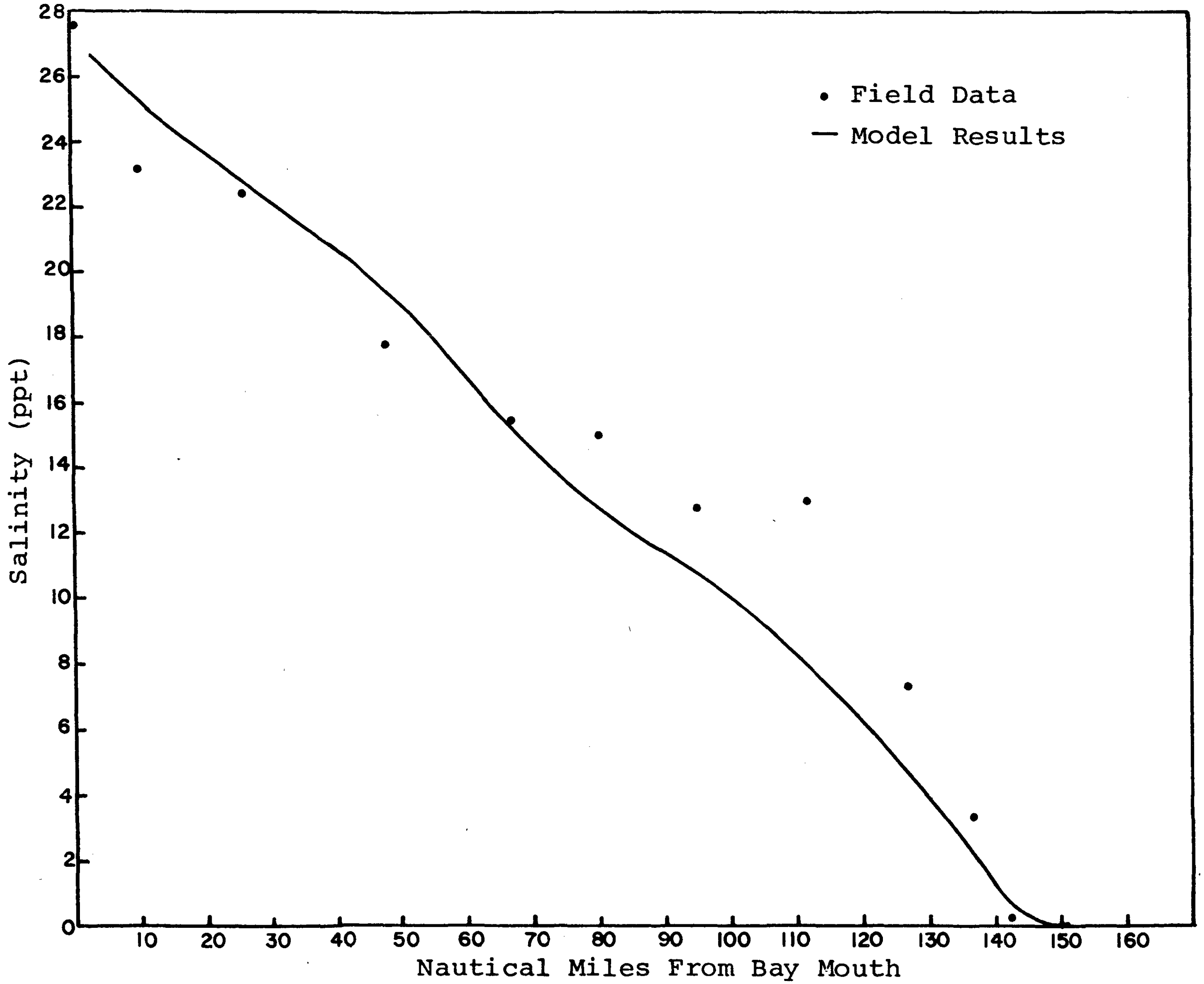


Figure VI -3. Results of salinity calibration for Susquehanna River flow of 84,300 cfs. (The field data are cross-sectional average values at slack before flood on April 11, 1968. The model results are tidal minimum values).

I. Verification with Salinity Distribution

The salinity distribution predicted by the model for freshwater flow rates of :

River	flow rate (cfs)
Susquehanna	25100
Potomac	7000
James	4800

is presented in Figure VI-4. The values of AK and TK were derived from the calibration values. They were 4.5 for AK and 0.0 for TK.

The field data shown in the figure for comparison are based on samples taken over a 4-day period and recorded in the data bank of the Chesapeake Bay Institute, Johns Hopkins University. The sampling was done without regard to tidal phase. The cross-sectional average values were calculated according to the following assumptions:

1) Uniform cross-sectional width at all depths
2) Uniform lateral salinity distribution
3) Linear variation in salinity between sampling depths

The preceding 20 day average freshwater flow rates, determined as in calibration procedure, were:

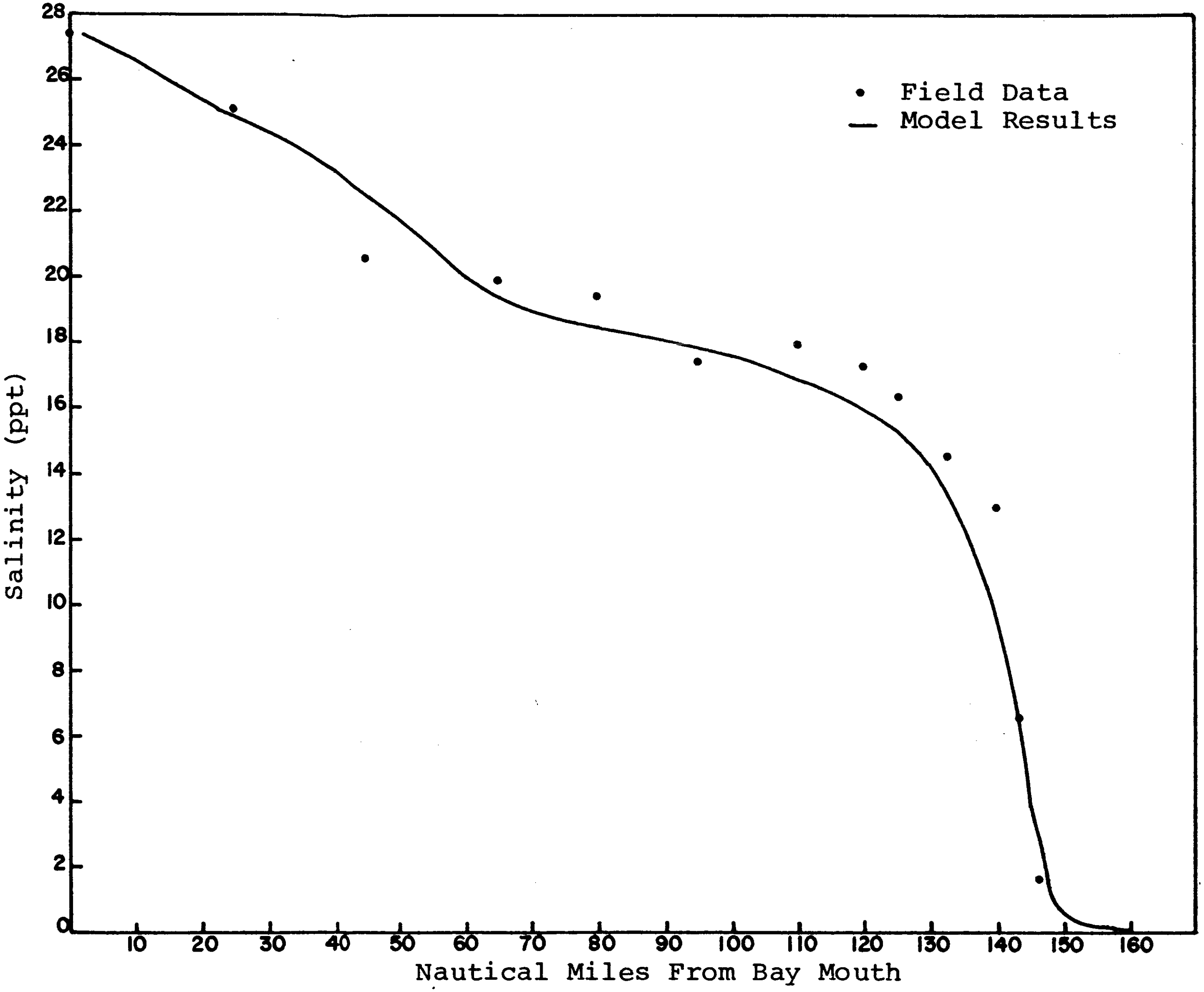


Figure VI-4. Results of salinity verification for Susquehanna River flow of 25,100 cfs. (The field data are cross-sectional average values on December 8-11, 1969. The model results are tidal average values).

River	flow rate (cfs)
Susquehanna	26485[1]
Potomac	4564[2]
James	2446[2]

[1] Data reduced from U.S. Dept. of Interior Geol. Survey (1972).

[2] Data reduced from U.S. Dept. of Interior Geol. Survey (1970).

Since the Potomac and James discharges have little effect on the salinity distribution in the Bay, the disparity between the actual values and those used in the model run is not significant.

J. Unit Response Curves

1. Total Phosphorus

Figures VI-5 and VI-6 are the phosphorus unit response curves corresponding to Susquehanna River flows of 6400 cfs and 70300 cfs respectively. Figure VI-5 demonstrates the predominance of point sources, particularly those of the Baltimore area, under low freshwater inflow conditions. (The curve of all sources is somewhat lower than the sum of the individual curves due to non-zero boundary conditions for each curve and computer truncation errors).

The effects of the Baltimore area point sources might be, however, somewhat less extreme than indicated here. The phosphorus loadings were estimated on the basis of total plant capacity discharges and general concentration values, rather than actual data. Moreover, the model treats

Figure VI-5. Unit response curve for total phosphorus corresponding to a Susquehanna River freshwater inflow of 6,400 cfs.

KEY

1) Susquehanna River non-point sources

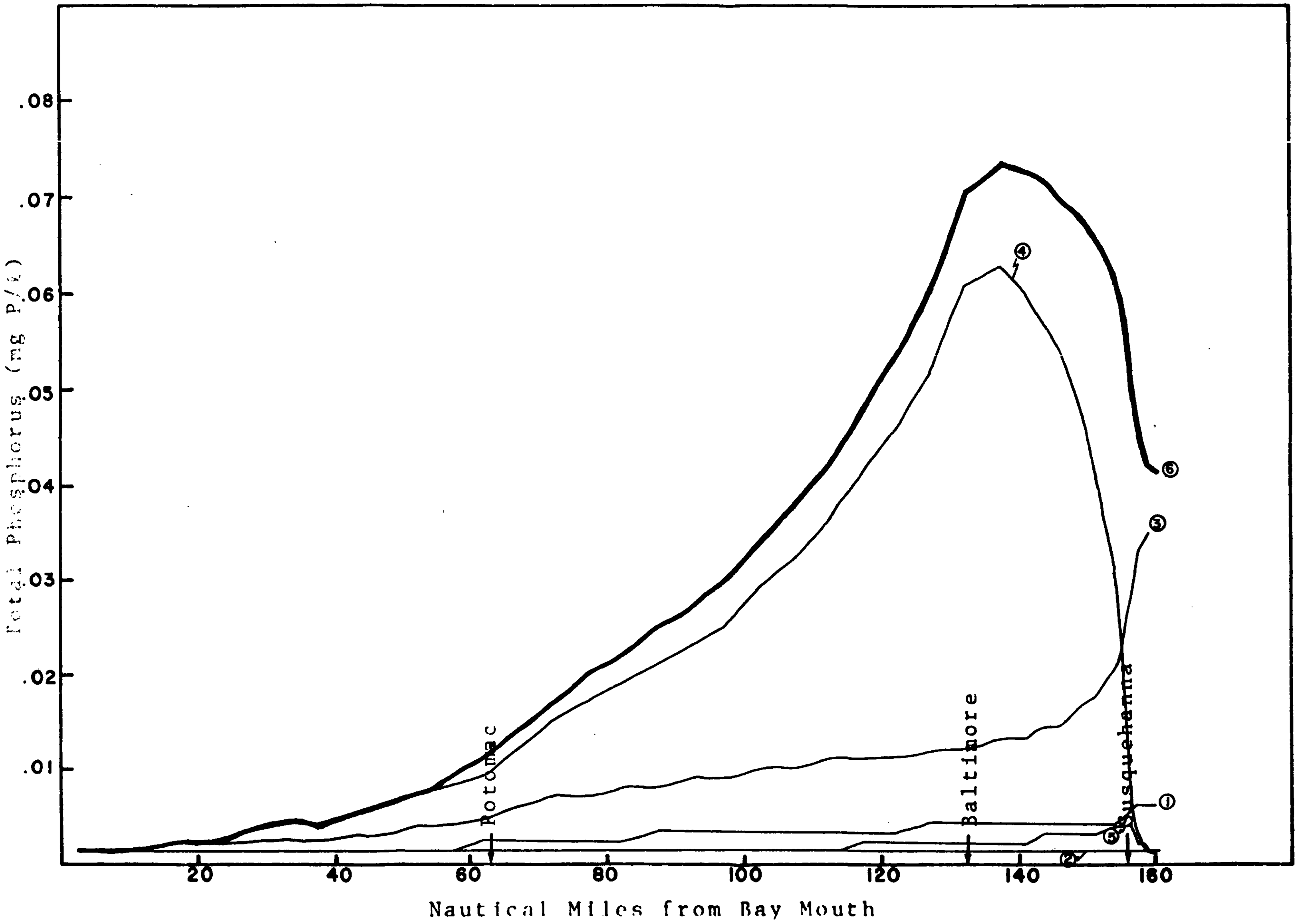
2) Other non-point sources

3) Susquehanna River point sources

4) Baltimore area point sources

5) Other point sources

6) All sources



.08
.07
.06
.05
.04
.03
.02
.01
Total Phosphorus (mg P/ℓ)
20
40
60
80
100
120
140
160
180
Nautical Miles from Bay Mouth
Potomac
Baltimore
Susquehanna
①
②
③
④
⑤
⑥

Figure VI-6. Unit response curve for total phosphorus corresponding to a Susquehanna River freshwater inflow of 70,300 cfs.

KEY

1) Susquehanna River non-point sources

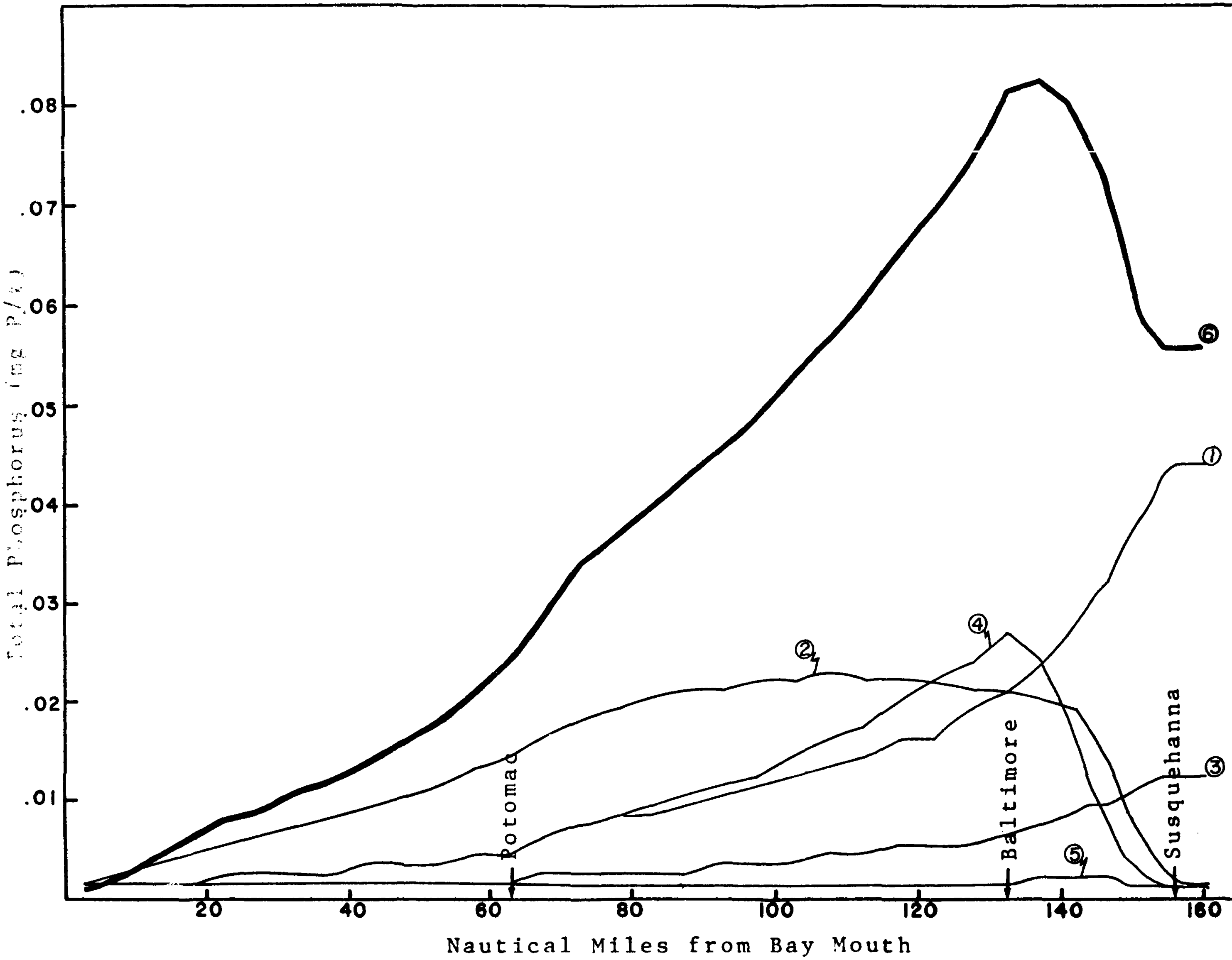
2) Other non-point sources

3) Susquehanna River point sources

4) Baltimore area point sources

5) Other point sources

6) All sources


Total Phosphorus (mg P/l)
.08
.07
.06
.05
.04
.03
.02
.01
20
40
60
80
100
120
140
160
Nautical Miles from Bay Mouth
Potomac
Baltimore
Susquehanna
①
②
③
④
⑤
⑥

the loadings as if they were discharged directly into the Bay, whereas they are actually discharged into the Back and Patapsco Rivers, and are, therefore, subject to some decay and settling before reaching the Bay. The significance of their effect on the Bay, however, is substantiated by the local maximum concentrations observed in the Baltimore area of the Bay by Clark, et al. (1973), .

Figure VI-6 shows the increased importance of non-point sources and decreased importance of point sources under high flow conditions. As discussed in Chapter IV, most of the non-point source load of phosphorus (not including the Susquehanna River) proposed in the model arises from marsh land. The yield values applied to marsh land throughout the Bay were developed through regression analyses by Clark et al. (1974) for scouring and innundation of marshes on the lower Susquehanna River. The lower Susquehanna marshes, however, are non-tidal, so their characteristics might be quite different than those on the Bay. No corresponding data on tidal marshes in this area were available. Since the Bay marshes appear to be a significant source of phosphorus under some conditions, determination of actual yields through field studies would increase the reliability of water quality predictions for the Bay.

2. Total Nitrogen

Figures VI-7 and VI-8 are the nitrogen unit response curves corresponding to Susquehanna River flows of 6400 cfs and 70300 cfs, respectively. In both figures the dominance

Figure VI-7. Unit response curve for total nitrogen corresponding to a Susquehanna River freshwater inflow of 6400 cfs.

KEY

1) Susquehanna River non-point sources

2) Other non-point sources

3) Susquehanna River point sources

4) Baltimore area point sources

5) Other point sources

6) All sources

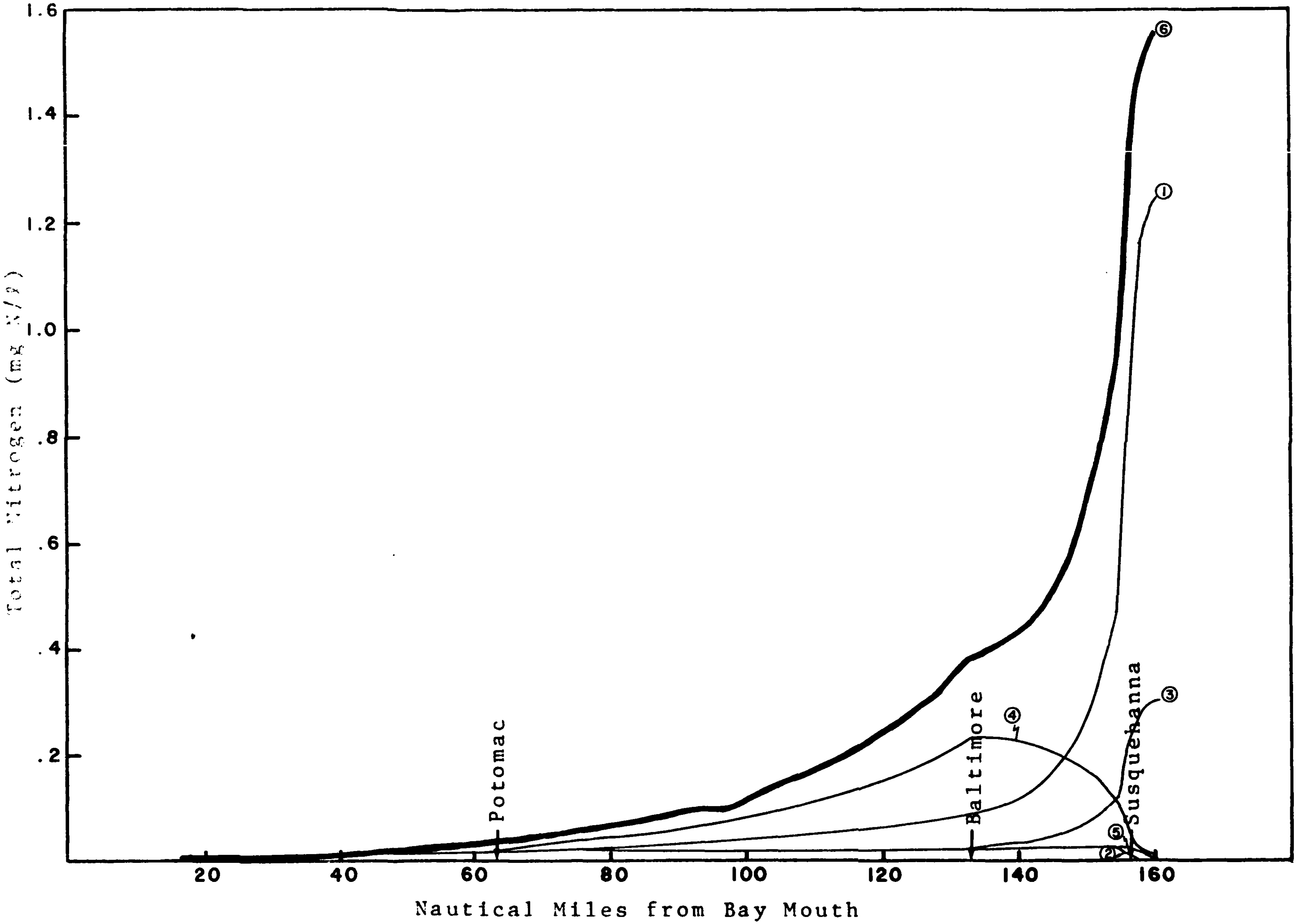

1.6
1.4
1.2
1.0
.8
.6
.4
.2
Total Nitrogen (mg N/l)
20
40
60
80
100
120
140
160
Nautical Miles from Bay Mouth
Potomac
Baltimore
Susquehanna
⑥
①
③
④
⑤
②

Figure VI-8. Unit response curve for total nitrogen corresponding to a Susquehanna River freshwater inflow of 70,300 cfs.

KEY

1) Susquehanna River non-point sources

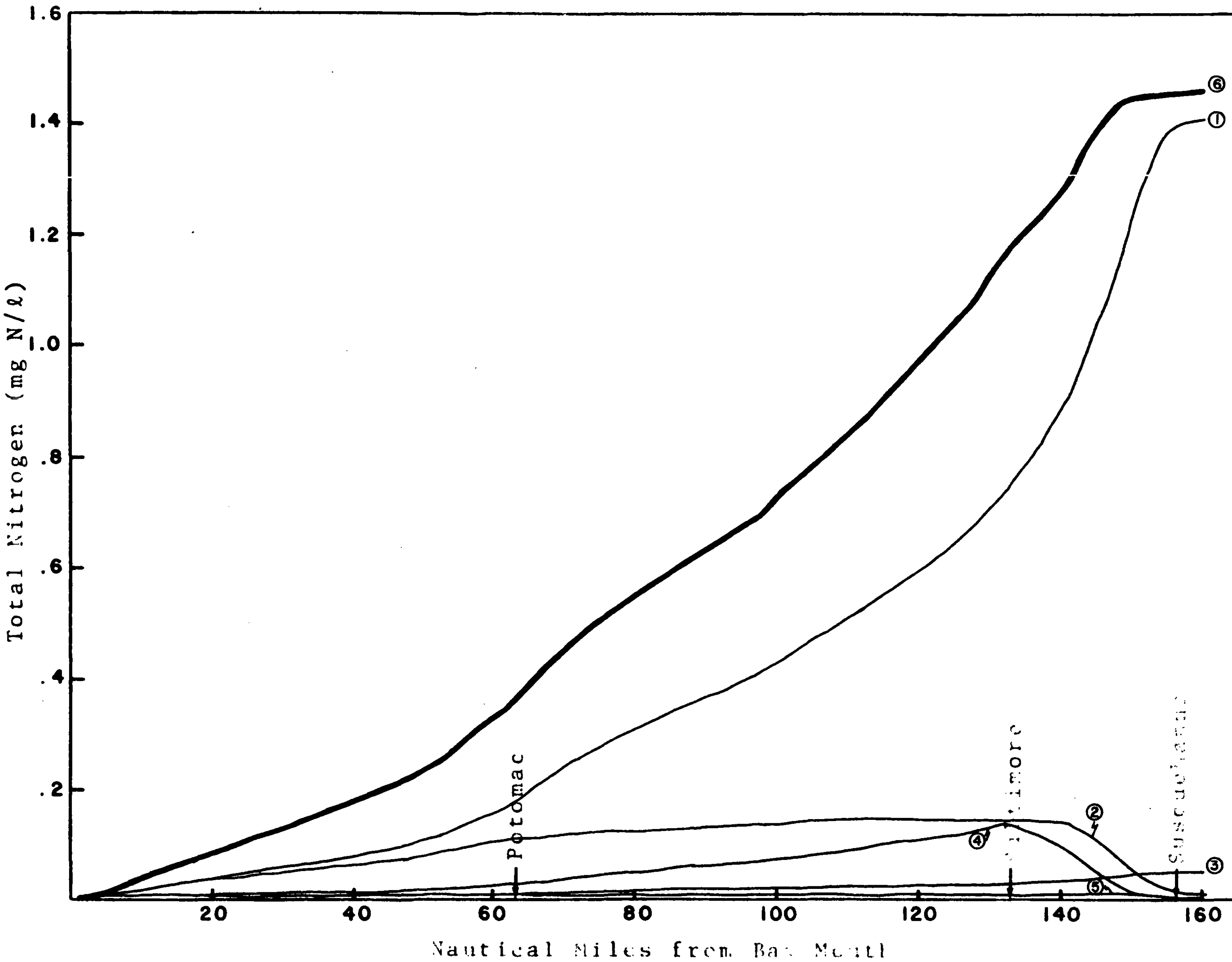
2) Other non-point sources

3) Susquehanna River point sources

4) Baltimore area point sources

5) Other point sources

6) All sources


Total Nitrogen (mg N/ℓ)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
20
40
60
80
100
120
140
160
Nautical Miles from Bay Mouth
Potomac
Baltimore
Susquehanna
⑥
①
②
③
④
⑤

of the Susquehanna non-point source loadings is evident. Figure VI-7 shows a significant impact from the Baltimore area point sources, as well. Since the nitrogen loadings undergo some degree of settling and decay before reaching the Bay, the actual impact of these point sources may be somewhat more moderate than indicated here. Figure VI-8 shows the diminished influence of the point sources, both absolutely and relatively, under high freshwater flow conditions.

3. Dissolved Oxygen (DO)

Figure VI-9 is the unit response curve of the dissolved oxygen deficits for a Susquehanna River flow of 6400 cfs. The major oxygen consumption appears to result from the estimated benthic demand in the mid-Bay region. No field data on benthic demand was available so the benthic demand values were estimated from typical values observed in the tributaries. Explicit determination of the benthic demand through field studies would enhance the reliability of the model predictions. A narrow but somewhat high peak at the Bay head results from point and non-point BOD sources on the lower Susquehanna. Most of this load appears to originate from non-point sources.

Figure VI-9. Unit response curve of dissolved oxygen deficit corresponding to a Susquehanna River freshwater inflow of 6400 cfs.

KEY

1) Susquehanna River point and non-point source and Atlantic Ocean inflow

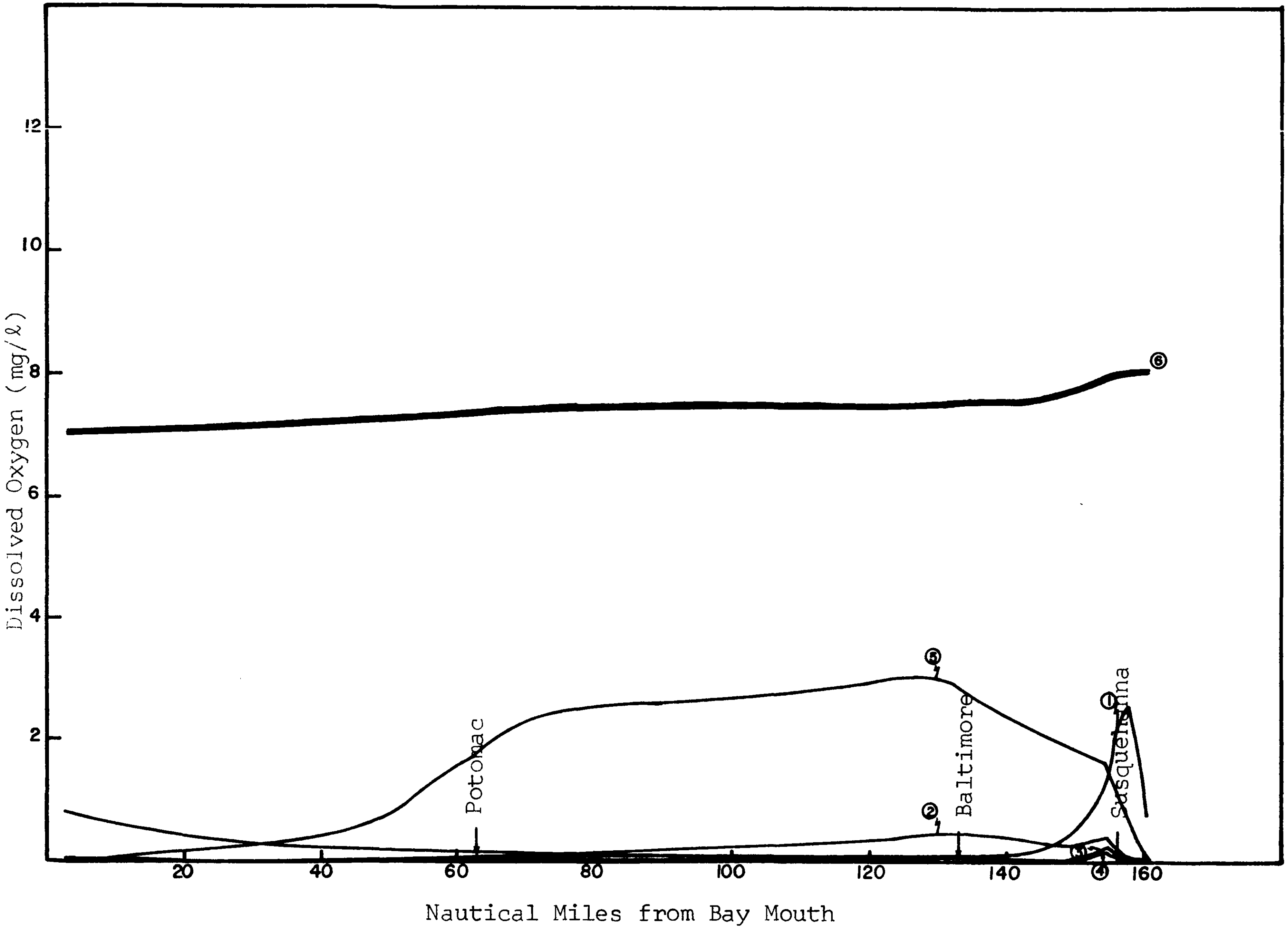
2) Baltimore area point sources

3) Other point sources

4) Other non-point sources

5) Benthal oxygen demand

6) Saturation oxygen level


12
10
8
6
4
2
Dissolved Oxygen (mg/ℓ)
20
40
60
80
100
120
140
160
Nautical Miles from Bay Mouth
Potomac
Baltimore
Susquehanna
①
②
③
④
⑤
⑥

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VII. Projected Future Pollutant Loadings

A. Data Sources and Limitations

See Chapter IV concerning the major tributaries and Table IV-7.

B. Expected 1977 Pollution Loading Levels

For the purpose of 1977 waste discharge abatement level analyses, EPA (Environmental Protection Agency) has required states to classify all water bodies as water quality limited segments or effluent limited segments. The Virginia portion of the Chesapeake Bay was classified as effluent limited segment, except a few small coastal basins and tributaries. The Maryland portion of the Bay was classified as water quality limited segment, especially with respect to phosphorus.

Two groups of point sources were considered in this study. The major tributaries of the Bay - the Susquehanna, Potomac, and James Rivers - were considered point sources for the purposes of the model. In addition, all identifiable major (discharge ≥ 0.5 MGD) municipal and industrial facilities discharging into the Bay or one of its tributaries at distances less than 10 nautical miles from the Bay were considered. (For a detailed summary and discussion see Chapter IV).

1. Major tributaries

a. Susquehanna River

The projected pollutant loadings from the Susquehanna to the Bay resulting from the application of

1977 ("best practical technology") discharge standards to Susquehanna River point sources cannot be assessed without a model of the lower Susquehanna River. Instead, the pollutant loadings resulting from 50%, 70%, and 90% point source abatement were used in the 1977 water quality projections (Tables VII-1 through VII-5). (The 100% point source abatement value, used for the 1985 {"elimination of discharge"} condition is also presented here.) The loading values for total phosphorus and total nitrogen under various freshwater inflow conditions were calculated by interpolation and extrapolation of estimates by Clark, et al. (1974). The nitrogenous biochemical oxygen demand values were calculated from total Kjehldahl nitrogen (TKN) values in the Clark study by applying the 4.57 stoichiometric ratio of oxygen to ammonia nitrogen in the nitrification process.

The derivation of the ultimate carbonaceous biochemical oxygen demand (CBOD) values for 0% point source reduction in Tables VII-1 through VII-5 is described in Chapter IV. Because the point source contribution to the present CBOD loading is considered negligible, no CBOD loading reduction is expected to result from lower Susquehanna River point source discharge abatement.

b. Potomac River

As discussed in Chapter IV, all loadings to the Bay from the Potomac River were assumed to have originated from non-point sources. The data presented in IV-4, therefore, were used in the 1977 (and 1985) water quality projections.

Table VII-1. Pollutant Loadings from the Susquehanna River, river flow = 2700 cfs (76.5 cms)

%, Point Source Reduction	Total-P mg/ℓ	Total-N mg/ℓ	NBOD mg/ℓ	CBOD mg/ℓ	DO* mg/ℓ
0	0.034	1.57	4.57	2.48	7.26
50	0.017	1.39	2.94	2.48	7.26
70	0.010	1.30	2.35	2.48	7.26
90	0.003	1.23	1.84	2.48	7.26
100	0.0	1.17	1.43	2.48	7.26

* assume 90% of saturated oxygen concentration

Table VII-2. Pollutant Loadings from the Susquehanna River, river flow = 6,400 cfs (181 cms)

%, Point Source Reduction	Total-P mg/ℓ	Total-N mg/ℓ	NBOD mg/ℓ	CBOD mg/ℓ	DO* mg/ℓ
0	0.041	1.55	3.87	2.35	7.26
50	0.025	1.41	2.68	2.35	7.26
70	0.018	1.34	2.24	2.35	7.26
90	0.009	1.30	1.80	2.35	7.26
100	0.006	1.25	1.50	2.35	7.26

Table VII-3. Pollutant Loadings from the Susquehanna River, river flow = 25,100 cfs (710 cms)

%, Point Source Reduction	Total-P mg/ℓ	Total-N mg/ℓ	NBOD mg/ℓ	CBOD mg/ℓ	DO mg/ℓ
0	0.052	1.50	2.90	2.16	8.6
50	0.041	1.40	2.27	2.16	8.6
70	0.037	1.37	2.05	2.16	8.6
90	0.032	1.35	1.75	2.16	8.6
100	0.029	1.33	1.60	2.16	8.6

Table VII-4. Pollutant Loadings from the Susquehanna River, river flow = 38,600 cfs (1090 cms)

%, Point Source Reduction	Total-P mg/ℓ	Total-N mg/ℓ	NBOD mg/ℓ	CBOD mg/ℓ	DO mg/ℓ
0 (present condition)	0.055	1.48	2.58	2.10	10.2
50	0.046	1.45	2.15	2.10	10.2
70	0.043	1.44	1.95	2.10	10.2
90	0.040	1.42	1.75	2.10	10.2
100 (1985 goal)	0.036	1.41	1.66	2.10	10.2

Table VII-5. Pollutant Loadings from the Susquehanna River, river flow = 70,300 cfs (1990 cms)

%, Point Source Reduction	Total-P mg/ℓ	Total-N mg/ℓ	NBOD mg/ℓ	CBOD mg/ℓ	DO mg/ℓ
0	0.056	1.46	2.47	2.03	12.1
50	0.051	1.44	2.28	2.03	12.1
70	0.049	1.43	2.20	2.03	12.1
90	0.046	1.43	2.10	2.03	12.1
100	0.044	1.42	2.06	2.03	12.1

c. James River

To evaluate the projected future pollutant loadings, the origins of the present loadings at the river mouth (Table IV-5) were assessed. The major point sources discharging into the tidal James are concentrated in three areas: Richmond, Hopewell and Hampton Roads (including the Elizabeth River System). The contribution of BOD, nitrogen and phosphorus to the Bay by the point sources around Richmond and Hopewell areas are negligible because of their distances from the mouth. (Hopewell is about 75 miles {121 km} from the mouth, Richmond is about 100 miles {161 km} from the mouth). The major contribution of pollutants from the James to the Bay, therefore, is from the point sources and non-point source of urban runoff on both sides of the Hampton Roads.

The present total CBOD loadings from the point sources in the Hampton Roads area average 129,000 lb/day, of which 90% is from the municipal sewage treatment plants. All municipal plants utilize primary treatment with average effluent BOD_5 concentrations of 120 mg/ℓ. Assuming all these plants will be upgraded from primary treatment to secondary treatment, the present and projected future pollutant discharges, together with percentage reduction, from these point sources are listed in the following:

	Total-P	Total-N	NBOD	CBOD
present (lb/day)	7,540	25,000	114,000	129,000
1977 (lb/day)	5,880	15,600	59,000	32,300
% Reduction	22	38	48	75
1985 (lb/day)	0	0	0	0
% Reduction	100	100	100	100

Under low flow conditions, it is expected that the pollutant loadings from non-point sources are negligible compared with those from point sources. The above percentage reductions, therefore, were applied to the freshwater flow conditions of 1020, 1200, and 4800 cfs (29, 34 and 136 cms), and the projected loadings are listed in Tables VII-6, VII-7, and VII-8. Under the high flow conditions, it was assumed that 50% of pollutant loadings at the river mouth were contributed by point sources. The above percentage reductions were applied to 50% of the present loadings and the results were listed in Tables VII-9 and VII-10. In view of the insignificant effects of the pollutant loadings from the James River on the water quality of the Bay as predicted by the model, the above assumptions are justifiable without more elaborated delineation of point and non-point sources.

2. Other Point Sources

The discharge rates for 1977 ("best practical technology") were estimated from National Pollutant Discharge Elimination System (NPDES) permit limitations for 1977 or on the basis of secondary treatment of domestic sewage if permits were not available (Table VII-11).

Table VII-6. Pollutant Loadings from the James River river flow = 1020 cfs (29 cms)

	Total-P lb/day	Total-N lb/day	NBOD lb/day	CBOD lb/day	DO* mg/ℓ
present	340	825	3770	11000	6.55
1977	270	515	1950	2750	6.55
1985	0	0	0	0	6.55

* assume 90% of saturated oxygen concentration

Table VII-7. Pollutant Loadings from the James River, river flow = 1200 cfs (34 cms)

	Total-P lb/day	Total-N lb/day	NBOD lb/day	CBOD lb/day	DO mg/ℓ
present	400	970	4430	13000	6.55
1977	310	605	2300	3250	6.55
1985	0	0	0	0	6.55

Table VII-8. Pollutant Loadings from the James River, river flow = 4800 cfs (136 cms)

	Total-P lb/day	Total-N lb/day	NBOD lb/day	CBOD lb/day	DO mg/ℓ
present loadings	1600	3880	17700	51600	7.76
1977 loadings	1300	2400	9200	12900	7.76
1985 loadings	0	0	0	0	7.76

Table VII-9. Pollutant Loadings from the James River, river flow = 12500 cfs (354 cms)

	Total-P lb/day	Total-N lb/day	NBOD lb/day	CBOD lb/day	DO mg/ℓ
present loadings	4170	10900	49800	134500	9.1
1977 loadings	3711	8800	37800	94000	9.1
1985 loadings	2080	5450	24900	67250	9.1

Table VII-10. Pollutant Loadings from the James River, river flow = 19300 cfs (547 cms)

	Total-P lb/day	Total-N lb/day	NBOD lb/day	CBOD lb/day	DO mg/ℓ
present loadings	6440	15800	72200	208000	10.8
1977 loadings	5700	12800	55000	130000	10.0
1985 loadings	3220	7900	36100	10400	10.8

Table VII-11. Estimated Chesapeake Bay Point Source Average Mass Emission Rates for 1977 (lbs/day)

Model Reach #	Source	Flow Rate (MGD)	CBOD	TKN	NBOD	NO_2NO_3-N	TN	TP
2	Bainbridge NTC	0.7	263	105	480	22	127	19
5	Havre de Grace	5.0	1877	751	3432	154	905	25
6	Perryville	1.5	282	57	260	0	57	6
7	Aberdeen	1.13	425	170	777	35	205	49
9	Sod Run	4.0	375	601	2747	124	725	Nov-Mar: 100, Mar-Nov: 17
10	Edgewood Arsenal	3.0	750	451	2061	93	544	205
11	Joppatown	0.75	375	113	516	23	136	71
12	Back River	65.0	20630	9762	44612	2007	11769	4448
13	Cox Creek	15.0	5630	2253	10296	463	1716	914
	Patapsco	42.0	15772	6309	28832	1297	7606	2874
	Bethlehem Steel	120.0	45036	22818	104278	3705	26523	8211
15	Annapolis	10.0	3753	1502	6864	309	1811	317
24	Pine Hill Run	3.0	1125	451	2061	93	544	205
29	Standard Products	4.4	8610	0	0	0	0	0
	Haynic Products	8.64	13335	0	0	0	0	0
36	American Oil (Yorktown)	1.8	513	190	868	0	190	0
	VEPCO (Yorktown)		0	0	0	0	0	0
	Naval Mine Depot	.52	126	78	357	22	100	36
39	HRSD - Chesapeake Elizabeth	13.0	4883	1953	8925	401	2354	890

(Complete elimination of point sources was assumed for 1985).

a. CBOD

BOD_5 1977 permit limitations were available for all point sources except the Federal facilities, Back River STP (and therefore Bethlehem Steel Co., which reuses 120 MGD of Back River effluent), Patapsco STP, and HRSD-Chesapeake Elizabeth. In these cases a 30 mg BOD_5/ℓ effluent concentration (secondary treatment) was assumed and combined with the flow rate (see next paragraph) to estimate mass emission rates. CBOD emission rates were calculated from BOD_5 rates, assuming BOD_5 is composed entirely of carbonaceous matter and has a decay coefficient of .22/day (base e).

b. Flow rates

Where available, flow rates were calculated from NPDES permit limitations on BOD_5 mass emissions and concentrations for 1977 or the latest prior date. Otherwise, the flow rates from Table IV-7 were used (i.e. no plant expansion between now and 1977 was assumed).

c. Total Kjeldahl Nitrogen (TKN), Nitrogenous BOD (NBOD), and Nitrite/Nitrate Nitrogen (NO_2 & NO_3 - N)

Since no NPDES permit limitations on TKN were imposed for Federal or municipal facilities, their TKN mass emission rates were estimated on the basis of an 18 mg/ℓ effluent concentration (secondary treatment).

Bethlehem Steel's NPDES ammonia nitrogen limit for 1976 was added to its 1977 influent TKN (from Back River STP effluent) to obtain the 1977 TKN emission rate.

The American Oil NPDES 1977 permit limitation for ammonia nitrogen was used for the TKN emission rate.

Since neither the NPDES permits nor the EPA Effluent Guidelines and Standards specified TKN discharge rates, no TKN discharge was assumed from Standard Products (fish processing) Haynie Products (fish processing), or VEPCO (energy production).

NBOD rates were calculated from TKN rates on the basis of the stoichiometric ratio 4.57 of oxygen to ammonia nitrogen in the nitrification process.

Federal, municipal, and Bethlehem Steel NO_2 &NO_3-N rates were estimated on the basis of a 3.7 mg/ℓ effluent concentration (Metcalf and Eddy, 1972, American Chemical Society, 1969). No NO_2 &NO_3-N discharge was assumed for American Oil, Standard Products, Haynie Products, or VEPCO, since no limits were specified by either NPDES permits of the EPA Effluent Guidelines and Standards.

d. Total Phosphorus (TP)

NPDES 1977 phosphorus limitations were used for Havre de Grace, Perryville, and Sod Run projected emission rates. For other Federal and municipal facilities and Bethlehem Steel, if the actual 1973-1974 measured phosphorus concentration was less than 8.2 mg/ℓ, a standard secondary effluent concentration (Amer. Chem. Soc., 1969), the mass emission rate was calculated on the basis of the actual concentration. Otherwise the 8.2 mg/ℓ concentration was used.

Since neither NPDES permits nor EPA Effluent Guidelines and Standards specified phosphorus discharge rates, no TP discharge was assumed for American Oil, Standard Products, Haynie Products, or VEPCO.

C. Expected 1983 Pollutant Loading Levels

Since the Bethlehem Steel Co. is the only significant industrial point source and no NPDES permit beyond 1977 is available at the present time, it is assumed that the projected pollutant discharge rate in 1983 ("best available technology") will be the same as that of 1977. It is also assumed that all municipal sewage treatment plants will provide secondary treatment both in 1977 and 1983, therefore, no separate estimate of point source discharge rates was made for 1983.

D. Comparison of 1974 and 1977 Point Source Pollutant Loadings

A comparison of current estimated point source pollutant loadings with those projected for 1977 are presented in Tables VII-12 through VII-15. The negative percent reduction values calculated for some sources result from projected increases in effluent flow levels in 1977 as determined from NPDES permits. (See section B of this chapter).

Table VII-12. Comparison of 1974 and 1977 Point Source Phosphorus Loadings

Model Reach #	Source	1974 (TP)	1977 (TP)	(% reduction)
2	Bainbridge NTC	19	19	(0)
5	Havre de Grace	81	25	(69)
6	Perryville	36	6	(83)
7	Aberdeen	49	49	(0)
9	Sod Run	33	Nov. -Mar. : 100 Mar. -Nov. : 17	(-208) (48)
10	Edgewood Arsenal	205	205	(0)
11	Joppatown	71	71	(0)
12	Back River	5695	4448	(22)
13	Cox Creek	518	914	(-76)
	Patapsco	1577	2874	(-82)
	Bethlehem Steel	10515	8211	(22)
15	Annapolis	190	317	(-67)
24	Pine Hill Run	263	205	(22)
29	Standard Products	0	0	-
	Haynie Products	0	0	-
36	American Oil (Yorktown)	0	0	-
	VEPCO (Yorktown)	0	0	-
	Naval Mine Depot	36	36	(0)
39	Birchwood Gardens	55	0	(100)
	HRSD - Oceana	44	0	(100)
	HRSD - Chesapeake Elizabeth	1139	890	(22)
	TOTAL	20526	Nov. -Mar. :18376 Mar. -Nov. :18287	(11)

Table VII-13. Comparison of 1974 and 1977 Point Source Nitrogen Loadings

Model Reach #	Source	1974 (TN)	1977 (TN)	(% reduction)
2	Bainbridge NTC	127	127	(0)
5	Havre de Grace	434	905	(-108)
6	Perryville	290	57	(80)
7	Aberdeen	205	205	(0)
9	Sod Run	1159	725	(37)
10	Edgewood Arsenal	544	544	(0)
11	Joppatown	136	136	(0)
12	Back River	18822	11769	(37)
13	Cox Creek	2461	1716	(30)
	Patapsco	5212	7606	(-46)
	Bethlehem Steel	62226	26523	(57)
15	Annapolis	1737	1811	(-4)
24	Pine Hill Run	869	544	(37)
29	Standard Products	0	0	-
	Haynie Products	0	0	-
36	American Oil (Yorktown)	1314	190	(86)
	VEPCO (Yorktown)	0	0	-
	Naval Mine Depot	100	100	(0)
39	Birchwood Gardens	145	0	(100)
	HRSD - Oceana	145	0	(100)
	HRSD - Chesapeake Elizabeth	3764	2354	(37)
	TOTAL	99690	55312	(45)

Table VII-14. Comparison of 1974 and 1977 Point Source NBOD Loadings

Model Reach #	Source	1974 NBOD	1977 NBOD	(% reduction)
2	Bainbridge NTC	480	480	(0)
5	Havre de Grace	1983	3432	(-73)
6	Perryville	1325	260	(80)
7	Aberdeen	777	777	(0)
9	Sod Run	5292	2747	(48)
10	Edgewood Arsenal	1061	2061	(-94)
11	Joppatown	516	516	(0)
12	Back River	86017	44612	(48)
13	Cox Creek	11247	10296	(8)
	Patapsco	23819	28832	(-21)
	Bethlehem Steel	284373	104278	(63)
15	Annapolis	7938	6864	(14)
24	Pine Hill Run	3971	2061	(48)
29	Standard Products	0	0	-
	Haynie Products	0	0	-
36	American Oil (Yorktown)	6005	868	(86)
	VEPCO (Yorktown)	0	0	-
	Naval Mine Depot	357	357	(0)
39	Birchwood Gardens	548	0	(100)
	HRSD - Oceana	663	0	(100)
	HRSD - Chesapeake Elizabeth	7201	8925	(48)
	TOTAL	453573	217366	(52)

Table VII-15. Comparison of 1974 and 1977 Point Source CBOD Loadings

Model Reach #	Source	1974 CBOD	1977 CBOD	(% reduction)
2	Bainbridge NTC	263	263	(0)
5	Havre de Grace	2664	1877	(30)
6	Perryville	410	282	(31)
7	Aberdeen	425	425	(0)
9	Sod Run	2550	375	(85)
10	Edgewood Arsenal	1125	750	(33)
11	Joppatown	375	375	(0)
12	Back River	52041	20630	(60)
13	Cox Creek	4785	5630	(-18)
	Patapsco	76560	15772	(79)
	Bethlehem Steel	96077	45036	(53)
15	Annapolis	10125	3753	(63)
24	Pine Hill Run	1703	1125	(34)
29	Standard Products	9428	8610	(9)
	Haynie Products	14931	13335	(11)
36	American Oil (Yorktown)	5259	513	(90)
	VEPCO (Yorktown)	0	0	-
	Naval Mine Depot	126	126	(0)
39	Birchwood Gardens	218	0	(100)
	HRSD - Oceana	609	0	(100)
	HRSD - Chesapeake Elizabeth	6509	4883	(25)
	TOTAL	286183	123760	(57)

The overall reductions in each pollutant category reflect the dominance of the Baltimore area point sources, for which the following reduction percentages were estimated:

TP	TN	NBOD	CBOD
10	46	54	62

Literature Cited

American Chemical Society. 1969. Cleaning our environment: the chemical basis for action. P. 109, Washington, D. C.

Clark, L. J., V. Guide and T. H. Pheiffer. 1974. Summary and conclusions from the forthcoming Technical Report 60 "Nutrient transport and accountability in the lower Susquehanna River basin". E.P.A. Annapolis Field Office, Region III.

Metcalf and Eddy, Inc. 1972. Wastewater engineering: collection, treatment, disposal. P. 257. McGraw-Hill Book Co.

VIII. Residuals

Within the Chesapeake Bay region as covered in this site study, the major residuals-generating sources are municipal waste treatment plants. Only two major industries are present: 1) the American Oil Company refinery at Yorktown, Virginia and 2) the Bethlehem Steel Plant at Sparrows Point, Maryland.

A. General

Much of the following discussion is modified from a report by Malcolm Pirnie Engineers to the Hampton Roads Sanitary District Commission. (Malcolm Pirnie Engineers, Inc. 1974).

Sludges from most secondary and advanced wastewater treatment systems will contain significant quantities of organic materials and some inorganic materials useful as a weak fertilizer or soil conditioner.

If thickened and dewatered to about 20 percent solids, these sludges can be reduced to small quantities of ash with thermal destruction methods such as incineration. This solids handling scheme, however, requires substantial amounts of energy input. If the sludges can be dewatered to about 30 percent solids, the sludge often can be thermally destroyed with minimal energy input. Sludges dewatered to more than 30 percent solids usually have a high enough energy content that thermal destruction can result in a net gain of useful energy. The resultant ash is greatly reduced in volume and essentially sterile, making it highly ammenable to disposal in a sanitary landfill.

B. Ultimate Disposal Methods

1. Landfill

Sewage sludge is not considered to be suitable for construction landfill material in many areas where leaching might result in contamination of ground or surface waters. Additionally, unless adequate and prompt soil covering is used, odor generation and the propagation of nuisance organisms may occur. In general, the use of sludge for this purpose is considered both undesirable and undependable.

Sludge disposal in a suitable municipal sanitary landfill site is more desirable. The possibility of undesirable materials reaching local ground or surface waters through leaching or runoff is high, however, and in addition, the volume requirements might be prohibitive considering the limited number of municipal sites which are available.

By incinerating sludge, the amount of space required is minimized and the ash is more suitable for disposal in a landfill operation, thereby achieving a greater site life and reduced land requirements.

2. Agricultural Usage

In lieu of thermal destruction and sanitary landfill, agricultural methods of solids disposal have been evaluated which would utilize the fertilizer or soil conditioning value of the sludges. While these processes appear attractive, none have been demonstrated on wet mineral soil such as those which predominate in many areas of the lower Bay. These processes include:

1. Drying a dewatered sludge cake and selling the dried product as a soil conditioner.
2. Composting the dewatered cake with refuse into a useful material.
3. Applying digested sludge to agricultural soils to increase crop production.

While sludge drying and preparation of soil conditioner may be feasible, several possible difficulties have been identified. The system requires the use of large amounts of energy to dry the sludge and in that regard is not better than incineration. The sale of dried product is necessary to make this approach viable. Commitment to a program producing a soil conditioner would be contingent upon a reliable outlet for the product. The availability of a dependable outlet for this material would have to be developed.

The third alternative is being utilized by the HRSD in an area north of Hampton Roads with an anaerobically digested sludge. Studies which have been conducted in other areas indicate that given the proper site conditions, the principal of sludge utilization for agricultural purposes is a feasible disposal method. Numerous studies have been conducted to determine the suitability of applying wastewaters or sludges to well-drained mineral soils or wet peat areas.

Difficulties which might be encountered in poorly drained mineral soil areas include: contamination of ground waters or degradation of surface waters as a result of leaching or runoff from the application area; deterioration of soil quality as a result of the buildup of nitrogen compounds or heavy metals; and nuisance or public health problems.

Assuming sufficient acreage of suitable soils can be found, an agricultural operation in the proximity of a plant could be initiated which might reduce the overall cost of solids disposal. Grass sod or seed, Christmas trees or pulpwood such as sycamore might be cultivated as non-edible cash crops which could yield a relatively fast return on the necessary investment. The process would also allow realization of environmental benefits including recycling of nutrients and conservation of energy resources. While this method appears to have potential, its application at any site would be appropriate only if extensive tests of soil drainage, groundwater, and sludge characteristics demonstrate the feasibility of this alternative prior to implementation on a large scale. Furthermore, drainage control and monitoring systems would be necessary to insure protection of water resources and soil conditions.

During extended periods of poor climatic conditions, it would be more desirable to destroy the solids thermally than to store them for the extended periods and possibly create nuisances. A thermal destruction process is recommended for large plants to operate as a seasonal disposal method and as a back-up for land disposal method or reclamation procedures.

C. Present Practices

1. Municipal Sludge Disposal

At present Baltimore City sewage sludge is digested anaerobically and landfilled at the Back Creek Plant site or hauled by truck to sites where it is utilized as a soil conditioner. Similar practices are utilized in the Hampton Roads Sanitary District and we assume at the smaller plants on the upper Bay. Table VIII-1 shows the estimated quantities of sludge generated from municipalities discharging into the Bay in 1974.

2. Bethlehem Steel

The residuals generated from the various processes within steel mills are usually land filled except for those which are reclaimed. In general about 25% of the solid wastes generated in the production of steel are recycled. The specific practices used at the Sparrows Point Plant are not known.

3. Standard and Haynie Products

Both of these industries are menhaden processing plants which utilize in so far as possible all the fish captured, i.e. they produce from the fish: fish meal, fish oils and fish solubles, and hence generate no solid waste.

4. American Oil Refinery at Yorktown

Sludges from the primary and secondary solids removal systems and the biological treatment facility are land filled and utilized in land farming as soil conditioners. The present quantities generated in 1974 are shown in Table VIII-1.

Sulfur removed from the crude oil is sold to the Virginia Chemical Corporation which then produces from it sulfur dioxide.

D. 1977 or BPT Residuals

The residuals generated under BPT technologies for point source discharges into the Bay are tabulated in Table VIII-2.

E. 1985-EOD Residuals

The residuals generated under EOD technologies for point source discharges into the Bay are tabulated in Table VIII-3.

F. Comparison of Residual Levels

Table VIII-4 compares the residual generation rates for 1974, 1977 and 1985 abatement levels.

Table VIII - I

Estimated Chesapeake Bay Point Source Residuals for 1974

	Source	Flow Rate (MGD)	Treatment	Dry Solids	
				lbs/day	lbs/year 10^6
Municipalities	Bainbridge	0.7	S	1094	0.40
	Harve de Grace	1.5	P	1530	0.55
	Perryville	1.0	S	1563	0.57
	Aberdeen	1.13	S	1766	0.64
	Sod Run	4.0	S	6252	2.28
	Edgewood Arsenal	3.0	S	4689	1.71
	Joppatown	0.75	S	1172	0.43
	Back River	65.00	S	101595	18.49 (1)
	Cox Creek	8.5	S	13286	4.84
	Patapsco	18.0	P	18360	3.34 (1)
	Bethlehem Steel	120.0	S	187560	34.14 (1) & (2)
	Annapolis	6.0	P	6120	2.23
	Pine Hill Run	3.0	S	4689	1.71
	Naval Mine Depot	0.52	S	813	0.30
	Birchwood Gardens	0.8	S	1250	0.46
	HRSD - Oceana	0.5	P	510	0.19
	HRSD - Ch. El.	13.0	S	20319	3.70 (1)
Industries	Bethlehem Steel	--	Base	291400	96.16 (5)
	Standard Products	4.4	(3)	0	0
	Haynie Products	8.6	(3)	0	0
	American Oil	1.8	S	3760 (4)	1.24 (4)

(1) A reduction in solids of 50% by anaerobic digestion was used to arrive at these estimates

(2) Solids handled at Back River Plant

(3) Recovery of all solids to products (eg., fish meal)

(4) Excluding inorganic salts mainly sulfur totaling about 3,000 tons/year

(5) Estimated from unit processes

Table VIII - 2

Estimated Chesapeake Bay Point Source Residuals for 1977

	Source	Flow Rate (MGD)	Treatment	Dry Solids	
				lbs/day	lbs/year 10^6
Municipalities	Bainbridge	0.7	S	1094	0.40
	Harve de Grace	5.0	S	7815	2.84
	Perryville	1.5	S	2345	0.85
	Aberdeen	1.13	S	1766	0.64
	Sod Run	4.0	S	6252	2.28
	Edgewood Arsenal	3.0	S	4689	1.71
	Joppatown	0.75	S	1172	0.43
	Back River	65.0	S	101595	18.49 (1) & (3)
	Cox Creek	15.0	S	23445	8.53
	Patapsco	42.0	S	65646	11.95 (1), & (3)
	Bethlehem Steel	120.0	S	187560	34.14 (1), (2), (3)
	Annapolis	10.0	S	15630	5.69
	Pine Hill Run	3.0	S	4689	1.71
	Naval Mine Depot	0.52	S	813	0.30
	HRSD - Ch. Eliz.	13.0	S	20319	3.70 (1)
Industries	Bethlehem Steel		Level 1	427000 (6)	141.00 (6)
	Standard Products	4.4	(4)	0	0
	HaynieProducts	8.64	(4)	0	0
	American Oil	1.8	S	3760(5)	1.24(5)

(1) A reduction in solids of 50% by anaerobic digestion was used to arrive at these estimates

(2) Solids handled at Back River Plant

(3) Incineration may be added in late 1977 or 1980

(4) Recovery of all solids to products (eg., fish meal)

(5) Excluding inorganic salts mainly sulfur totaling about 3,000 tons/year

(6) Estimated from unit processes and Maryland effluent permits

Table VIII - 3

Estimated Chesapeake Bay Point Source Residuals for 1985(1)

				Dry Solids	
	Source	Flow Rate (MGD)	Treatment	lbs/day	lbs/year 10^6
Municipalities	Bainbridge	0.7	S	1094	0.40
	Harve de Grace	5.0	S	9065	3.30
	Perryville	1.5	S	2720	1.00
	Aberdeen	1.13	S	2049	0.75
	Sod Run	4.0	S	6535	2.39
	Edgewood Arsenal	3.0	S	5439	1.98
	Joppatown	0.75	S	1360	0.50
	Back River	65.0	S	117845	21.45 (2) & (4)
	Cox Creek	15.0	S	27195	9.99
	Patapsco	42.0	S	76146	13.85 (2) & (4)
	Bethlehem Steel	120.0	S	217560	39.60 (2) & (3)
	Annapolis	10.0	S	18130	6.60
	Pine Hill Run	3.0	S	5439	1.98
	Naval Mine Depot	0.52	S	943	0.34
	HRSD - Ch. Eliz.	13.0	S	23570	4.29
Industries	Bethlehem Steel	--	Level 2	856000 (8)	285.45 (8)
	Standard Products	4.4	(5)	0	0
	Haynie Products	8.64	(5)	0	0
	American Oil	1.8	S	3760(6)	1.24(6)
				12850(7)	4.24(7)

(1) Removal of all suspended solids from the sewage effluents was assumed to arrive at these estimates

(2) A reduction in solids of 50% by anaerobic digestion was used to arrive at these estimates

(3) Solids handled at Back River Plant

(4) Incineration may be added in late 1977 or 1980

(5) Recovery of all solids to products (eg., fish meal)

(6) Excluding inorganic salts mainly sulfur totaling about 3,000 tons/year

(7) With ballast water salt removal

(8) Estimated from unit processes and Maryland effluent permits

Table VIII-4. Projected Residuals for Point Sources in the Chesapeake Bay Area

Target Year	Sludge Generation in Metric Tons Dry Weight Per Year		
	Total Municipal	Total Industrial	Total
Present Conditions	3.446×10^4	4.418×10^4	7.864×10^4
1977	4.248×10^4	6.452×10^4	1.070×10^5
1985	4.918×10^4	1.320×10^5	1.811×10^5

Literature Cited

Malcolm Pirnie Engineers, Inc. 1974. Advanced wastewater treatment, Atlantic Wastewater Treatment Plant, Virginia Beach, Virginia, Report for Hampton Roads Sanitation District. Newport News, Virginia.

IX. Projection of Future Water Qualities and Quantities

No significant changes in water quantity or water temperature in the Bay are anticipated. No projections of light, pH, specific conductance, or surfactants were made due to lack of data. Toxic substances and bacteria are discussed in Chapters XI and XIII.

The freshwater flow and pollutant loading conditions described in Chapters IV and VII were combined for simulation runs by the model. For each of the five selected flow conditions the model was run to simulate the water quality in the Bay proper under present, projected 1977 and 1985 pollutant loading conditions. As explained in Chapter VII, Section C, no separate water quality projection was made for the 1983 pollutant loading goals, since there is only one major industrial point source on the Bay.

The water quality parameters investigated include total phosphorus, total nitrogen and dissolved oxygen.

A. Total Phosphorus

Figures IX-1 - IX-5 show the total phosphorus distributions predicted by the model for each combination of pollutant loading and Susquehanna River flow condition discussed. The percentages indicated on the 1977 curves refer to the degree of phosphorus removal at the point sources on the lower Susquehanna River only, relative to their present levels. The discharges of the point sources

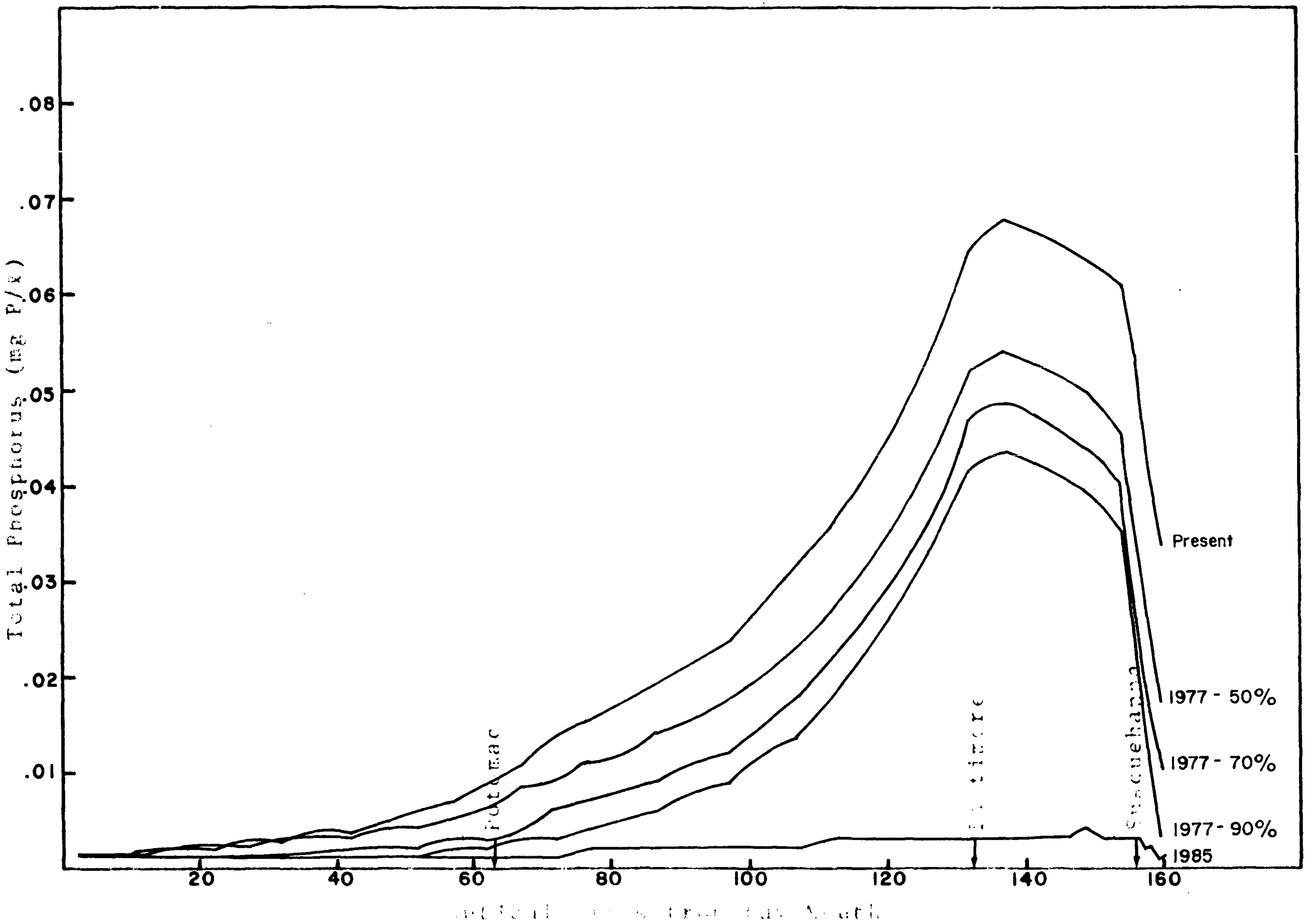

Figure IX-1. Model predictions of total phosphorus distribution for Susquehanna River flow of 2700 cfs.

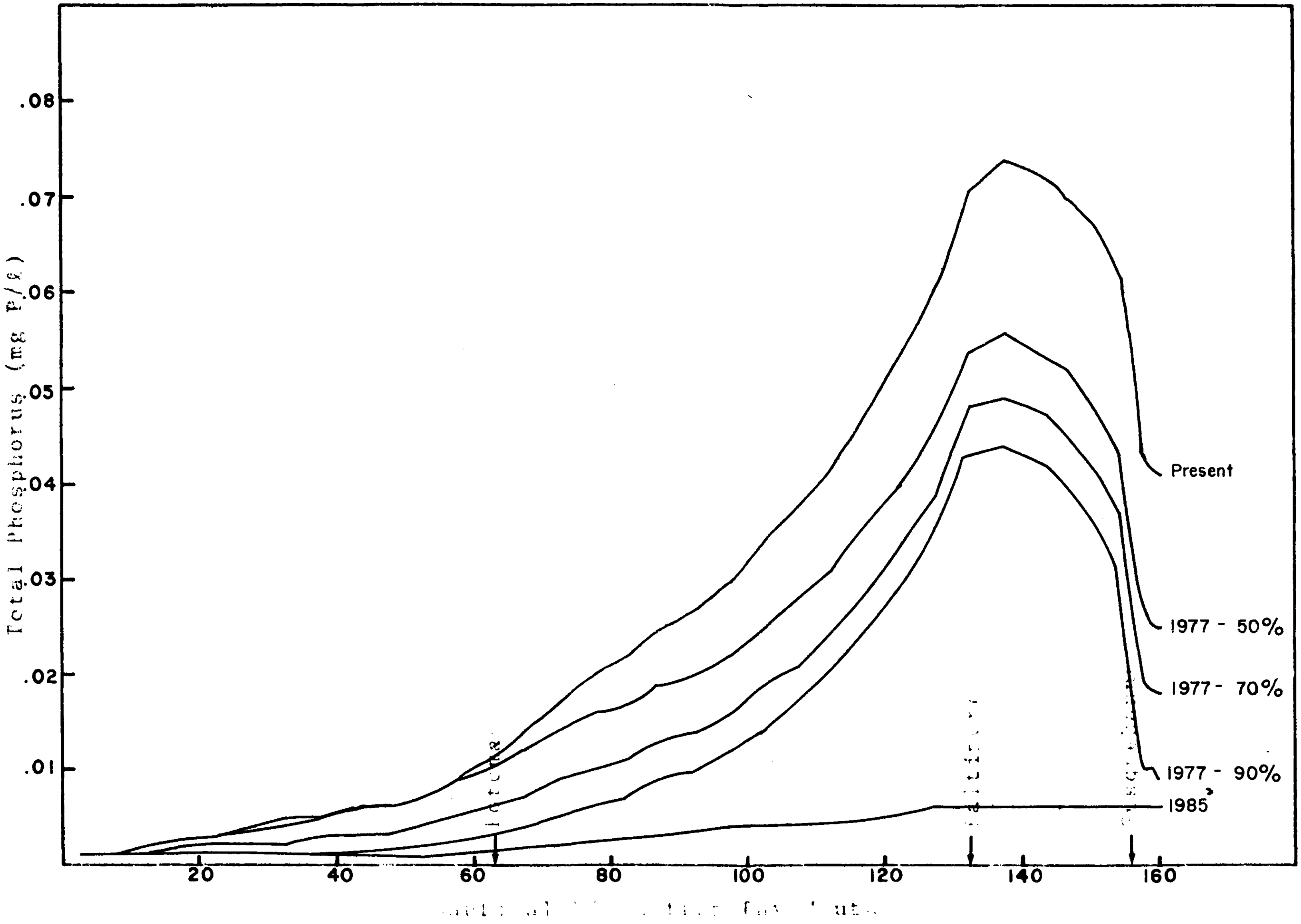

Figure IX-2. Model predictions of total phosphorus distribution for Susquehanna River flow of 6400 cfs.

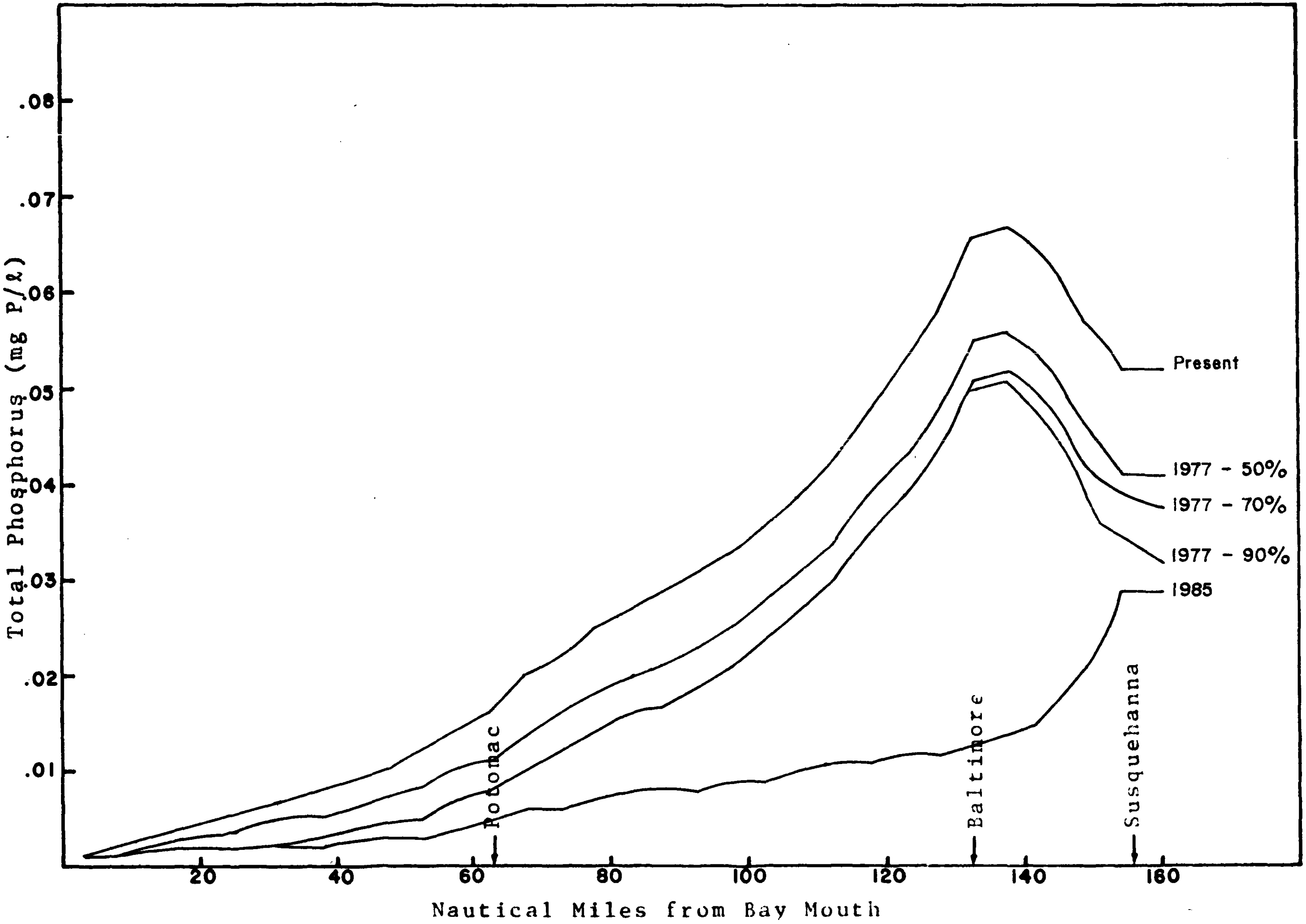

Figure IX-3. Model predictions of total phosphorus distribution for Susquehanna River flow of 25,100 cfs.

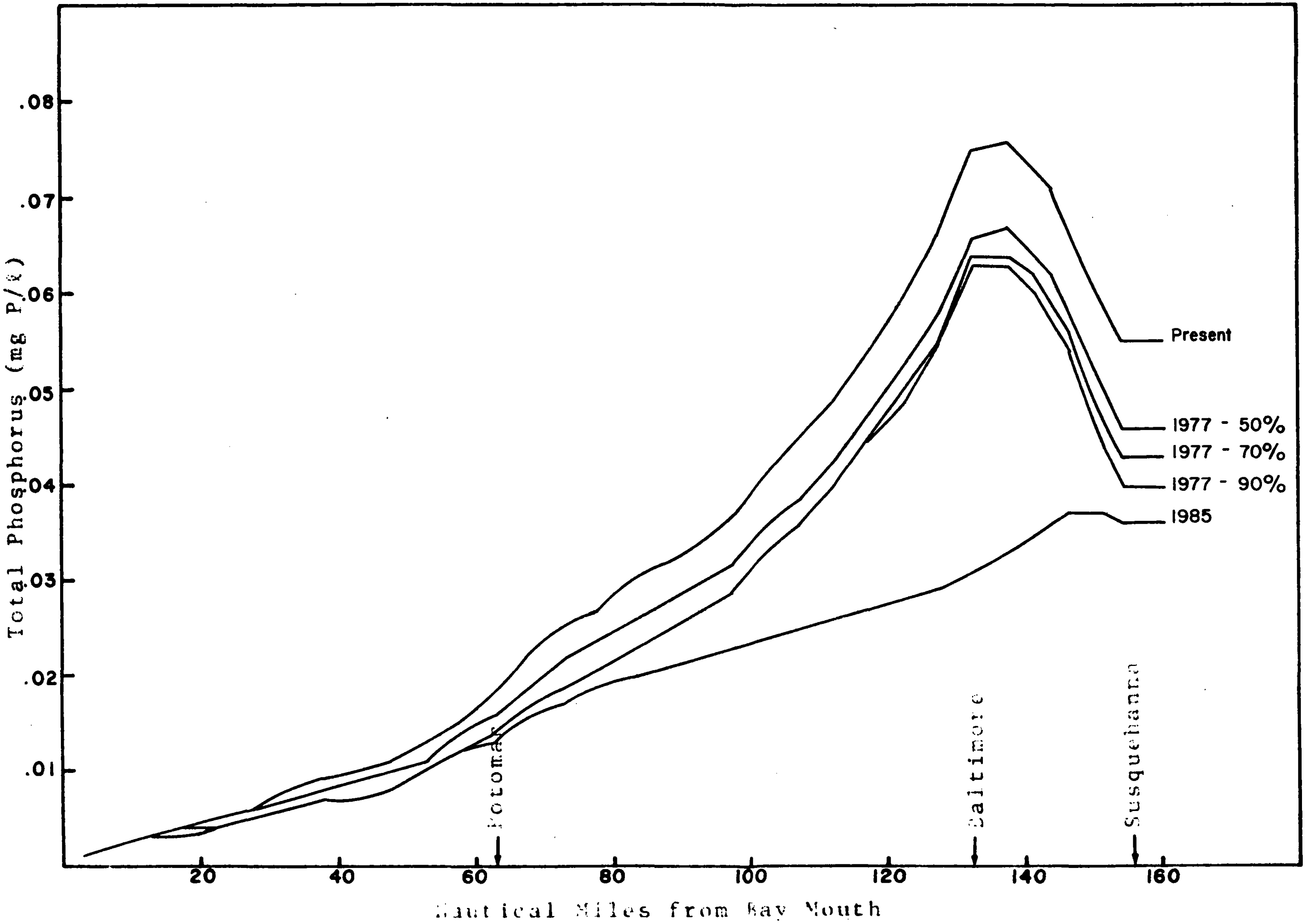

Figure IX-4. Model predictions of total phosphorus distribution for Susquehanna River flow of 38,600 cfs.

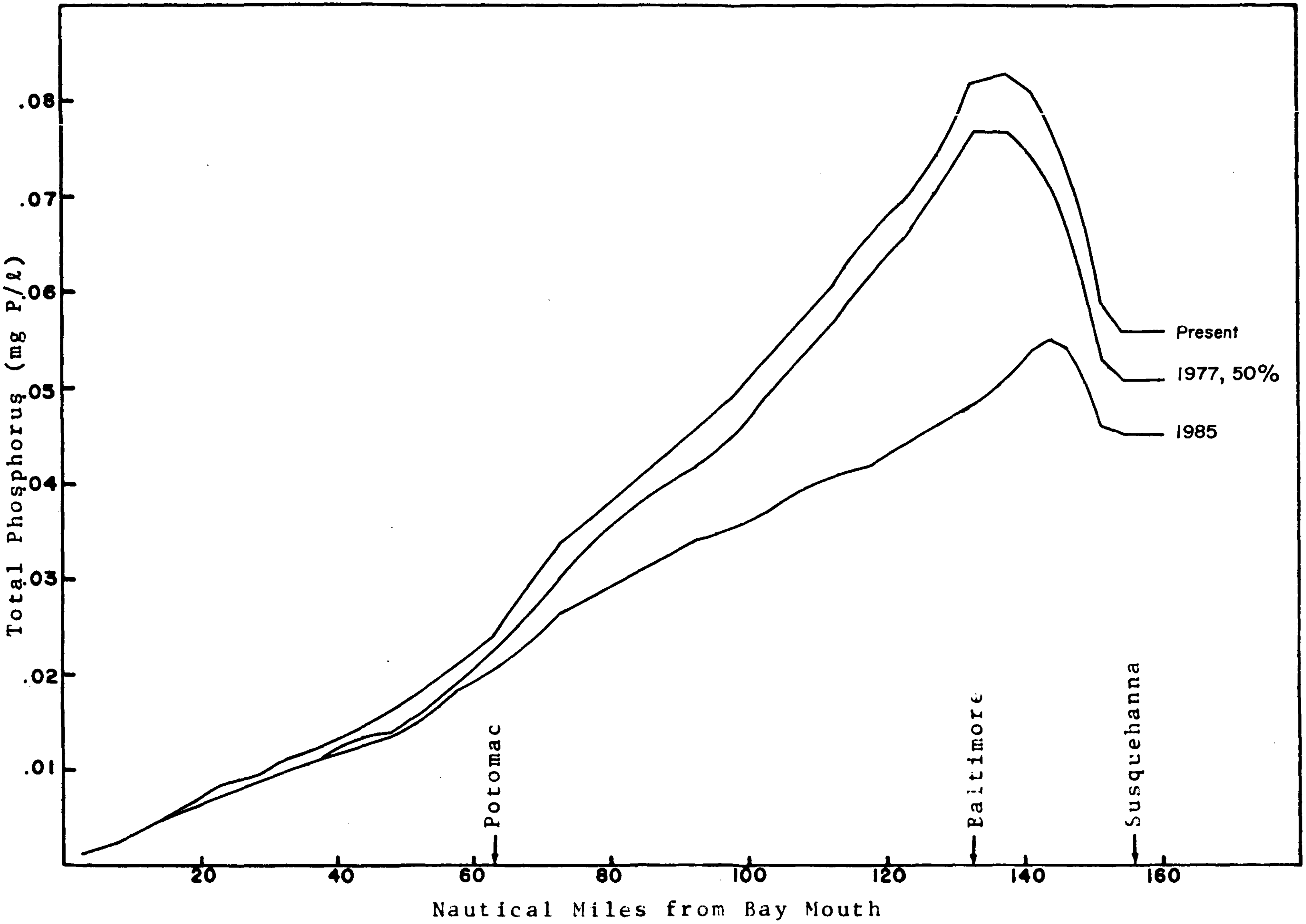

Figure IX-5. Model predictions of total phosphorus distribution for Susquehanna River flow of 70,3000 cfs.

on the Bay are the same for each set of 1977 curves. (For a more detailed explanation see Chapter VII.)

Figure IX-1 shows the total phosphorus distributions for a Susquehanna River flow of 2700 cfs (76.5 m^3/sec) (7-day 10-year low flow). The major peak in the vicinity of Baltimore Harbor exists for each pollutant loading condition except that of 1985, which represents a 100% reduction of point source loads both on the Bay and the lower Susquehanna River. The low upstream boundary concentration and the absence of any significant peak for the 1985 condition demonstrates the dominance of point sources on the phosphorus distribution at this freshwater inflow level. The differences in maximum concentrations corresponding to varied Susquehanna contributions for 1977 Bay loadings reflect the significance of the Susquehanna point sources on the phosphorus distribution in the Bay. An increase in phosphorus removal from 50% to 90% by Susquehanna point sources can lower the maximum phosphorus concentrations in the Bay by .010 mg P/ℓ. The predominant contribution, however, is clearly the point source loadings from the Baltimore Harbor area, as evidenced by the increase in concentration there, relative to the Susquehanna area. As explained in Chapter VI, Section 5, however, the impact of the Baltimore area point sources may be somewhat more moderate than indicated here.

Comparison of the 1977-50% curve with the present curve shows that the approximately 10% decrease in Baltimore point source loading, combined with a 50% decrease in Susquehanna point source loading leads to a decrease in maximum phosphorus concentration of .014 mg P/ℓ.

A similar pattern of phosphorus distributions exist for the 6400 cfs (181 m^3/sec) freshwater discharge condition (Figure IX-2). Here an increase in Susquehanna point source removal from 50% to 90% causes a decrease in the maximum Bay phosphorus concentration of .012 mg P/ℓ. The 10% decrease in Baltimore point source discharge and a 50% decrease in Susquehanna point source discharge combine for a 0.018 mg P/ℓ decrease in the maximum Bay phosphorus concentration. Due to the higher freshwater flow, the concentrations just upstream of the peak are slightly lower and those downstream of the peak slightly higher than for the 2700 cfs case.

The 25,100 cfs (710 m^3/sec) Susquehanna flow case (Figure IX-3) displays another similar distribution pattern. The higher upstream boundary concentration for 1985 and the smaller spread of the 1977 curves are the result of increased significance of non-point sources of phosphorus relative to point sources on the lower Susquehanna River at this higher freshwater flow level. This phenomenon is further evidenced by the 38,600 cfs (1090 m^3/sec) and 70,300 (1990 m^3/sec) flow conditions (Figures IX-4 and IX-5). For the 25,100 cfs and 38,600 cfs cases, the difference between the peaks of the 1977-50% curve and the 1977-90% curve is only 0.004 mg P/ℓ while for the 70,300 cfs case the difference is negligible and not shown.

The increase in peak values for corresponding curves under increasing freshwater inflow conditions, is a further demonstration of intensified influence of non-point sources of phosphorus with increased freshwater flow. Since, with the exception of Sod Run, the point source contributions are uniform for corresponding curves and the decay rates actually increase for increasing flow (which would tend to lead to decreasing values), the increasing values must be caused by non-point source loadings. Moreover, the small peaks between the Susquehanna and Baltimore areas on the 1985 curves for the 38,600 cfs and 70,300 cfs cases, are clearly caused by non-point sources - particularly, the marshes at the head of the Bay - since the 1985 curves represent complete point source elimination. Thus, there is an amplification of non-point source significance as freshwater flow increases. This trend was also observed in the unit response curves presented in Chapter VI.

The effect of a dimunition of Baltimore point source loadings between the present and 1977 is reflected in the 0.011 mg P/ℓ peak differences between the present and 1977-50% curves for both the 25,100 cfs and 38,600 cfs conditions and the 0.006 mg P/ℓ peak difference for the 70,300 cfs condition.

Another conspicuous feature of the system is the lengthy period required to reach equilibrium with respect to phosphorus, for changing conditions, due primarily to the very small decay rates for phosphorus as compared to those for oxygen demanding organic material, for example.

B. Total Nitrogen

Figures IX-6 - IX-10 show the total nitrogen distributions predicted by the model for each combination of pollutant loading and Susquehanna River flow condition discussed. The percentages indicated on the 1977 curves refer to the level of nitrogen reduction at the point sources on the lower Susquehanna River only, relative to their present levels. The discharges of the point sources of the Bay are the same for each 1977 curve. For a more detailed explanation see Chapter VII.

Figure IX-6 shows the total nitrogen distributions for a Susquehanna River flow of 2700 cfs (76.5 m^3/sec) (7-day 10-year low flow). The differences between the 1977 curves were so small as to make them virtually indistinguishable. In each curve, the high upstream boundary concentrations fall off rather sharply in spite of a somewhat low decay rate (0.01/day) due to the slow downstream transport at this very low freshwater flow level (allowing time for decay even at this low decay rate), the lack of any substantial nitrogen inputs between the Susquehanna and Baltimore areas, and dilution by the less nitrogen-rich water in the Bay. The high upstream boundary concentration for the 1985 curve, which represents a condition of complete point source elimination, shows the dominance of non-point sources of nitrogen relative to point sources on the lower Susquehanna River even at this low flow level. This dominance is observed to an even greater degree as the flow level increases (Figures IX-7 - IX-10). Not only does the 1985 upstream boundary

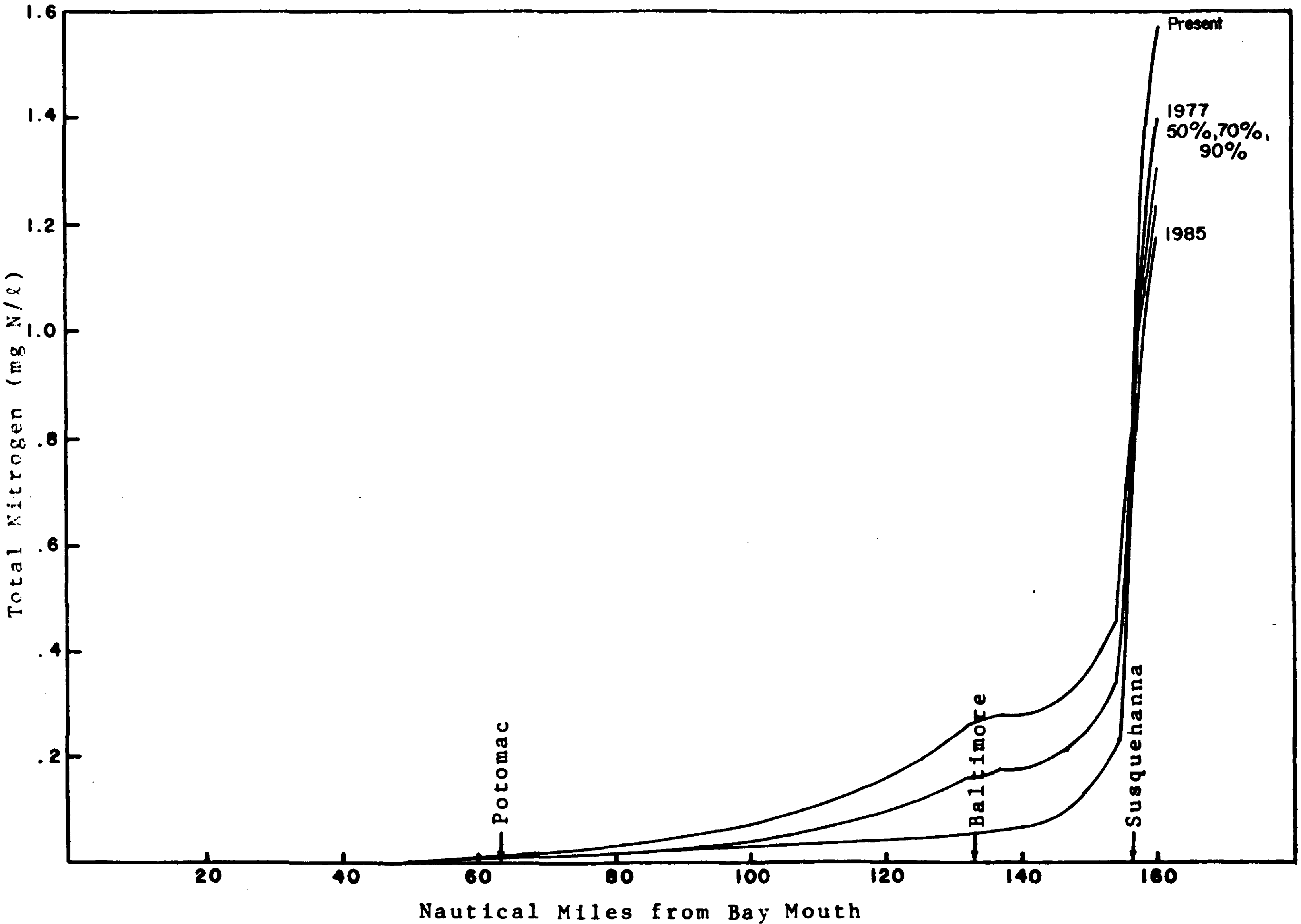

Figure IX-6. Model predictions of total nitrogen distribution for Susquehanna River flow of 2700 cfs.

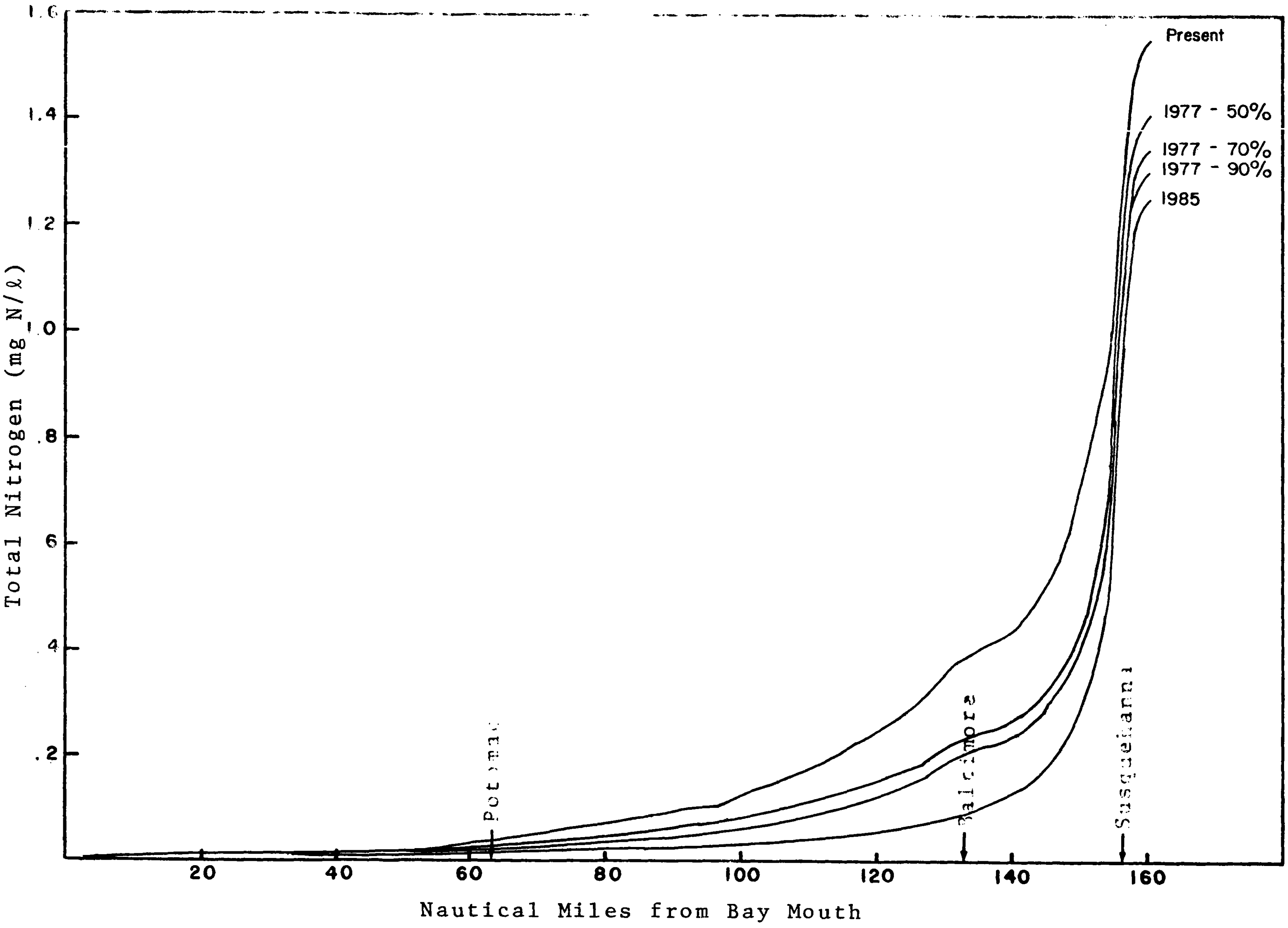

Figure IX-7. Model predictions of total nitrogen distribution for Susquehanna River flow of 6400 cfs.

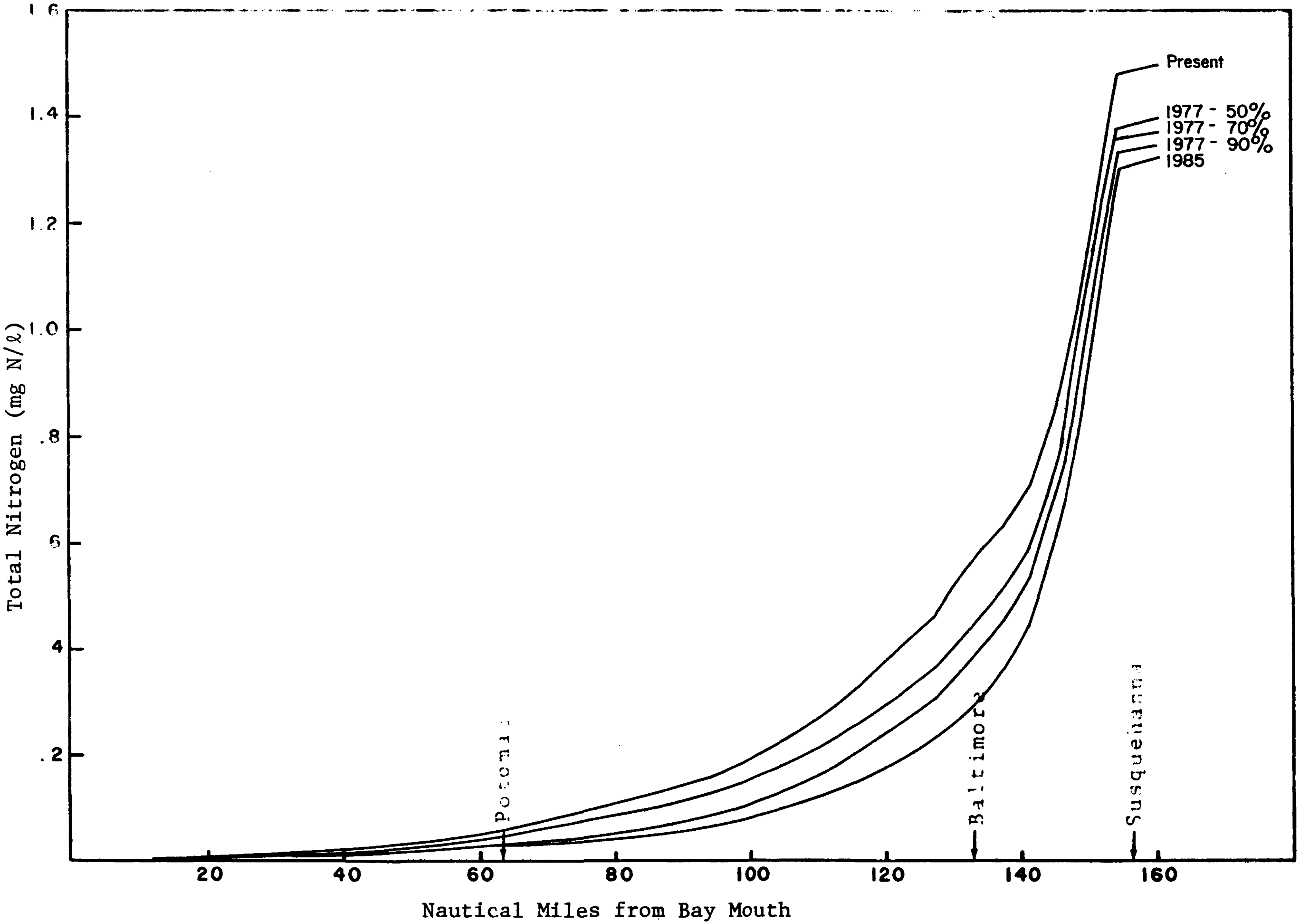

Figure IX-8. Model predictions of total nitrogen distribution for Susquehanna River flow of 25,100 cfs.

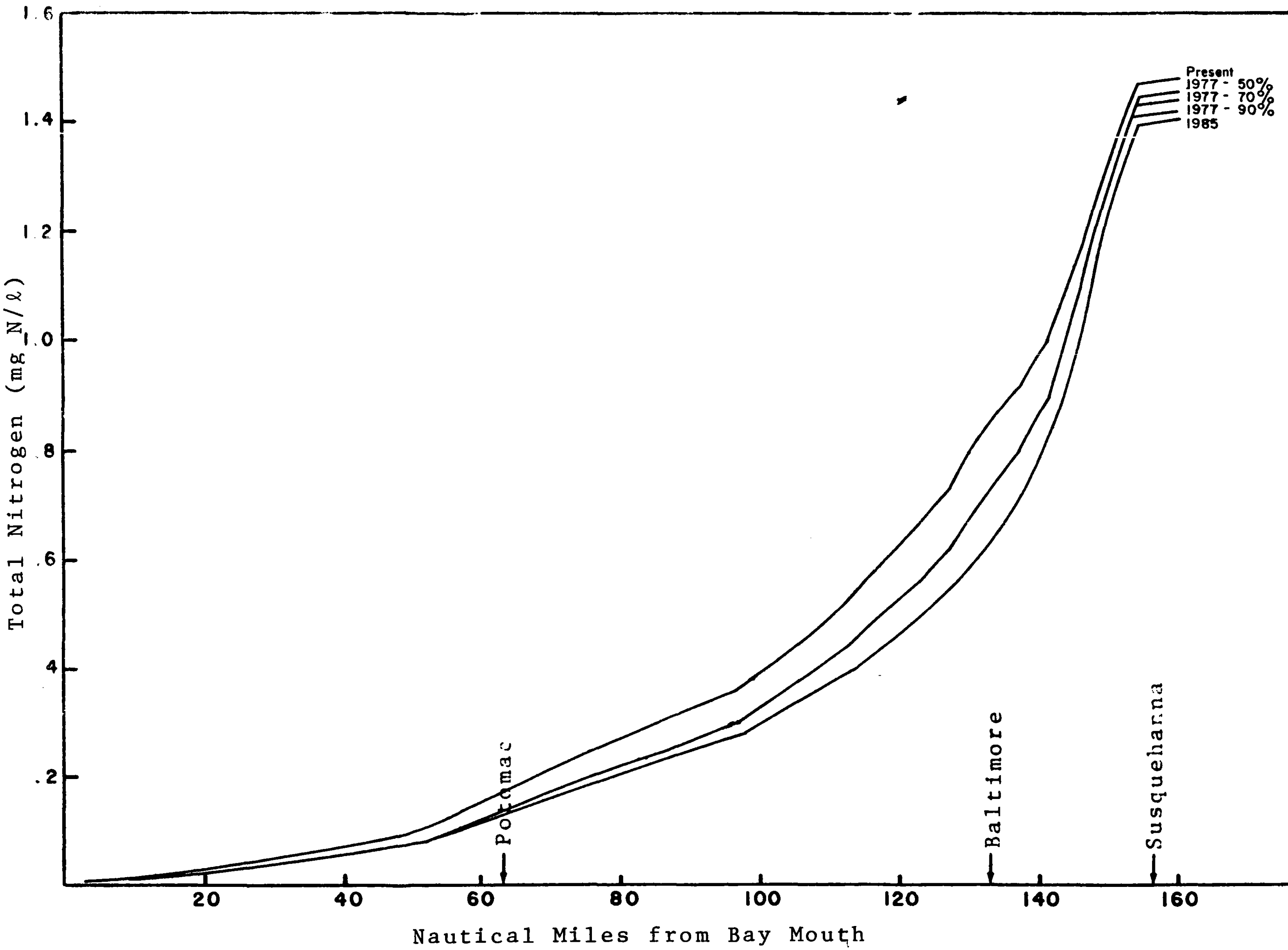

Figure IX-9. Model predictions of total nitrogen distribution for Susquehanna River flow of 38,600 cfs.

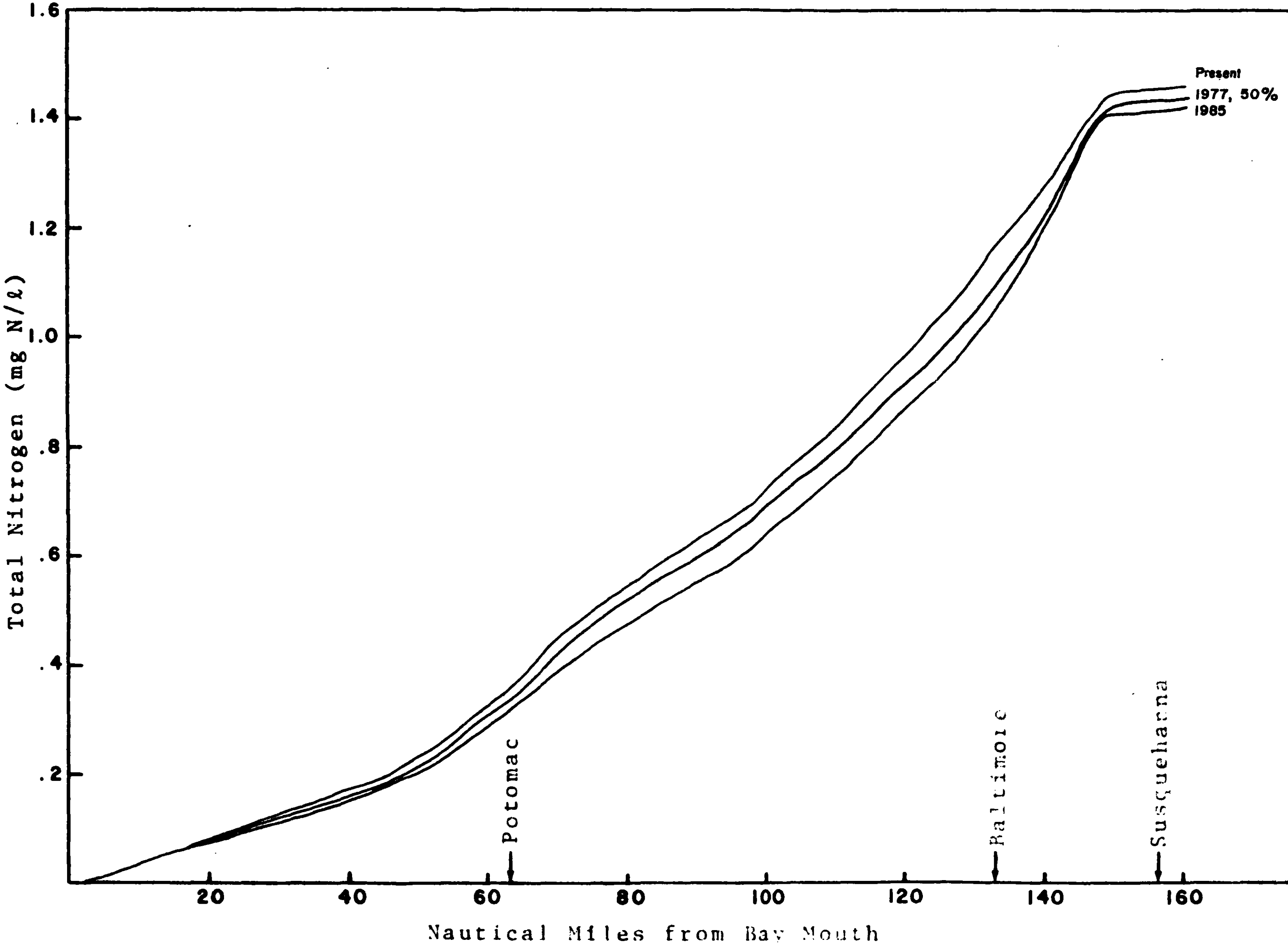

Figure IX-10. Model predictions of total nitrogen distribution for Susquehanna River flow of 70,300 cfs.

concentration rise with increasing freshwater flow, but also the difference between upstream boundary concentrations for the present and 1985 cases decreases with increasing flow.

The small peaks in the Baltimore Harbor area on the present and 1977 curves result mainly from point source nitrogen discharges, since the non-point source loadings on the Bay are negligible at this flow level. The impact of Baltimore point sources on the nitrogen distribution may be somewhat more moderate than indicated here, since some decay and settling of loadings occurs in the tributaries. Comparison of the present and 1977 curves show that the approximately 46% decrease in the Baltimore area point source nitrogen loading, combined with a 50% decrease in Susquehanna point source loading causes a 0.105 mg N/ℓ concentration decrease in the Baltimore area of the Bay.

The concentration predicted downstream of the Baltimore area falls off rapidly and becomes negligible below the mouth of the Potomac.

Figure IX-7, representing the predictions for the 6400 cfs (181 m^3/sec) Susquehanna flow level, shows a similar pattern. The decline of concentrations below the Susquehanna and Baltimore areas is somewhat blunted due to a more rapid downstream transport of nitrogen relative to the decay rate (which remains constant), a higher non-point source load in the Bay, and a smaller degree of dilution at this higher freshwater flow level. The higher concentrations in the Baltimore area for corresponding curves also result from these factors.

These trends - increased distance for concentration drops and higher concentrations in the Baltimore area (and throughout the Bay) - are manifest for each increase in freshwater flow level (Figures IX-8 - IX-10).

As in the case of phosphorus distribution, the system requires a lengthy period to reach equilibrium with respect to nitrogen for changing conditions, again due primarily to the small decay rate as compared to oxygen demanding organic material.

C. Dissolved Oxygen

Figure IX-11 shows the dissolved oxygen distributions under the condition of 2700 cfs (76.5 m^3/sec) Susquehanna flow (7-day 10-year low flow) and 27°C water temperature. Two DO sags exist for all three pollutant loading conditions. One sag is due to the loadings from the Susquehanna River and the other is due to the combined effect of Baltimore loadings and the higher benthic oxygen demand assumed for that portion of the Bay. For the 1977 loading condition, 50% point source reduction of nitrogenous BOD from the Susquehanna was used. The projected 1977 DO profiles with different degrees of point source reduction of NBOD may be estimated from the present and 1985 profiles, which are the lower and upper limits, respectively, corresponding to 0% and 100% NBOD point source reduction. The carbonaceous BOD contribution from the Susquehanna was assumed unchanged For a more detailed discussion see Chapter VII.

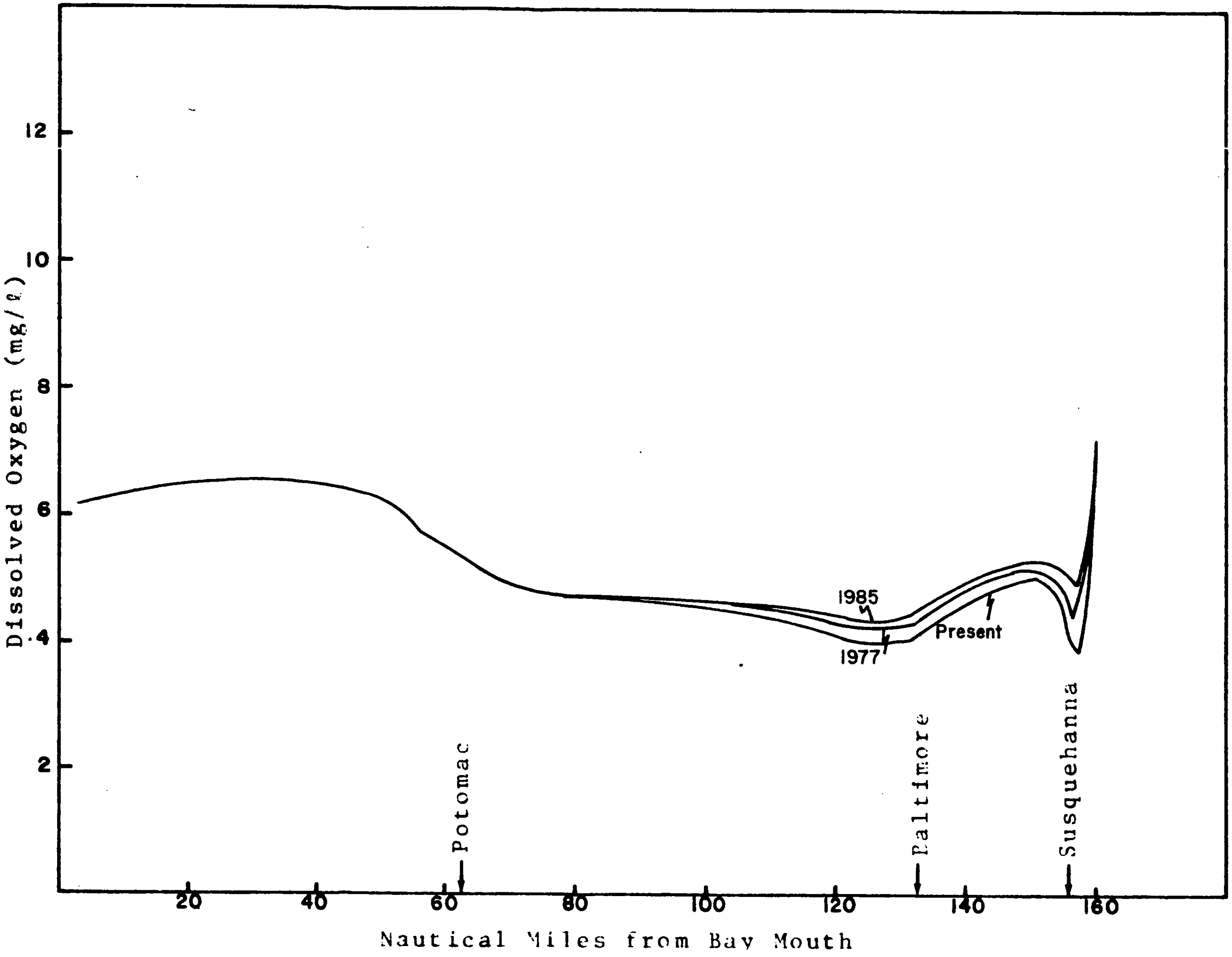

Figure IX-11. Model predictions of dissolved oxygen distribution for Susquehanna River flow of 2700 cfs.

The DO profiles show that the complete elimination of point sources will increase DO by about 1.0 mg/ℓ and 0.4 mg/ℓ at the first and second DO minima respectively. There is essentially no change in DO level throughout the lower Bay as the result of point source elimination.

Figure IX-12 shows the DO distributions under a 6400 cfs (181 m^3/sec) Susquehanna flow and a 27°C water temperature. The DO profiles under all three pollutant loading conditions are similar to those of the 2700 cfs (76.5 m^3/sec) freshwater flow condition, except that the levels of minimum DO are slightly higher.

Figures IX-13, IX-14, and IX-15 show the DO distributions under 25,100 cfs (710 m^3/sec), 38,600 cfs (1090 m^3/sec) and 70,300 (1990 m^3/sec) Susquehanna flows and 20°C, 10°C and 3°C water temperature respectively. There is no identifiable DO sag due to the pollutant loadings from the Susquehanna River because of the increased advection by higher freshwater flows. The location of minimum DO due to loadings from Baltimore migrates down the Bay as the flow increases. Because of the low water temperature at the times of high flow conditions, the DO concentration meets the water quality standard throughout the Bay proper.

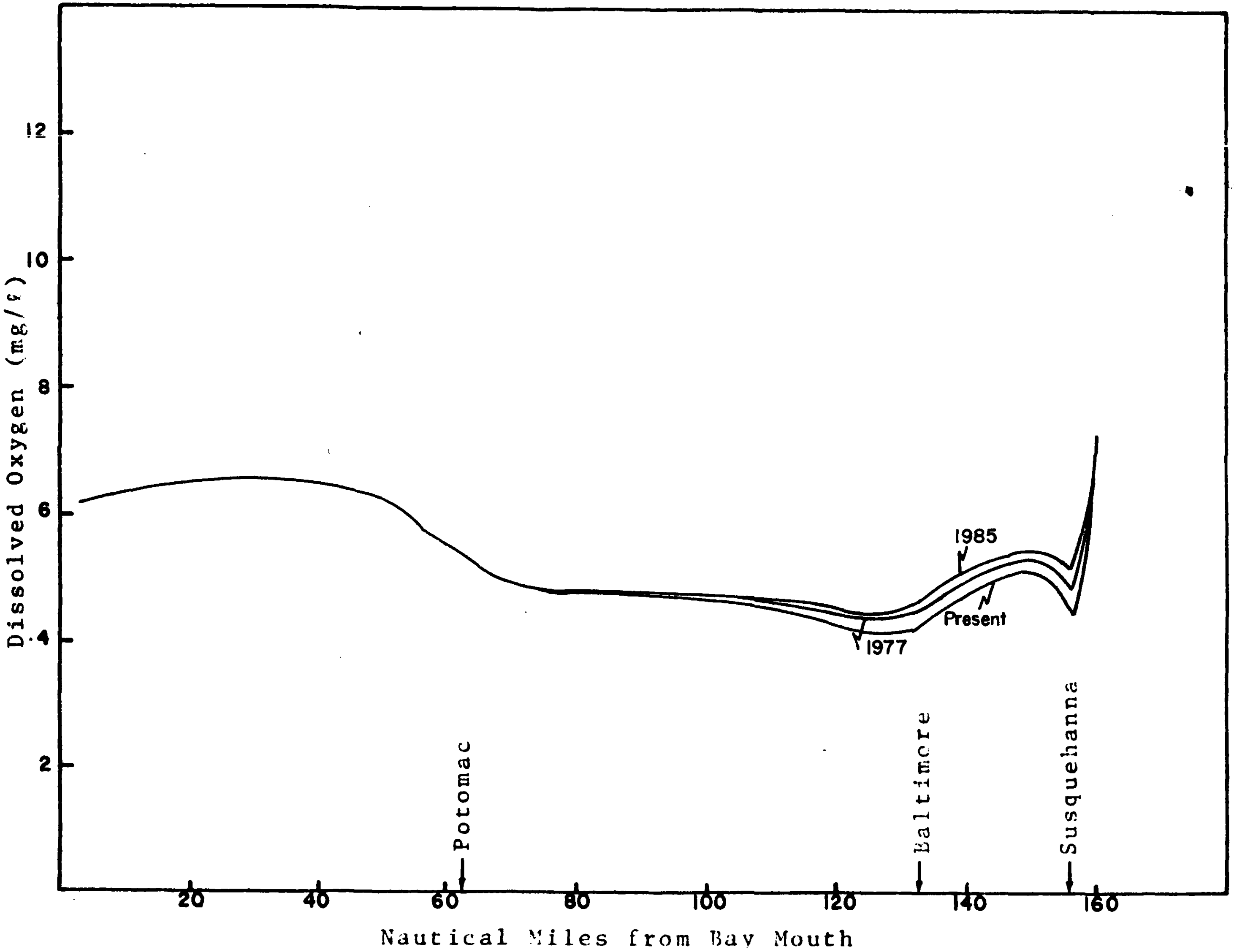

Figure IX-12. Model predictions of dissolved oxygen distribution for Susquehanna River flow of 6400 cfs.

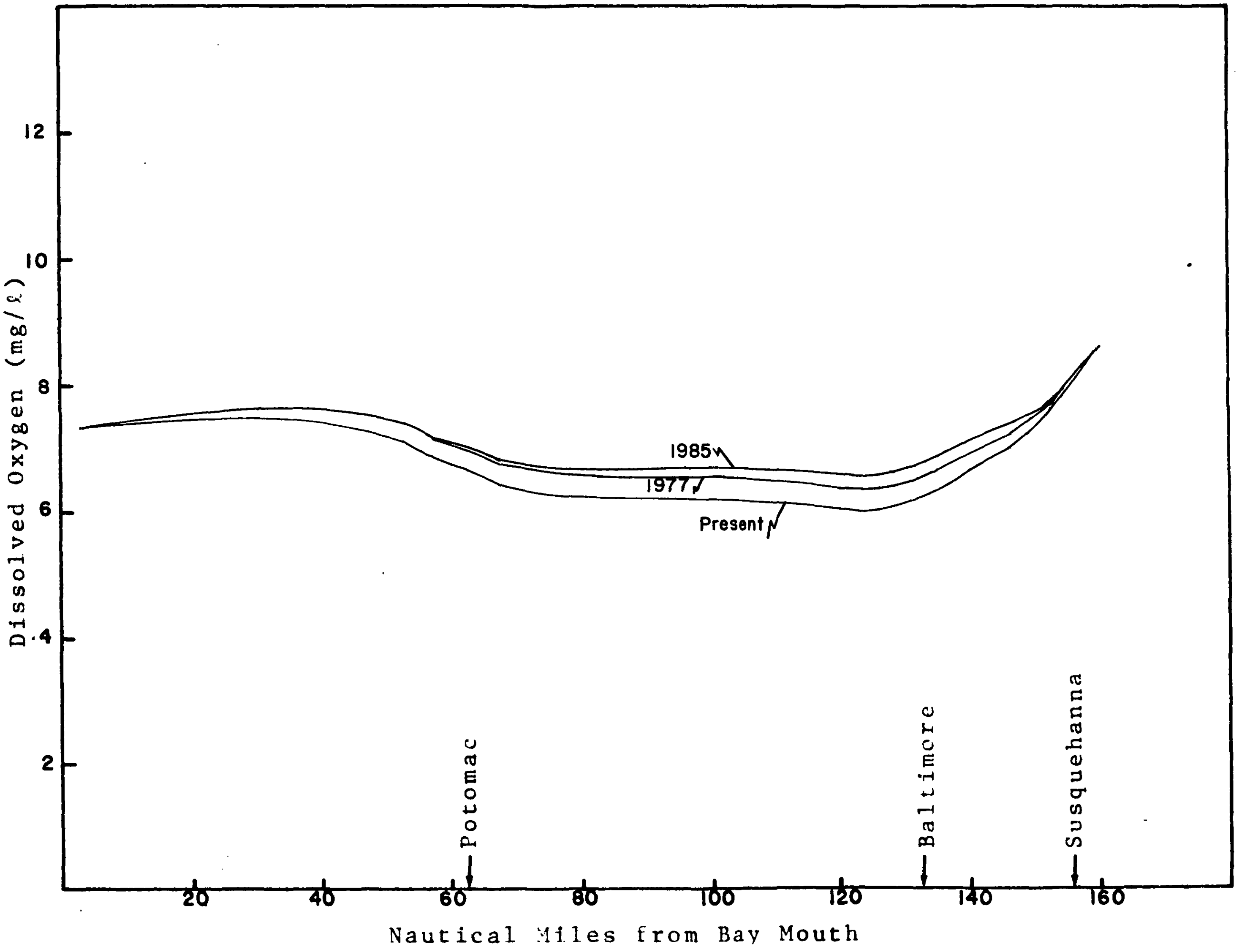

Figure IX-13. Model predictions of dissolved oxygen distribution for Susquehanna River flow of 25,100 cfs.

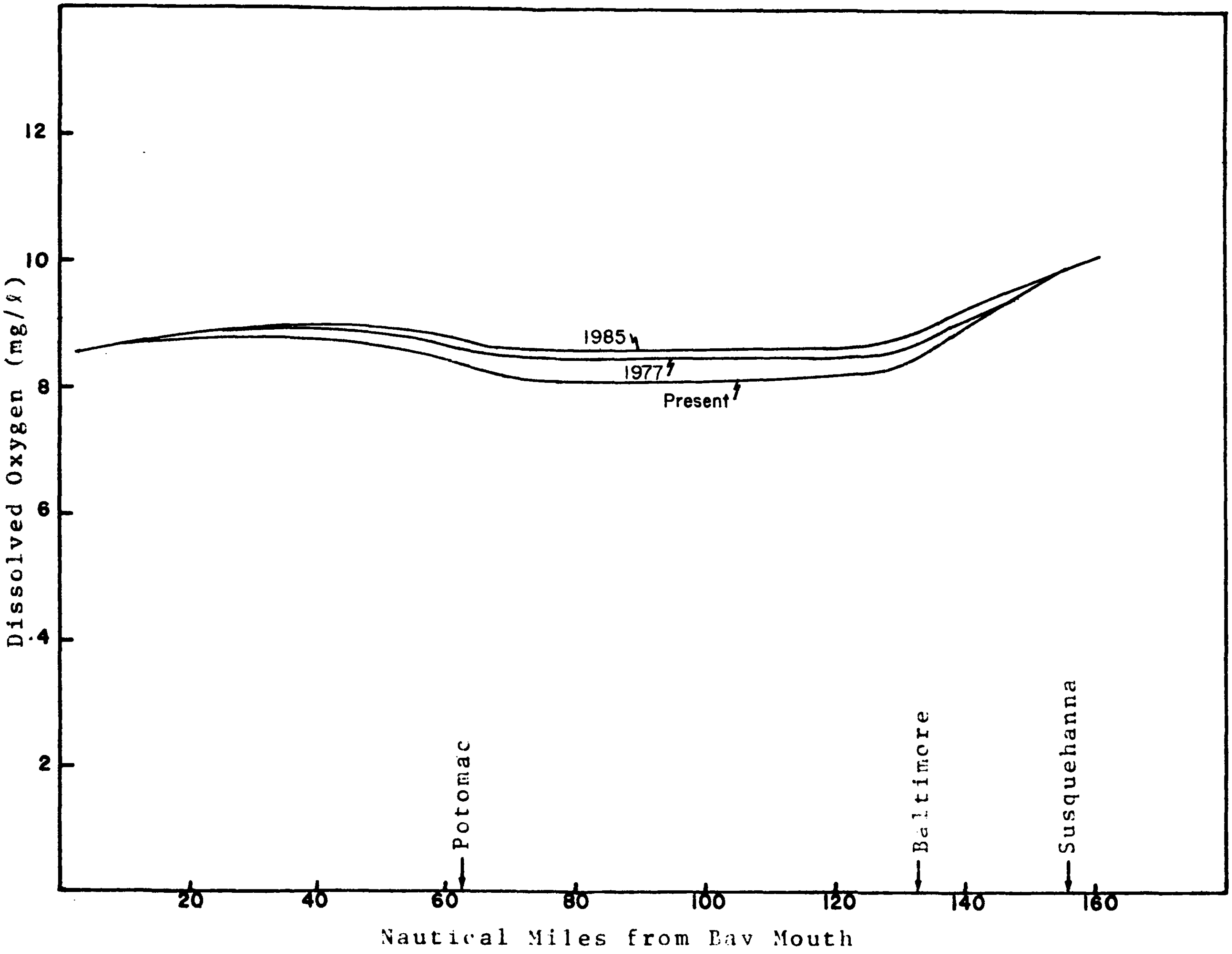

Figure IX-14. Model predictions of dissolved oxygen distribution for Susquehanna River flow of 38,600 cfs.

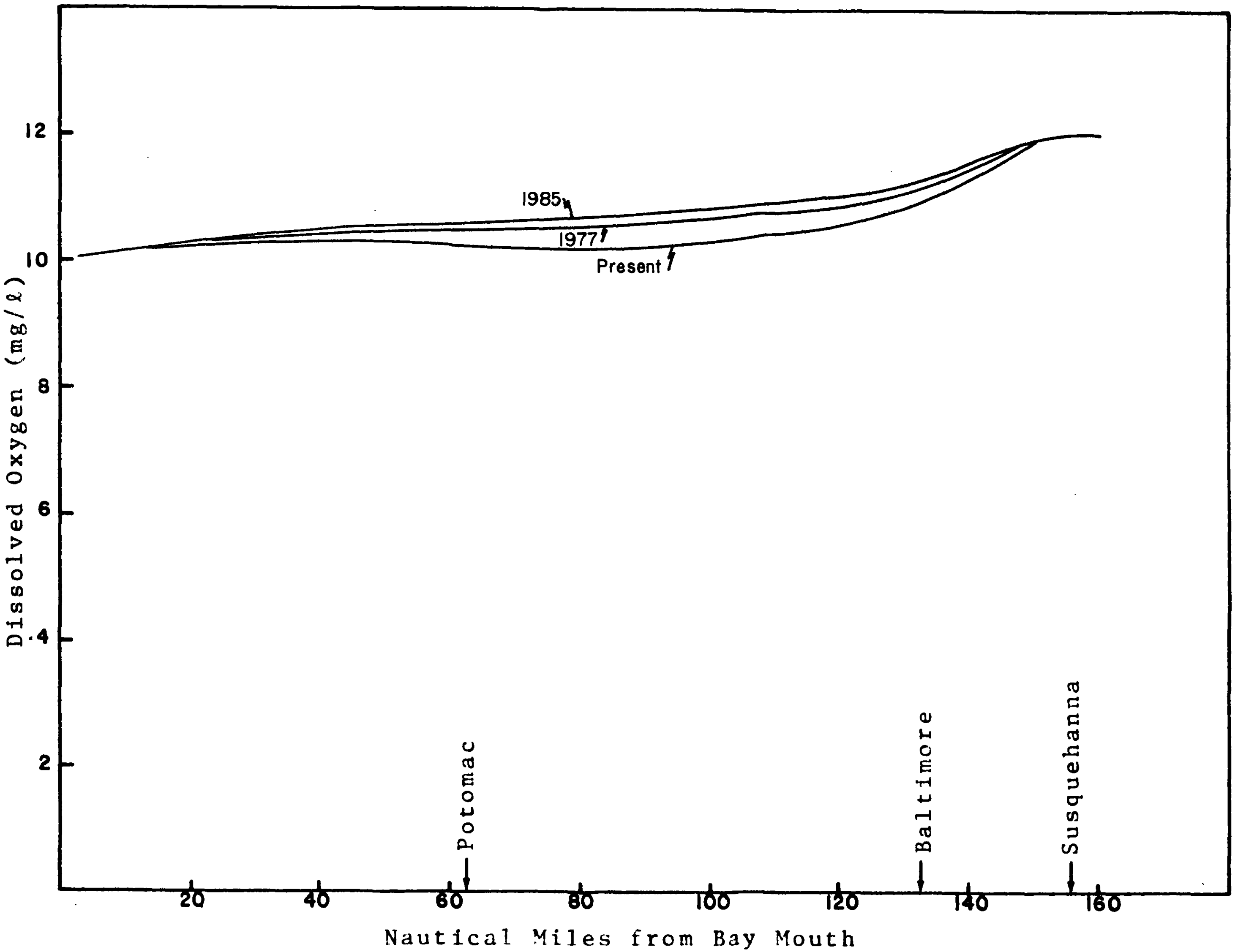

Figure IX-15. Model predictions of dissolved oxygen distribution for Susquehanna River flow of 70,300 cfs.

X. Comparison of Present and Projected Water Qualities to Federal and State Water Quality Standards

A. Data Sources and Limitations

The Maryland water quality standards were taken from the Maryland State Department of Natural Resources (1973) 08.05.04.01-08.05.04.11 Rules and Regulations. The Virginia standards are from the Virginia State Water Control Board (1974) Water Quality Standards. The Federal criteria are from EPA Proposed Criteria for Water Quality (1973).

B. Comparison

Coliform concentrations and their comparison to standards are discussed in Chapter XI . No field data for pH was available.

1. Dissolved Oxygen (DO)

Maryland class I waters (water contact recreation and aquatic life) and class II waters (shellfish harvesting) are subject to an oxygen standard of not less than 4.0 mg/liter at any time and not less than 5.0 mg/liter as a minimum daily average except where, and to the extent that, lower values occur naturally.

The Virginia portion of the Bay is classified as a class II water (Estuarine). The standard is therefore the same as in Maryland - 4.0 mg/liter minimum and 5.0 mg/liter minimum daily average except as a result of natural conditions "from time to time".

The proposed EPA criteria call for a minimum of 6.0 mg/liter except when temporary natural phenomena cause this value to be decreased, and an absolute minimum of 4.0 mg/liter.

As discussed in Chapter III, vertical average dissolved oxygen concentrations appear to drop below the 5 mg/liter (and 6 mg/liter) level only in the summer and early fall, the high temperature, low freshwater inflow season. At these times of violation there is naturally occurring extreme salinity stratification in the deep middle portions of the Bay. Vertical transport of oxygen is impeded and an oxygen concentration stratification results. Thus, with respect to DO, in the season of violations there exist two distinct layers at most stations deeper than 10 meters with DO concentration decreasing sharply below the 10 meter line.

Because the deep part of the channel is very narrow compared to width of the Bay as a whole, the DO concentrations of the upper layer alone are more representative of cross-sectional average DO values. The field data discussed in Chapter III (Taylor and Cronin 1974) show that the average DO concentration in the upper 4 meters always exceeded 5 mg/liter. The results of the water quality model reflect, for the most part, only the concentrations in the upper 10 meter layer.

The model results show violations of the 5 mg/liter standard under present loading conditions only for the two lowest freshwater inflow conditions (Susquehanna River flow of 2700 cfs and 6300 cfs). These violations, moreover, appear to result primarily from benthic oxygen demand and Susquehanna River BOD loadings. Most of the Susquehanna BOD loadings are generated by non-point sources. Reduction and/or elimination of point source BOD loadings, therefore, do not significantly improve the situation, according to the model predictions.

2. Ammonia

The EPA proposed criteria for ammonia is 0.1 of the 96-hour LC_{50} (concentration lethal to 50% of the test organisms) for the most important sensitive local species or 0.4 mg/liter. Since ammonia-nitrogen was not disaggregated from total nitrogen in this study it is difficult to discern whether the 0.4 mg/liter criteria is being violated. Where ammonia nitrogen field samples have been taken in the past (See data in Chapter III pertaining to 1969-1971) only occasional violations of the 0.4 mg/ℓ criteria have been observed, primarily in the summer months.

Studies by Clark, et al. (1974) indicate that the total Kjehldahl nitrogen (TKN) concentration at Conowingo, Maryland - the point of maximum Bay concentration - ranges from 0.62 to 1.00 mg/liter for the freshwater inflow levels considered in this study. The portion of TKN attributable to point sources varied between 69% for the 7-day 10-year low inflow condition to 17% for the high inflow condition. Since TKN is composed of both ammonia nitrogen and organic nitrogen, further field studies would be necessary to determine whether the ammonia criteria is being violated.

Literature Cited

Clark. L. J., V. Guide, and T. H. Pheiffer. 1974. Summary and conclusions from the forthcoming Technical Report 60 "Nutrient transport and accountability in the lower Susquehanna River basin". E.P.A. Annapolis Field Office, Region III.

Maryland State Department of Natural Resources. 1973. 08.05.04.01-08.05.04.11 rules and regulations promulgated by State of Maryland Water Resources Administration. Annapolis, Maryland.

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Virginia State Water Control Board. 1974. Water quality standards. Richmond, Virginia.

APPENDIX A

Table A-1 is a listing of point sources of pollutants significant to the Chesapeake Bay. Data for outfalls located in Maryland were compiled from information of the Maryland Water Resources Administration. All known Maryland point sources whose discharges enter the Bay or any portion of a bay tributary were included, with the exception of those falling into the Potomac River (Since the Potomac is being studied separately, the entire river is considered as a point source). Data for outfalls located in Virginia were compiled from office files of the Kilmarnock, Piedmont and Virginia Beach regional offices of the Commonwealth of Virginia Water Control Board. Similarly, all known Virginia point sources whose discharges enter the Bay or any tidal portion of a bay tributary were included -- with the exception of those entering into the Potomac.

The sources were grouped according to the Bay reach (as designated in the water quality mathematical model) which the effluent finally enters (see Table IV-1). Where known, the approximate distance from the relevant reach of the discharge has been indicated. This distance is particularly significant for non-conservative substances like biochemical oxygen demand (BOD), since their magnitudes may significantly diminish during the time spent in travel to the reach. Thus the impact on the Bay of a given level of BOD load would be expected to decrease with increasing distance from the Bay.

Where known, also, the state certified design flows - a rough indication of the magnitudes of the sources - has been indicated, although these flows may not coincide with actual flows.

Due to the multitude of point sources, more detailed information has been presented in Table A-2 only for the more significant sources. To that end in Table A-1 only those outfalls having design flows (or actual flows where design flows are unknown) greater than or equal to 0.5 million gallons per day (MGD) have been designated as major sources. Such sources are then examined further in Table A-2 0.5 MGD is equivalent to a municipal discharge in the population range of approximately 3300 to 5000. In the Maryland portion those sources not included in the major listings constituted less than 4% of the total flow from Maryland outfalls (not including the Potomac River). Although equivalent values for the Virginia outfalls cannot be estimated, the ratio of flows is likely to be similar.

In the expanded Table A-2 , where known, the type of activity associated with the source has been indicated. Known monthly average loadings of various constituents are presented. In the case of nutrients and BOD from Maryland outfalls, the values were calculated on the basis of flows and effluent concentrations. The flows of the Maryland outfalls are given as a composite average rather than monthly averages.

The total and fecal coliform values are reported in units of most probable number per 100 milliliters (MPN).

The monthly averages represent the geometric mean of all values reported for a month. Since the samplings are not done on a regular basis and since 9999.0 is a ceiling value, these reported monthly averages may not be accurate reflections of the true monthly average coliform concentrations.

Nutrient and coliform information was not available for Virginia outfalls.

Table A-1

POINT SOURCES OF POLLUTANTS ON THE CHESAPEAKE BAY

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
1	160-161	Susquehanna	Woodlawn Homes		0	0.06
			Benjamins Mobile Home Park		0	0.01
			Port Deposit		0	0.150
			Mt. Ararat Farm		0	0.02
2	159-160	Susquehanna	Bainbridge NTC	X	0	3.0
5	156-157	Susquehanna	Havre de Grace	X	0	1.5
6	153-156	Northeast	Northeast		4.5	0.3
			Morning Cheer Bible Camp		1.5	0.03
			Charlestown		0.8	0.187
			West Nottingham Academy		6.1	0.013
			Perryville	X	0.0	1.0
7	150-153	Swan Creek	Aberdeen	X	3.0	1.13
			Swan Harbor Dell Park		0.0	0.03
			Aberdeen Proving Grounds-Pusey		2.0	0.5
8	148-150	Spesutie Narrows	Aberdeen Proving Grounds-Ord.TC	X	0.0	2.8
		Elk	Thiokol Company		14.1	0.01
			Trinco Company		14.1	0.103
			Elkton	X	13.0	1.350
			Holly Hall		12.15	0.1
			Elk Neck State Park		3.0	0.108
			Chesapeake City-North		11.0	0.073
			Chesapeake City-South		11.0	0.087
			Chesapeake City-Corps		11.0	0.002
			Bohemia High School		9.0	0.015
			Cecilton		10.0	0.08
			Manchester Park			0.035

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
9	145-148	Sassafras	Galena		11.0	0.035
			Georgetown-Sas. Boat Co.		12.5	0.007
			Betterton		1.1	0.2
		Romney Creek	Sod Run	X	<2	4.0
			APG Phillips Field		<2	0.05
10	143-145	Bush River	Edgewood Arsenal	X	3.25	3.0
			Edgewood Biosensor			0.04
		Churn Creek	Worton School		4	0.045
11	140-143	Gunpowder River	Forge Heights		8.5	0.05
			Richlyn Manor		8.5	0.05
			River Valley Ranch		39.0	0.02
			Joppatown 1 & 2	X	8.0	0.75
			Manchester		40.0	0.25
			Hampstead		40.0	0.30
			Grunman Alc-Glenarm		14.8	0.005
			Koppers Co.-Glenarm		14.8	0.013
			Notchcliff Villa Maria Sanatorium		15.0	0.02
		Middle River	Martin Marietta Strawberry		2.5	0.015
12	135-140	Back River	Back River	X	9.0	70.
		Fairlee Creek	Fairlee		3.0	0.06
			Great Oaks Lodge		3.0	0.014
		Direct	Tolchester Nike Base 1 & 2		0.0	
13	130-135	Patapsco	Fort Smallwood		1.6	0.002
			Cox Creek	X	4.3	8.5
			Glidden Paint		4.4	0.004
			Ft. McHenry		8.7	
			Locust Pt. - Cafe		8.8	0.12
			Naval Research Center		8.9	0.12
			Patapsco	X	7.4	15.0
			Sea Land Service		7.5	0.002
			U. S. Gypsum		5.6	0.01
			Kennecott Ref. Co.		5.2	0.04
			U. S. Coast Guard	X	6.9	0.56

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
13 (cont'd)		Patapsco (cont'd)	Pitts-Des Moines Steel		8.0	0.002
			Holiday Mobil Estates-Jessup		16.0	0.10
			Koppers Co.-Hurman		16.1	0.012
			Severn Elementary School		16.1	0.01
			Parkway Ind. 1 & 2 - Dorsey		17.0	0.06
			State Roads Comm.-Brooklandville		19.3	0.008
			St. Timothy School		21.5	0.01
			Woodstock		15.2	0.04
			Mt. Airy		28.0	0.30
			Pheasant Ridge Mobil Estates		29.0	0.03
			Gaither Manor Apts.		18.5	0.045
			Henryton St. Hospital		18.5	0.07
			Sykesville Apts.		23.0	0.06
			Westinghouse-Sykes		23.0	0.018
			AT&T Finksburg		30.0	0.001
			Westminister	X	35.0	3.0
			Black & Decker-Hampstead		30.0	0.15
			S. Carroll High School		18.5	0.02
			Springfield St. Hospital	X	18.5	0.75
			Taylor Manor		20.0	0.018
			Allegheny Utility		15.0	0.001
			Md. School for Deaf-Columbia		15.0	0.018
			Waterloo		15.0	0.054
			Watermont Swim Club		15.0	0.02
			Dorsey		15.0	0.02
			Back River (Beth Steel)	X	5.2	120.0
			Montrose School			0.06
14	125-130	Chester	Chestertown	X	28.5	0.9
			Millington		42.5	0.07
			Centerville		20.6	0.375
			Queenstown		11.0	0.06
			E. Correctional Camp		24.0	0.03
			Sause Motor Inn (Kent Narrows)		6.1	0.024

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
15	120-125	Severn	Dreams Landing		5.0	0.02
			Annapolis	X	2.0	5.5
			Severn River Naval Command		2.5	0.4
			Bay Manor Nursing Home		3.5	0.023
			Charterhouse Motor Lodge		3.5	0.015
		Direct	Sandy Pt. Park		0.0	0.01
			Broad Neck		0.0	4.0
		Severn	Ft. Meade Ind.		1.5	
16	115-120	South	Crownsville St. Hospital		11.5	1.0
			Sum. Hill Trailer Park		10.0	0.019
			Mayo River Boat Motel		3.0	0.008
			Broad Creek-Riva		8.5	0.50
			Edgewater Elementary		5.5	0.06
			Woodland Beach		4.5	0.75
			Sylvan Shores		7.5	0.25
		Direct	Mayo School		0.0	0.009
		South	U. S. Coast Guard		1.0	0.008
17	110-115	West	Pirate's Cove		3.0	0.006
			Chesapeake Yacht Club		2.0	0.005
			Shadyside Ches. Inst. Co.		0.0	0.006
		Miles	St. Michaels		13.0	0.10
		Wye	Chesapeake College		22.0	0.015
		E. Bay	Islander Enterprises		8.7	0.021
			Stevens Village Utilities		8.7	0.04
		West	Patuxent Mobile Estates		2.0	0.02
		Direct	Bennett Crain		0.0	
18	105-110	Direct	Rose Haven		0.0	0.120
			N. Beach		0.0	0.20
			Tilghman School		0.0	0.004

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
19	100-105	Direct	Chesapeake Beach		0.0	0.15
			Randle Cliffs Naval Research		0.0	0.075
		Choptank	Greensboro		56.0	0.28
			Ridgely		51.0	0.20
			Denton		48.0	0.23
			Easton		34.0	7.0
			Preston		30.0	0.06
			Secretary		25.0	0.06
			E. NewMarket		26.0	0.03
			Cambridge	X	19.0	8.1
			Dorchester San. Dist. #1		17.0	0.74
			Trappe		15.0	0.09
			Oxford		13.0	0.112
21	90-95	Direct	Prince Fredrick		2.0	0.15
			Baltimore Gas & Electric		0.0	0.01
23	80-85	Patuxent	Wayson's Mobile Home Ct.			0.03
			Harwood SSHS		47.0	0.04
			Lyons Creek Mobile Home Estates		40.0	0.06
			Maryland City	X	63.0	0.75
			Maryland House of Correction-Jessup	X	70.0	0.60
			Parkway Manor Motel		65.0	0.015
			Patuxent	X	62.0	2.0
			Davidsonville Nike Base Housing		53.0	0.004
			Ft. Meade #1	X	65.0	2.1
			Ft. Meade #2	X	65.0	1.5
			Northern H.S.-Chaneyville		33.0	0.04
			Solomons Naval Ord.		6.0	0.20
			Central Farms- Univ. Md.		78.0	0.008
			JHU Lab.-Scaggsville		75.0	0.16
			Savage 1,2,3	X	70.0	1.67
			Transcontinental Gas-Ellicott		86.0	0.003
			W.R. Grade-Simpsonville		75.0	0.02
			Andrews Field Motel		50.0	0.005

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
23 (cont'd)		Patuxent (cont'd)	Belair Bowie	X	60.0	2.2
			Bowie St. Coll.		60.0	0.08
			Bowie Race Track		60.0	0.105
			Collington-Pointer Rd.	X	56.0	0.98
			Croom Voc. Sch. Adm.		44.0	0.001
			Croom Voc. Sch. Train.		44.0	0.001
			Hillmeade		60.0	0.072
			Marlboro Meadows		44.0	0.60
			Marlton		44.0	0.3
			Pepco-Chalk Pt.		24.0	0.01
			Tucker's Restaurant		50.0	0.01
			Wash. Nat. Arena		50.0	0.10
			Western Branch	X	50.0	5.0
			Andrews AF #3		50.0	0.48
			Cedar Pt. Officers Cl.		3.0	0.149
			Cedar Pt. Radar Sta.		1.0	0.0075
			Maryland Manor			0.07
		Little Patuxent	Waxter's Detention Center			0.007
		Patuxent	Burtonsville Elem. School			0.003
			Edgemeade School			0.005
			Edgemeade Adm.			0.005
			Parkway	X		4.5
			Patuxent Wildlife Hdqtrs.			0.025
			Patuxent Wildlife Res. Center			0.003
			Patuxent Wildlife Private Club			0.015
24	75-80	Direct	Pine Hill Run-Lex. Park	X	0.0	2.1
26	65-70	Direct	Pt. Lookout State Park		0.0	0.01
27	60-65	Direct	Potomac River	X	0.0	

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles from Bay Reach	Design Flow, MGD
29	50-55	Cockrell Creek	Std. Products Co.	X	< 3	4.4
			Haynie Products-Reedsville	X	< 3	8.64
			T.C. Slaughter Co.-Reedsville			0.01
30	45-50	Nanticoke	Vienna		47.0	0.06
			Sharptown		53.0	0.15
			Mardella H.S.		52.0	0.014
			Poplar Hill		38.0	0.02
		Wicomico	Salisbury	X	50.0	6.8
			Salisbury Police		52.0	0.005
			Fruitland	X	48.0	0.5
			Crown, Cork & Seal		48.0	0.02
			Delmar		56.0	0.30
		Nanticoke	Federalsburg		67.0	0.60
			Col. Richardson School		73.0	0.05
		Manokin	Princess Anne		31.0	0.35
			Westover-Eng. Grill		31.0	
		L. Amm.	Carvel Hall Cutlery		14.0	0.01
			Crisfield	X	14.0	1.0
			Sarah Peyton School		14.0	0.01
			U. Md. Seafood Lab.		13.0	0.001
		Pocomoke	Snowhill	X	27.0	0.50
			Pocomoke City	X	15.0	8.25
			Pocomoke City-Holiday Inn		15.0	0.015
			Pocomoke City - 76 Truck Stop		15.0	0.006
			Pocomoke City - Quality Courts		15.0	0.015
			Pocomoke City - Twin Towers		15.0	0.019
31	40-45	Antipoison	Va. Seafoods (Palmor)			0.0005
32	35-40	Rappahannock	Barnhardt Farms	X	13.0	
			FMC Corp-Fredericksburg	X	93.0	
			Fredericksburg STP	X	93.0	3.5
			Christ Church School		18.0	0.04
			S. Stafford Sanitary District		96.0	0.42

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
32 (cont'd)		Rappahannock	Tappahannock		37.0	0.2
			Urbanna		15.0	0.05
			Tidewater Mem. Hospital-Tappahannock		37.0	0.034
			Grafton Village		95.0	0.136
			Ferry Farms		93.0	0.12
			Levi-Strauss		40.0	0.04
			Kilmarnock		15.0	0.093
			Tides Inn		10.0	0.02
			Tides Golf Lodge		10.0	0.025
			Duffy Mott Co.			
			Washington Lee H.S.			0.014
			Correction Field Unit #17			0.012
			W. Norris Lowery			0.001
			Mosquito Creek Subdiv. & Marina			
			Rogue Pt. Subdiv.			
			Kilmer Pt. Develop.			
		Direct	Rapp. Community College			0.018
36	15-20	York	American Oil-Yorktown	X	4.0	
			VEPCO - Yorktown	X	7.0	
			Marine Env. Protect. West Point		29.0	0.3
			Camp Peary, N.		17.5	0.1
			Camp Peary, S.		16.5	
			Capehart Housing		13.0	0.185
			Naval Mine Depot	X	7-8.7	0.52
			Cheatham Annex		9.6	0.12
			Yorktown		8.0	0.1
			Coast Guard Res. & Train. Center		5.5	0.15
		Fox Mill Cr.	Gloucester Sanitary District			0.15
		Mobjack Bay	Matthews High School		7.0	0.01
			Thomas Hunter School		7.0	0.005
			Matthews Courthouse		7.0	0.01
		York	Colonial National Park		4.3	0.1
			Toano		21.7	0.015

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
36 (cont'd)		York	Congress Inn Motel			
			USN Weapons Testing Sta.			
		Pamunkey	Chesapeake Corp.	X	29.0	16.3
			Battlefield Park ES		62.0	
			Blue Star Estates		74.2	
			Kingwood Subdiv.		74.2	
			Convict Camp #14A		74.2	
			J. P. Barrett School		86.3	0.02
			Pearson Corner ES		86.3	
			Hanover School for Boys		87.2	0.04
			Hanover Courthouse		89.8	
		York	Achilles ES			0.006
			Gloucester H.S.			0.035
			Hamilton Holmes E.S.			0.006
		Direct	Matthews Corp.			0.01
37	10-15	Poquoson	Harwoods Mill Filtration Plant		< 3	
38	5-10	Back River	Big Bethel Reservoir		< 4	
			Langley AFB		< 4	
			York Crab and Oysters		< 4	
			Dawson Packing Co.		< 4	
			Ewell & Freeman Seafood		< 4	
		James	HRSD-Boat Harbor	X	8.7	12.0
			Yates ES		13.9	
			HRSD-James River	X	17.4	5.0
			Newport News City Farm		17.4	
			Jersey Park Subdiv.		17.4	0.001
			Smithfield E.S.		17.4	0.080
			Pinewood Hgts. Subdiv.		19.0	0.040
			Smithfield STP		21.0	0.2
			Reservoir E.S.		18.0	
			Stoneybrook Estates		18.0	
			U.S. Army Transportation Center Fort Eustis	X	21.7	2.95

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		James	Vepco-Surry		28.7	0.003
			HRSD-Williamsburg	X	29.5	9.6
			Berkeley H.S.		31.0	
			Birchwood Utilities		31.0	0.047
			Walthrop Trailer Park		31.0	
			Jamestown Foundation		34.7	0.08
			Town of Surry		35.6	0.008
			Ewell Hall Subdivision		36.5	0.120
			Eastern State Hospital	X	36.5	0.542
			Ruthville H.S.		53.8	
			Barnett's H.S.		58.2	
			Harrison L. National Fish Hatchery		58.2	
			Berkley Manor		60.8	
			North School		60.8	
			Riversedge Subdivision		62.5	0.04
			City of Hopewell	X	66.0	3.0
			U.S. Gov't.-Ft. Lee	X	66.0	1.6
			National Aniline Co.		66.0	
			Allied Chemical (Fiber Div.)		66.0	0.09
			Continental Can		66.0	0.120
			Hercules		66.0	0.11
			American Tobacco		67.5	0.022
			ICI America		67.5	0.009
			Varina E.S.		69.3	
			Harbour E. Mobile Homes		71.0	0.09
			VEPCO Power Station		75.3	
			Flippo's Trailer Park		75.3	
			Quail Oaks		75.3	0.228
			Ross Ford		75.3	
			Centralia Gardens		75.3	0.2
			Chester Lagoon		75.3	0.12
			Chesterfield Courthouse		75.3	0.03
			Reynolds Metals		75.3	0.02
			Jones Mechanical Co.		77.0	
			Bellwood Manor		77.0	0.208

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		James	Snowhite Motel		77.0	
			O. H. Robins		77.9	
			Baker E.S.		77.9	
			Varina H.S.		77.9	
			Pinecrest Ctr.		78.8	0.005
			Falling Creek STP	X	80.5	6.0
			Midlothian H.S.		80.5	
			E. I. DuPont		81.4	0.040
			City of Richmond	X	85.3	54.0
			Mobil Service Station		85.9	
			Hechler Village	X	85.9	0.5
			Lawndale Farms		85.9	0.12
			Sanitary District #3-Gilles Creek	X	85.9	0.5
			Henrico Volunteer Rescue Squad		85.9	
			Mobil Service Station		85.9	
			Champs Restaurant		85.9	
			Fass Bros. Fish Co.		0.04	
			Hampton Rds. Bridge Tunnel		0.43	
			USN Sewells Pt. Complex		0.43	
			Sheller-Globe Corp.		0.43	
			Hampton Paint Mfg. Co.		0.87	
			Ft. Monroe Cooling Towers		0.87	
			L. D. Amory & Co.		0.87	
			Clyde R. Royals Inc.		0.87	
			P. K. Hunt & Co.		1.04	
			Chesapeake Crab Co.		1.3	
			Hampton Roads Seafood Ltd.		1.3	
			Lawson Seafood Co.		1.7	
			Old Dominion Crab. Co.		5.6	
			Blake & Bass Seafood Co.		5.6	
			Benson-Phillips Co., Inc.		5.6	
			Martin & Richardson Seafood Co.		5.6	
			Nansemond-Adams Oyster Co.		8.9	
			N.N. Shipbuilding & Dry Doc. Co.	X	10.4	
			Lone Star (Benns Church)		15.6	
			Lee Hall Filtration Plant-N.N.		17.4	

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		James	Bendix Corp.		17.4	7.85
			Dow Badische	X	24.5	
			S.W. Edwards & Sons		35.9	
			Airco Industrial Gases		65.1	
			Hercules Inc.	X	65.1	
			Allied Chemicals (Agri. Div.)	X	65.1	
			Continental Can	X	65.1	
			Puremade Products		65.1	
			Allied Chemicals (Plastics)	X	65.1	
			Firestone Synthetic Fibers	X	65.1	
			Allied Chemicals (Fibers)	X	66.9	
			Lone Star (Shirley)	X	68.6	
			Sadler Materials Corp.		71.2	
			ICI America		70.2	
			Amer. Tobacco Co.	X	71.5	
			Lone Star (Curles Neck)	X	72.3	
			Lone Star (Jones Neck)	X	71.7	
			Lone Star (Varina)	X	72.2	
			Vepco (Chesterfield)	X	75.0	
			Reynolds Metals		75.1	
			Lone Star (Kingsland)	X	75.3	
			DuPont (James River Plant)	X	76.9	
			Koppers Co.		77.9	
			National Cylinder Gas		79.4	
			Texaco (Distribution)		79.6	
			DuPont Spruance	X	79.9	
			Texaco (Research)		81.0	
			Federal Paper Board Co.	X	83.2	
			Airco Welding		83.5	
			Richmond Guano		84.0	
			C&O Railroad		84.1	
			Lone Star (Dock St.)		84.7	
			Carter Sand & Gravel		84.7	
			Lehigh Cement		84.7	
			Vepco (12th St.)	X	85.4	
			James River Paper		86.0	

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		James	Battery Park Fish & Oyster		15.9	
			Smithfield Ham Co.		18.0	
			Smithfield Packing Co.	X	18.0	
			ITT Gwaltney	X	18.4	
		Elizabeth	HRSD-Army Base	X	15.9	11.0
			HRSD-W. Branch	X	8.5	2.0
			Portsmouth Coast Guard Base		8.5	
			City of Portsmouth-Pinners Pt.	X	10.2	15.0
			Intercoastal Steel		10.2	
			Poplar Hall Subdiv.		10.2	0.32
			Gulf Oil		11.9	
			Greenbriar Subdiv.		14.6	
			HRSD-Deep Creek	X	14.6	0.465
			HRSD-Washington	X	15.4	0.5
			Deep Creek School		15.4	
			Deep Creek E.S. & H.S.		16.3	
			Central E.S.		18.0	
			HRSD-Great Br.		18.9	0.25
			Convict Camp #22		18.9	0.012
			Oak Hill Convalescent Home		19.8	
			E. W. Chittum E.S.		13.4	
			Service Master Rug Cleaning		16.5	
			Indian River E.S. & H.S.		16.5	
			Woodstock E.S.		17.3	
			Carolanne Farms	X	18.2	0.760
			Wayside Motel		18.2	
			Kempsville Meadows		18.2	
			Holiday Inn Motel		18.2	
			Lakeville Estates		19.1	0.06
			Kempsville E.S.		19.1	
			St. Gregory's Catholic School		19.9	
			Kempsville Jr. H.S.		19.9	
			Kempsville Union		19.9	
			Chesapeake & Potomac Dial Bldg.		19.9	
			HRSD-Lambert's Pt.	X	8.5	20.0
			Humble Oil		5.4	

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		Elizabeth	USN Craney Island Fuel Factory		7.6	
			Va. Chemical, Inc.	X	8.8	
			Norfolk & Western Railroad		9.1	
			J. H. Miles Co.		10.0	
			Norfolk Coca-Cola Bottling		10.6	
			Norfolk Shipbldg. & Dry Dock		11.9	
			U. S. Gypsum		12.3	
			Norfolk Naval Shipyard	X	12.6	
			Proctor & Gamble		12.6	
			Gulf Oil		12.7	
			Lone Star		12.8	
			F. S. Royster	X	12.9	
			Atlantic Creosoting		13.3	
			Cargill, Inc.		13.5	
			Allied Feed Mills		13.7	
			Portsmouth Paving		13.8	
			Texaco, Inc.		13.9	
			Republic Cresoting		13.9	
			Eppinger & Russell	X	14.8	
			USN Weapons Station		15.0	
			Swift Agri. Chem.	X	15.5	
			Smith-Douglas Fertilizer	X	15.9	
			Weaver Fertilizer	X	16.2	
			Vepco (Portsmouth)	X	16.6	
			Vepco (Norfolk)	X	13.6	
			Norfolk Shipbuilding & Dry Dock		13.9	
			Lone Star		14.0	
			CPC International		14.0	
			Norfolk Shipbuilding & Dry Dock		14.2	
			H. B. Hunter		14.8	
			Ford Motor Company	X	14.4	
			Chevron Asphalt		15.9	
			Western Branch Diesel		10.0	
			Norfolk Coca-Cola Bottling		13.0	
		Chickahominy	Convict Camp #16		53.0	0.012
			New Kent E.S.		53.0	
			Menzel Bros.		48.6	

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		Appomattox	Enon Area		67.0	0.12
			Norax, Inc.		68.7	
			Ashton Creek Lagoon		71.3	0.4
			Old Stage Motor Lodge		71.3	
			Walthall Motel		71.3	0.020
			Sunoco Service Station		71.3	0.003
			Humble Oil Service Station		71.3	0.003
			Indian Hill Motel		71.3	
			Phillips 66 Service Station		71.3	
			John Tyler Community College		71.3	
			Fed. Reform.		72.2	0.1
			Harrougate E.S.		73.1	
			Allied Chemical Tech. Center		73.1	0.02
			Va. Baptist Children's Home		73.1	0.006
			Convict Camp #13		73.1	0.020
			Carver H.S.		73.1	
			City of Colonial Heights	X	73.1	1.0
			Matoaca Area		73.1	0.1233
			Matoaca H.S.		74.8	0.014
			Red Hill Trailer Park		75.7	0.045
			City of Petersburg	X	76.6	7.0
			Camelot Subdiv.		77.4	0.045
			Allied Chem. Tech. Ctr.		42.0	
			Lone Star (Dale Stone)		42.0	
			Lone Star (Puddledock)	X	74.4	
			Friend Sand & Gravel		74.8	
		Nansemond	Tidewater Community College		7.0	0.14
			Wynnewood Subdivision		9.7	0.046
			Senior Citizens Home		10.6	0.005
			Windsor H.S.		21.0	0.08
			Windsor E.S.		21.0	0.04
			Tyler H.S.		21.0	
			Isle of Wight Academy		21.0	0.045
			John F. Kennedy H.S.		23.6	0.015
			E. Suffolk Gardens		23.6	0.04
			Mt. Zion E.S.		23.6	
			Forest Glen H.S.		23.6	0.08

Reach No.	Nautical Miles From Bay Mouth	River Basin	Point Source	Major	Nautical Miles From Bay Reach	Design Flow, MGD
38 (cont'd)		Nansemond	Louise Obici Hospital		23.6	0.105
			City of Suffolk	X	23.6	2.0
			Yates E.S.	X	25.4	
			Eberwine Bros.		10.2	
			USN Radio Transmitter		7.7	
			Virginia Packing Co.		23.2	
			Portsmouth Paving Co.		23.6	
			Pruden Packing		24.1	
39	0-5	Lynnhaven	Sam Finley, Inc.		< 2	
		Direct	Little Creek Naval Base		0.0	
			Sadler Materials Corp.		0.0	
		Lynnhaven	Day E.S. & Cox H.S.		0.9	0.032
			Thalia E.S.		4.3	0.010
			Laskin Road Shopping Center		4.3	
			Birchwood Gardens	X	4.3	0.8
			Princess Anne H.S.		4.3	
			Tidewater Exec. Ctr.		4.3	
		Direct	White Heron Motel		0.0	0.012
			Little Creek E.S.		0.0	0.007
			Cardinal Estates		0.0	0.137
			HRSD-Oceana Naval Air Station	X	0.0	0.5
			Shapeco Shopping Center		0.0	
			Tarraliton E.S.		0.0	0.007
			Camellia Trailer Court		0.0	
			HRSD-Chesapeake - Elizabeth	X	0.0	20.0
			Linkhorn Park E.S.		0.0	

Table A-2

MONTHLY AVERAGE LOADINGS FROM MAJOR (>0.5 MGD) POINT SOURCE EFFLUENTS

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
2	Bainbridge NTC	0.0	1973	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.6												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)				3.6	3.6	4300	3.6		131				
Fec. Col. (MPN)				3.0	3.0	930	3.0		26				

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
5	Havre de Grace	0.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.4												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)					43			58					
Fec. Col. (MPN)					3.6			8.3					

MONTHLY AVERAGE LOADINGS FROM MAJOR (>0.5 MGD) POINT SOURCE EFFLUENTS

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
2	Bainbridge NTC	0.0	1974	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.6								
DO (ppm)		8.1							
BOD$_5$ (lbs/day)		60							
P-ortho (lbs/day)		14							
P-poly (lbs/day)		2.5							
P-tot. (lbs/day)		16.5							
Tot. Col. (MPN)		20							
Fec. Col. (MPN)		3.3							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
5	Havre de Grace	0.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	1.4								
DO (ppm)		7.45	9.00						
BOD$_5$ (lbs/day)		619	537						
P-ortho (lbs/day)		42	36						
P-poly (lbs/day)		35	37						
P-tot. (lbs/day)		77	74						
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
6	Perryville	1.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.0												
DO (ppm)												2.95	
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)			23	430	3	9300	1500	4300	1500			1500	
Fec. Col. (MPN)			3.6	43	3	430	43	2300	430			150	

7	Aberdeen	3.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.1												
DO (ppm)												5.0	
BOD_5 (lbs/day)												119	
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day													
Tot. Col. (MPN)					9999		93	2738	632				
Fec. Col. (MPN)					669		3	200	46				

8	Aberdeen Proving Ground Ord TC	0.0	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.6												
DO (ppm)												6	
BOD_5 (lbs/day)												85	
Tot. Col. (MPN)												9999	
Fec. Col. (MPN)												1500	

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
6	Perryville	1.0						1974			Municipal
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)	1.0									
	DO (ppm)		8.0	7.87							
	BOD_5 (lbs/day)		255	325							
	P-ortho (lbs/day)		23	28							
	P-poly (lbs/day)		13	9							
	P-tot. (lbs/day)		35	36							
	Tot. Col. (MPN)		4625								
	Fec. Col. (MPN)		525								
7	Aberdeen	3.0									Municipal
	Flow (MGD)	1.1									
	DO (ppm)		6.7								
	BOD_5 (lbs/day)		257								
	P-ortho (lbs/day)		42								
	P-poly (lbs/day)		6								
	P-tot. (lbs/day)		48								
	Tot. Col. (MPN)										
	Fec. Col. (MPN)										
8	Aberdeen Proving Ground Ord TC	0.0									Federal
	Flow (MGD)	0.6									
	DO (ppm)										
	BOD_5 (lbs/day)										
	Tot. Col. (MPN)										
	Fec. Col. (MPN)										

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
8	Elkton	13.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.9												
DO (ppm)												7.3	
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)			930	3.6	3.3	3.0	656	3.0	124		43	2300	
Fec. Col. (MPN)			23	3.0	3.0		3.0	3.0	26		3.0	1100	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
9	Sod Run	<2	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	3.2												
DO (ppm)													
BOD_5 (lbs/day)													
P-ortho (lbs/day)													
P-poly (lbs/day)													
P-tot. (lbs/day)													
Tot. Col. (MPN)					9999			9999	656				
Fec. Col. (MPN)					430			9999	190				

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
10	Edgewood Arsenal	3.25	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.6												
DO (ppm)													9.8
BOD_5 (lbs/day)													15
Tot. Col. (MPN)													3.6
Fec. Col. (MPN)													3.0

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
8	Elkton	13.0	1974	Municipal

	Comb	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.9								
DO (ppm)		8.5							
BOD_5 (lbs/day)		263							
P-ortho (lbs/day)		45							
P-poly (lbs/day)		12							
P-tot. (lbs/day)		57							
Tot. Col. (MPN)		58							
Fec. Col. (MPN)		17							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
9	Sod Run	<2	Municipal

	Comb	Jan	Feb
Flow (MGD)	3.2		
DO (ppm)		8	7.9
BOD_5 (lbs/day)		668	721
P-ortho (lbs/day)		179	179
P-poly (lbs/day)		29	37
P-tot. (lbs/day)		208	216
Tot. Col. (MPN)			
Fec. Col. (MPN)			

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
10	Edgewood Arsenal	3.25	Federal

	Comb
Flow (MGD)	0.6
DO (ppm)	
BOD_5 (lbs/day)	
Tot. Col. (MPN)	
Fec. Col. (MPN)	

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
11	Joppatown 1&2	8.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	.65												
DO (ppm)											3.95	3.4	8.4
BOD_5 (lbs/day)											57		22
NH_3-N											37		
NO_3-N											27		
NO_2-N											4		
P-ortho (lbs/day)											62		
P-poly (lbs/day)											4		
P-tot. (lbs/day)											66		
Tot. Col. (MPN)			230	930			93	462	656		727	3.6	
Fec. Col. (MPN)			43	3.0			3.6	3.0	99		93	3.0	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
12	Back River	9.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	70												
DO (ppm)											3.7		
BOD_5 (lbs/day)											5266		
Tot. Col. (MPN)											737	9999	1516
Fec. Col. (MPN)											136	6557	373

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Cox Creek	4.3	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	8.5												
DO (ppm)											6.5		5.4
BOD_5 (lbs/day)											425.6		893.8
NH_3-N													915.0
NO_3-N													730.6
NO_2-N													.709
Chloride													3638.8

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
11	Joppatown 1&2	8.0						1974			Municipal
	Flow (MGD)	.65									
	DO (ppm)		4.2	4.1							
	BOD$_5$ (lbs/day)		168	112							
	NH$_3$-N										
	NO$_3$-N										
	NO$_2$-N										
	P-ortho (lbs/day)		48	55							
	P-poly (lbs/day)		8	6.5							
	P-tot. (lbs/day)		56	61							
	Tot. Col. (MPN)		2300								
	Fec. Col. (MPN)		30								
12	Back River	9.0									Municipal
	Flow (MGD)	70									
	DO (ppm)										
	BOD$_5$ (lbs/day)										
	Tot. Col. (MPN)		1085								
	Fec. Col. (MPN)		136								
13	Cox Creek	4.3									Municipal
	Flow (MGD)	8.5									
	DO (ppm)		2.68	3.8							
	BOD$_5$ (lbs/day)		1950.6	2184.7							
	NH$_3$-N		1035.6	1021.4							
	NO$_3$-N										
	NO$_2$-N		.709	.851							
	Chloride		3674.3	3064.3							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
13 cont'd	Cox Creek	4.3	Municipal							1973						
	P-ortho (lbs/day)															295.1
	P-poly (lbs/day)															26.2
	P-tot. (lbs/day)															319.0
	Tot. Col. (MPN)						9999							43.0		
	Fec. Col. (MPN)						9990							23.0		
13	Patapsco	7.4	Municipal													
	Flow			17												
	DO (ppm)												2.9	4.1		
13	US Coast Guard	6.9	Federal													
	Flow (MGD)			.56												
	DO (ppm)												6.5	6.8	8.2	
	NH_3-N												116.8	79.4	50.5	
	NO_3-N															
	NO_2-N												.093	.047	.047	
	Chloride												630.9	1238.4	897.3	
	P-ortho (lbs/day)												32.7	32.7	22.9	
	P-poly (lbs/day)												1.4	1.4	.935	
	P-tot. (lbs/day)												34.1	34.1	23.8	
	Tot. Col. (MPN)					23	8.3	3.0	173	105	23	6.4	3.0	3.0	11.7	16.7
	Fec. Col. (MPN)					3.0	3.0		9999	624	190	4.7			83	43

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
13 cont'd	Cox Creek	4.3	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
P-ortho (lbs/day)		523.5	610.0						
P-poly (lbs/day)		58.1	38.3						
P-tot. (lbs/day)		581.3	645.1						
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Patapsco	7.4	Municipal

	Comp
Flow	17
DO (ppm)	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	US Coast Guard	6.9	Federal

	Comp	Jan	Feb
Flow (MGD)	.56		
DO (ppm)		6.6	7.5
NH_3-N		84.1	70.1
NO_3-N		.467	
NO_2-N		.047	.280
Chloride		1121.6	616.9
P-ortho (lbs/day)		24.3	22.0
P-poly (lbs/day)		20.6	.467
P-tot. (lbs/day)		26.2	22.4
Tot. Col. (MPN)		105	
Fec. Col. (MPN)		15	

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
13	Westminister	35.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.8												
DO (ppm)												9.6	
BOD_5 (lbs/day)												20.0	
Tot. Col. (MPN)										3.0			

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Springfield St. Hosp.	18.5	Hospital

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	.04												
DO (ppm)											4.55		2.1
BOD_5 (lbs/day)											10.7		8.3
Tot. Col. (MPN)							430		2300	3.6	93	430	
Fec. Col. (MPN)							230		3.6	3.0	9.1		43.0

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Back River (Bethel Steel)	5.2	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	133												
DO (ppm)											3.7		
BOD_5 (lbs/day)											8990.0		
Tot. Col. (MPN)											737	9999	1516
Fec. Col. (MPN)											136	6557	373

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
14	Chestertown	28.5	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	.6												
DO (ppm)										7.0			
Tot. Col. (MPN)			3.0	13.6	302	12.7		86	9.7	44	82	76	9.1
Fec. Col. (MPN)			3.0	3.0	6.6	3.0		25	4.5	3.2	3.7	5.2	3.3

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
13	Westminister	35.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.8								
DO (ppm)									
BOD_5 (lbs/day)									
Tot. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Springfield St. Hosp.	18.5	Hospital

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	.04								
DO (ppm)									
BOD_5 (lbs/day)									
Tot. Col. (MPN)									
Fec. Col. (MPN)									

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
13	Back River (Bethel Steel)	5.2	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	120								
DO (ppm)									
BOD_5 (lbs/day)									
Tot. Col. (MPN)		1085							
Fec. Col. (MPN)		136							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
14	Chestertown	28.5	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	.6								
DO (ppm)									
Tot. Col. (MPN)		3.3							
Fec. Col. (MPN)		3.0							

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
15	Annapolis	2.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	4.9												
DO (ppm)											2.34		
BOD$_5$ (lbs/day)											2167		
NH$_3$-N											654.2	572.5	
NO$_3$-N													
NO$_2$-N											.82	.82	
Chloride											12880.5	11040	
P-ortho (lbs/day)											200.4	134.9	
P-poly (lbs/day)											45.0	8.2	
P-tot. (lbs/day)											245.3	143.1	
Tot. Col. (MPN)				21.0	20	118	150	192	99	227	880	9.1	63
Fec. Col. (MPN)				7.3	3.0	3.0	9.1	27	29	72	188	3.0	18.3

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
19	Cambridge	19		Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	6.4												
DO (ppm)													
BOD$_5$ (lbs/day)													
Tot. Col. (MPN)			173		1320	230	230		9999	485	3811	67	41
Fec. Col. (MPN)			173		669	43	5.2		1500	51	244	656	10.4

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
23	Maryland City	63		Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	.85												
DO (ppm)										8.3	9.0	8.9	8.7
BOD$_5$ (lbs/day)													49.7
NH$_3$-N													
NO$_3$-N													
NO$_2$-N													
P-ortho (lbs/day)										67.4	49.7	38.3	20.8
P-poly (lbs/day)										4.3		2.1	2.8
P-tot. (lbs/day)										71.6	49.7	40.4	23.4
Tot. Col. (MPN)			8.7	68.7	37.7	67	57	413	8.1	140	726	309	3.5
Fec. Col. (MPN)			3.0	3.2	3.1	6.7	4.3	21.5	3.0	22	54	6.1	4.2

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
15	Annapolis	2.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	4.9								
DO (ppm)			3.55						
BOD$_5$ (lbs/day)			4089.1						
NH$_3$-N		572.5	572.5						
NO$_3$-N		5.32	6.5						
NO$_2$-N		.82	.82						
Chloride		5683.8	8259.9						
P-ortho (lbs/day)		49.1	167.7						
P-poly (lbs/day)		12.3	8.2						
P-tot. (lbs/day)		61.3	175.8						
Tot. Col. (MPN)		49							
Fec. Col. (MPN)		12							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
19	Cambridge	19	Municipal

	Comp	Jan	Feb
Flow (MGD)	6.4		
DO (ppm)		6.8	
BOD$_5$ (lbs/day)		2510.2	
Tot. Col. (MPN)		296	
Fec. Col. (MPN)		100	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Maryland City	63	Municipal

	Comp	Jan	Feb
Flow (MGD)	.85		
DO (ppm)		6.9	5.4
BOD$_5$ (lbs/day)			49.7
NH$_3$-N		106.4	99.3
NO$_3$-N		7.1	11.3
NO$_2$-N		.14	14.2
P-ortho (lbs/day)		55.7	25.5
P-poly (lbs/day)		4.6	2.1
P-tot. (lbs/day)		60.3	27.7
Tot. Col. (MPN)		43	
Fec. Col. (MPN)		3.1	

Reach No. Point Source Nautical Miles from Bay Reach Activity

23 Maryland House of Corrections 70.0 1973 Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	.60												
DO (ppm)										7.1	7.45		7.2
BOD_5 (lbs/day)											75.1		
NH_3-N													
NO_2-N													
P-ortho (lbs/day)										18.5	25.5		22.5
P-poly (lbs/day)										3.5	2.5		3.5
P-tot. (lbs/day)										22.0	28.0		26.0
Tot. Col. (MPN)			456	2365	41	26	78	193	58	72	29.0	65	79
Fec. Col. (MPN)			14	77	3.2	4.3	11.2	14.6	3.0	6.6	6.1	13.3	656

23 Patuxent 62 Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	2.2												
DO (ppm)										8.1	9.6	8.0	9.7
BOD_5 (lbs/day)													
P-ortho (lbs/day)										161.5	190.9	174.4	60.6
P-poly (lbs/day)										12.9	16.5		7.3
P-tot. (lbs/day)										174.4	207.5	174.4	67.9
Tot. Col. (MPN)			12	65	551	59	263	1087	175	87	1282	287	627
Fec. Col. (MPN)			3.0	5	10.6	3.7	15.8	99	21	6.6	42.5	14	58

23 Fort Meade #1 65.0 Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	1.8												
DO (ppm)										9.1	8.55	8.9	9.2
BOD_5 (lbs/day)											135.2		
P-ortho (lbs/day)										64.6	90.1	85.6	114.2
P-poly (lbs/day)										6.0	18.0		7.5
P-tot. (lbs/day)										70.6	108.2	85.6	121.7
Tot. Col. (MPN)			647	18	29	118	21	23	46	41	18	7	14
Fec. Col. (MPN)			33	3.1	4	11	3.0	7	7	6	4.1	3.9	4.5

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
23	Maryland House of Corrections	70.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	.60								
DO (ppm)		7.9	7.2						
BOD_5 (lbs/day)		160.2	120.2						
NH_3-N		40.1	38.1						
NO_3-N		2.3	3.9						
NO_2-N		.70	1.4						
P-ortho (lbs/day)		20.5	22.5						
P-poly (lbs/day)		5.0	5.5						
P-tot. (lbs/day)		25.5	28.0						
Tot. Col. (MPN)		15							
Fec. Col. (MPN)		3.0							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Patuxent	62	Municipal

	Comp	Jan	Feb
Flow (MGD)	2.2		
DO (ppm)		5.87	2.6
BOD_5 (lbs/day)		220.3	
P-ortho (lbs/day)		135.9	
P-poly (lbs/day)		15.6	
P-tot. (lbs/day)		151.5	
Tot. Col. (MPN)			
Fec. Col. (MPN)		3.1	

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Fort Meade #1	65.0	Federal

	Comp	Jan	Feb
Flow (MGD)	1.8		
DO (ppm)		9.0	6.8
BOD_5 (lbs/day)		195.3	225.3
P-ortho (lbs/day)		41.3	
P-poly (lbs/day)		10.5	
P-tot. (lbs/day)		51.8	
Tot. Col. (MPN)			
Fec. Col. (MPN)			

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity			
23	Fort Meade #2			65.0				1973			Federal			
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Flow (MGD)	1.5												
	DO (ppm)										8.9	7.8	8.6	9.8
	BOD_5 (lbs/day)											112.7		
	P-ortho (lbs/day)										63.9		73.9	57.6
	P-poly (lbs/day)										8.8		3.8	16.3
	P-tot. (lbs/day)										72.6		77.6	73.9
	Tot. Col. (MPN)			16	318	246	75	177	72	31	68	19	20	25
	Fec. Col. (MPN)			3	23	3.36	3.36	3.0	12	6	5	5	7	3.3
23	Savage 1, 2, 3			70.0							Municipal			
	Flow (MGD)	4.0												
	DO (ppm)										7.5	8.7	7.3	9.5
	BOD_5 (lbs/day)											100.1	600.8	267
	NH_3-N											3.3		
	NO_3-N											136.9		
	NO_2-N											.33		
	P-ortho (lbs/day)										233.7	242	140.2	120.2
	P-poly (lbs/day)										13.4	1.7		6.7
	P-tot. (lbs/day)										247.0	243.7	140.2	126.9
	Tot. Col. (MPN)			1732	232	294	545	477	396	298	359	131	371	285
	Fec. Col. (MPN)			100	12	8	15	18	24	22	40	13	42	15
23	Belair Bowie			60.0							Municipal			
	Flow (MGD)	2.37												
	DO (ppm)										7.55	7.4	8	7.1
	BOD_5 (lbs/day)										435.1		138.4	
	NO_3-N													3.6
	NO_2-N										3.6	3.4	3.0	2.8

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
23	Fort Meade #2	65.0	1974	Federal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	1.5								
DO (ppm)		9.0	6.8						
BOD_5 (lbs/day)		195.3	225.3						
P-ortho (lbs/day)		41.3							
P-poly (lbs/day)		10.5							
P-tot. (lbs/day)		51.8							
Tot. Col. (MPN)		13							
Fec. Col. (MPN)		3							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Savage 1, 2, 3	70.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	4.0								
DO (ppm)		9.5	6.8						
BOD_5 (lbs/day)		4906.9	433.9						
NH_3-N									
NO_3-N									
NO_2-N									
P-ortho (lbs/day)		250.4	130.2						
P-poly (lbs/day)		26.7	23.4						
P-tot. (lbs/day)		273.7	153.5						
Tot. Col. (MPN)		139							
Fec. Col. (MPN)		8							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Belair Bowie	60.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	2.37								
DO (ppm)		6.4	6.6						
BOD_5 (lbs/day)			395.6						
NO_3-N		1.98							
NO_2-N		2.0	1.8						

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
23 cont'd	Belair Bowie	60.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P-ortho (lbs/day)										235.4	215.6	245.2	245.2
P-poly (lbs/day)										19.8	9.9	4.0	25.7
P-tot. (lbs/day)										255.1	225.5	249.2	271
Tot. Col. (MPN)			5	5	4	181	979	74	1947	1282	157	10	21
Fec. Col. (MPN)			3.0	3.0	3.0	16	40	6	28	18	9	3.2	3.0

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Callington-Pointer Rd.	56.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	0.9												
DO (ppm)										7.45	7.0	9.85	7.2
BOD_5 (lbs/day)										112.7			
NO_3-N										151.0			
NO_2-N										.3	.3	.38	.23
P-ortho (lbs/day)										51.8	48.8	50.3	54.1
P-poly (lbs/day)										4.5	5.3	2.3	7.5
P-tot. (lbs/day)										56.3	54.1	52.6	61.6
Tot. Col. (MPN)			6557	260	997	1559	4635	2601	38	128	58	159	4
Fec. Col. (MPN)			177	5	140	18	44	11	3.0	3.0	3.1	161	3.0

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Western Branch	50.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)	5.5												
DO (ppm)										8.35		8.6	8.6
BOD_5 (lbs/day)										459		596.7	
NO_3-N										101			385.5
NO_2-N										29.8			29.8
P-ortho (lbs/day)										220.3		298.3	192.8
P-poly (lbs/day)										4.6		4.6	9.2
P-tot. (lbs/day)										224.9		302.9	201.9
Tot. Col. (MPN)			42	43	14	301	643	105	315	8234	1946	1117	3503
Fec. Col. (MPN)			4	3.1	3.9	3.1	25	3.4	6	969	401	201	32

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
23 cont'd	Belair Bowie	60.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
P-ortho (lbs/day)		219.5	213.6						
P-poly (lbs/day)		10.0	15.8						
P-tot. (lbs/day)		229.4	229.4						
Tot. Col. (MPN)		6							
Fec. Col. (MPN)		3.0							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Collington-Pointer Rd.	56.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	0.9								
DO (ppm)		8	8.9						
BOD_5 (lbs/day)									
NO_3-N									
NO_2-N		.08	.15						
P-ortho (lbs/day)		42.8	46.6						
P-poly (lbs/day)		6.0	6.0						
P-tot. (lbs/day)		48.8	52.6						
Tot. Col. (MPN)		6							
Fec. Col. (MPN)		3.0							

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity
23	Western Branch	50.0	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)	5.5								
DO (ppm)		9.45	9.1						
BOD_5 (lbs/day)		459							
NO_3-N		371.8	87.2						
NO_2-N		.46	.46						
P-ortho (lbs/day)		72.1	55.1						
P-poly (lbs/day)		32.1	4.6						
P-tot. (lbs/day)		75.3	59.7						
Tot. Col. (MPN)		663							
Fec. Col. (MPN)		6							

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity			
23	Parkway							1973						
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Flow (MGD)	4.7												
	DO (ppm)										4.55	4.8	10.6	7.9
	BOD_5 (lbs/day)										2078.7			
	NO_3-N													18.0
	NO_2-N										3.9	2.7	.39	.39
	P-ortho (lbs/day)										254.9	254.9	307.9	286.3
	P-poly (lbs/day)										15.7	15.7	11.8	19.6
	P-tot. (lbs/day)										270.6	270.6	319.7	305.9
	Tot. Col. (MPN)			11	40	27	54	111	209	45	425	50	34	101
	Fec. Col. (MPN)			3.0	3.0	3.0	3.2	3.2	8	4	16	3.0	3.2	3.1
24	Pine Hill Run			0.0							Municipal			
	Flow (MGD)	2.1												
	DO (ppm)										7.6		8.7	
	BOD_5 (lbs/day)										350.5		350.5	
	Tot. Col. (MPN)				29	750	75	9999		2300	230	93		686
	Fec. Col. (MPN)				9	15.0	3.6	9999		36	3.0	3.0		69
27	Potomac River										Major Tributary			

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
23	Parkway							1974			
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)	4.7									
	DO (ppm)		6.8	7.5							
	BOD_5 (lbs/day)										
	NO_3-N										
	NO_2-N		.39	.39							
	P-ortho (lbs/day)		254.9	211.8							
	P-poly (lbs/day)			23.5							
	P-tot. (lbs/day)		254.9	235.3							
	Tot. Col. (MPN)		21								
	Fec. Col. (MPN)		3.0								
24	Pine Hill Run			0.0							Municipal
	Flow (MGD)	2.1									
	DO (ppm)										
	BOD_5 (lbs/day)										
	Tot. Col. (MPN)		430								
	Fec. Col. (MPN)		19								
27	Potomac River										Major Tributary

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity			
30	Salisbury	50.0						1973			Municipal			
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Flow (MGD)	3.0												
	DO (ppm)										7.8	1.9	4.4	
	BOD$_5$ (lbs/day)										1977.8	1076.5		
	Tot. Col. (MPN)			7	37	40	150	150	14	32	26	25	14	20
	Fec. Col. (MPN)			3	5	4	15	4	3	6	3	4	3	3
30	Crisfield	14.0									Municipal			
	Flow (MGD)	.55												
	DO (ppm)										7.1		3.4	
	BOD$_5$ (lbs/day)										82.6			
	Tot. Col. (MPN)			56	2036	73	230	210	752	46	950	3	3145	31
	Fec. Col. (MPN)			4	343	9	37	10	46	43	63	3	254	3
30	Snowhill	27.0									Municipal			
	Flow (MGD)	.5												
	Tot. Col. (MPN)				9999		23	3	430	499	1626	146	162	200
	Fec. Col. (MPN)				9999		3.6	3.0	2.1	219	731	10	7	27
30	Pocomoke City	15.0									Municipal			
	Flow (MGD)	.63												
	Tot. Col. (MPN)			3.0		1100	4300	230						
	Fec. Col. (MPN)			3.0		3.6	230	11.0						
30	Fruitland	48									Municipal			
	Flow (MGD)	.12												
	Tot. Col. (MPN)			3	3	3	7	23	3	150	5	6	3	
	Fec. Col. (MPN)			3	3	3	3	3	3	23	3	3		

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Activity
									1974			
30	Salisbury	50.0										Municipal
	Flow (MGD)		3.0									
	DO (ppm)			9.0								
	BOD_5 (lbs/day)			525.7								
	Tot. Col. (MPN)			93								
	Fec. Col. (MPN)			9								
30	Crisfield	14.0										Municipal
	Flow (MGD)		.55									
	DO (ppm)			6.8	6.9							
	BOD_5 (lbs/day)											
	Tot. Col. (MPN)			230								
	Fec. Col. (MPN)			3.0								
30	Snowhill	27.0										Municipal
	Flow (MGD)		.5									
	Tot. Col. (MPN)			170								
	Fec. Col. (MPN)			19								
30	Pocomoke City	15.0										Municipal
	Flow (MGD)		.63									
	Tot. Col. (MPN)											
	Fec. Col. (MPN)											
30	Fruitland	48.0										Municipal
	Flow (MGD)		.12									
	Tot. Col. (MPN)			3								
	Fec. Col. (MPN)											

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Activity
29	Standard Products	<3							1973							Fish Processing
	Flow (MGD)												3.9	0	0	
	BOD_5 (lbs/day)												3990		0	
29	Haynie Products	<3														Fish Processing
	Flow (MGD)												11.2		0	
	BOD_5 (lbs/day)												7937		0	
32	Barnhardt Farms	13														Duck Farms
	Flow (MGD)															
	BOD_5 (lbs/day)															
32	FMC Corp - Fredericksburg	93														Petro-chemical
	Flow (MGD)									5.42	6.32	5.37				
	BOD_5 (lbs/day)									678	686	538				
32	Fredericksburg STP	93														Municipal
	Flow (MGD)									2.2	2.63	2.38				
	BOD_5 (lbs/day)									476	525	475				
36	American Oil - Yorktown 1&2	4														Refinery
	Flow (MGD)							52								
	BOD_5 (lbs/day)							2393								
36	VEPCO - Yorktown	7														Energy Production
36	Navy Mine Depot	7.87														Mine Depot

Reach No.	Point Source	Nautical Miles from Bay Reach										Activity
29	Standard Products	<3							1974			Fish Processing
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)			0	0	0	0	0.7	1.7	3.8	4.1	
	BOD_5 (lbs/day)			0	0	0	0	577	2390	3793	2490	
29	Haynie Products	<3										Fish Processing
	Flow (MGD)			0	0	0	0	1.3	8.1	6.6	4.8	
	BOD_5 (lbs/day)			0	0	0	0	119	848	941	682	
32	Barnhardt Farms	13										Duck Farms
	Flow (MGD)				1	1	1	1	1	1	1	
	BOD_5 (lbs/day)				787	763	777	241	451	333	275	
32	FMC Corp - Fredericksburg	93										Petro-chemical
	Flow (MGD)											
	BOD_5 (lbs/day)											
32	Fredericksburg STP	93										Municipal
	Flow (MGD)			2.5	2.2	2.2						
	BOD_5 (lbs/day)			596	495	468						
36	American Oil - Yorktown 1&2	4										Refinery
	Flow (MGD)											
	BOD_5 (lbs/day)											
36	VEPCO - Yorktown	7										Energy Production
36	Navy Mine Depot	7.87										Mine Depot

Reach No.	Point Source	Nautical Miles from Bay Reach	Activity	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				1973												
36	Chesapeake Corp	29	Pulp & Paper Manufacturing													
	Flow (MGD)															11.0
	BOD_5 (lbs/day)															37300
38	HRSD Boat Harbor	8.7	Municipal													
	Flow (MGD)				20.7	22.1	23.4	24.5	21.5	23.5	23.3	20.4	19.2	20.0	17.4	16.8
	BOD_5 (lbs/day)				16228	20090	22053	24111	18468	20775	20987	17864	18735	19682	20026	18915
38	HRSD James River	17.4	Municipal													
	Flow (MGD)				8.73	8.66	9.7	9.8	8.25	9.3	8.14	9.1	9.0	9.1	8.9	9.9
	BOD_5 (lbs/day)				1383	2383	2993	4087	3027	3801	1901	3253	1583	1670	1925	1818
38	US Army Transportation	21.7														
38	HRSD Williamsburg	29.5	Municipal													
	Flow (MGD)				3.3	3.8	3.9	4.5	5.1	5.4	5.4	5.6	5.6	5.7	5.1	4.5
	BOD_5 (lbs/day)				661	761	390	375	510	360	315	327	841	1236	1276	3002
38	Eastern State Hospital	36.5	Hospital													
38	City of Hopewell	66.0	Municipal													
	Flow (MGD)											3.4	3.05	2.55	2.6	3.0
	BOD_5 (lbs/day)											1750	1739	1763	1568	1952
38	US Government - Ft. Lee	66.0														

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
								1974			
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
36	Chesapeake Corp			29							Pulp & Paper Manufacturing
	Flow (MGD)		9.6	10.5	10.9	10.2	11.2	10.5	10.8	10.5	
	BOD_5 (lbs/day)		25141	34524	38317	37413	36606	36700	34876	36950	
38	HRSD Boat Harbor			8.7							Municipal
	Flow (MGD)		22.8	24.2	20.9	20.9		18.4			
	BOD_5 (lbs/day)		22438	18366	16385	17430		20716			
38	HRSD James River			17.4							Municipal
	Flow (MGD)		11.27	11.05	10.33	10.2		10.08			
	BOD_5 (lbs/day)		1880	1567	1120	1531		1345			
38	US Army Transportation			21.7							
38	HRSD Williamsburg			29.5							Municipal
	Flow (MGD)		4.7	4.8	4.8	4.7		4.5			
	BOD_5 (lbs/day)		2156	1841	4484	901		1839			
38	Eastern State Hospital			36.5							Hospital
38	City of Hopewell			66.0							Municipal
	Flow (MGD)		2.84	2.04		3.77	3.05	4.1			
	BOD_5 (lbs/day)		1477	1106		2070	2468	2380			
38	US Government - Ft. Lee			66.0							

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Activity
38	Falling Creek	80.5							1973							Municipal
	Flow (MGD)			4.1	5.0	4.3	4.5	3.5	2.9	2.9	3.3	2.9	2.9	2.8	4.6	
	BOD_5 (lbs/day)			410	542	359	300	233	193	193	193	121	218	280	384	
38	City of Richmond	85.3														Municipal
	Flow (MGD)				62.3	55.9	64.2	54.8	55.1	54.7	54.9	49	45.5	45	57.3	
	BOD_5 (lbs/day)			67863	40514	52203		48445	61129	48840	57244	24670	12513	9382	8602	
38	Hechler Village	85.9														Municipal
38	Sanitary District #3 - Gillie Creek	85.9														Municipal
38	Newport News Shipbuilding and Drydock Co.	10.4														Shipbuilding & Repair
38	Dow-Badische	24.5														Chemical Manufacturing (Fibers)
	Flow (MGD)													6.1	6.0	
	BOD_5 (lbs/day)													145	99	
38	Hercules Inc.	65.1														Chemical Manufacturing
	Flow (MGD)											5.77	3.22	7.28	6.48	
	BOD_5 (lbs/day)											15852.5	4218.7	17739.5	15908	
38	Allied Chemical (Agri Div)	65.1														Chemical

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
38	Falling Creek			80.5				1974			Municipal
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)		5.6	5.6	4.9	4.7	3.8	3.6			
	BOD_5 (lbs/day)		607	654	531	431	412	360			
38	City of Richmond			85.3							Municipal
	Flow (MGD)		63.6	62.1	55.1	66.3	54.6	51.5			
	BOD_5 (lbs/day)		8487	11400	17003	6082	2732	1718			
38	Hechler Village			85.9							Municipal
38	Sanitary District #3 - Gillie Creek			85.9							Municipal
38	Newport News Shipbuilding and Drydock Co.			10.4							Shipbuilding & Repair
38	Dow-Badische			24.5							Chemical Manufacturing (Fibers)
	Flow (MGD)		5								
	BOD_5 (lbs/day)										
38	Hercules Inc.			65.1							Chemical Manufacturing
	Flow (MGD)		8.85	8.78	7.5	8.22	7.33				
	BOD_5 (lbs/day)		23406	23365	24653	23034	18167				
38	Allied Chemical (Agri Div)			65.1							Chemical

Reach No.	Point Source	Nautical Miles from Bay Reach														Activity
38	Continental Can	65.1							1973							Wood Products Manuf
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Flow (MGD)										21.4	21.5		18.7	18.5	
	BOD_5 (lbs/day)										56432	41266		51185	33347	
38	Allied Chemical Plastics	65.1														Chem Manuf (Petro-chemicals)
	Flow (MGD)													33.6		
	BOD_5 (lbs/day)					4365								9386	18239	
38	Firestone Synthetic Fibers	65.1														Chem Manuf (Fibers)
	Flow (MGD)			.61	.61	.61	.61	.61	.61	.61	.61	.61	.61	.61	.61	
	BOD_5 (lbs/day)			3612	5301	2096	2508	3195	3617	10256	3897	3856	10048	5968	3520	
38	Allied Chemical (Fibers)	66.9														Chem Manuf (Petro)
38	Lone Star (Shirley)	68.6														Dredging
38	Amer. Tobacco Co.	71.5														Tobacco Sheet Paper Manuf
	Flow (MGD)											1.36		1.07	1.06	
	BOD_5 (lbs/day)										723	737		196	410	
38	Lone Star (Curles Neck)	72.3														Dredging
38	Lone Star (Jones Neck)	71.7														Dredging

Reach No.	Point Source	Nautical Miles from Bay Reach									Activity
38	Continental Can			65.1				1974			Wood Products Manuf
		Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
	Flow (MGD)		18.9	18.3	18.7	18.7	19.9	20.7			
	BOD$_5$ (lbs/day)		52679	48562	41354	44631	45170	27984			
38	Allied Chemical Plastics			65.1							Chem Manuf (Petro-chemicals)
	Flow (MGD)										
	BOD$_5$ (lbs/day)										
38	Firestone Synthetic Fibers			65.1							Chem Manuf (Fibers)
	Flow (MGD)		.61	.61	.61			.4			
	BOD$_5$ (lbs/day)		3027	2015	2488			2185			
38	Allied Chemical (Fibers)			66.9							Chem Manuf (Petro)
38	Lone Star (Shirley)			68.6							Dredging
38	Amer. Tobacco Co.			71.5							Tobacco Sheet Paper Manuf
38	Lone Star (Curles Neck)			72.3							Dredging
38	Lone Star (Jones Neck)			71.7							Dredging

Reach No.	Point Source	Nautical Miles from Bay Reach														Activity
38	Lone Star (Varina)	72.2							1973							Dredging
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
38	VEPCO (Chesterfield)	75.0														Energy Production
38	Lone Star (Kingsland)	75.3														Dredging
38	Dupont (James River Plant)	76.9														Chemical Manuf
38	Dupont-Spruance	79.9														Chem Manuf (Resins & Fibers)
	Flow (MGD)											44.9		37.7	31.4	
	BOD_5 (lbs/day)											179		387	51	
38	Federal Paper Board Co.	83.2														Paper
38	VEPCO (12th St)	85.4														Energy Production
38	Smithfield Packing Co.	18.0														Meat Packing
	Flow (MGD)													1.16	1.16	
	BOD_5 (lbs/day)													3773	3195	
38	ITT Gwaltney	18.4														Hogmeat Products
	Flow (MGD)													.80	.74	
	BOD_5 (lbs/day)													192	358	

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Activity
38	Lone Star (Varina)	72.2		1974								Dredging
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
38	VEPCO (Chesterfield)	75.0										Energy Production
38	Lone Star (Kingsland)	75.3										Dredging
38	Dupont (James River Plant)	76.9										Chemical Manuf
38	Dupont-Spruance	79.9										Chem Manuf (Resins & Fibers)
	Flow (MGD)			40.4	29.5	13.9	27.9	39.5	39.8			
	BOD_5 (lbs/day)			167	421	280	272	52	783			
38	Federal Paper Board Co.	83.2										Paper
38	VEPCO (12th St)	85.4										Energy Production
38	Smithfield Packing Co.	18.0										Meat Packing
	Flow (MGD)			1.28								
	BOD_5 (lbs/day)			2455								
38	ITT Gwaltney	18.4										Hogmeat Products
	Flow (MGD)			.77								
	BOD_5 (lbs/day)			263								

Reach No. Point Source Nautical Miles from Bay Reach Activity

Reach No.	Point Source	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
38	HRSD-Army Base			5.9				1973			Municipal			
	Flow (MGD)		15.4	16.6	16.8	16.0	13.8	13.1	13.7	15.7	13.5	12.7	11.8	12.9
	BOD_5 (lbs/day)		11302	11214	13030	13477	13120	12236	12683	13225	12385	12075	12892	13771
38	HRSD - Lambert's Pt.			8.5							Municipal			
	Flow (MGD)		28.2	29.9	28.8	28.8	23.3	23.7	23.4	26.7	22	20.4	19.9	23.2
	BOD_5 (lbs/day)		21167	21196	24259	23539	23513	23719	22443	25608	21650	24329	23235	28894
38	HRSD - Western Branch			8.5							Municipal			
	Flow (MGD)		2.03	2.0	1.98	1.9	1.5	1.6	1.56	1.7	1.6	1.3	1.7	1.9
	BOD_5 (lbs/day)		1674	1968	1651	1759	1808	1641	1561	1885	2068	1735	2523	2234
38	City of Portsmouth (Pinner's Point)			10.2							Municipal			
	Flow (MGD)									13.5	10.8		8.9	11.6
	BOD_5 (lbs/day)									8094	9917		7305	7616
38	HRSD - Deep Creek			14.6							Municipal			
	Flow (MGD)		.584	.73	.580	.558	.390	.407	.357	.410	.335	.335	.3	.488
	BOD_5 (lbs/day)		253	219	174	121	94	108	197	226	341	151	161	248
38	HRSD - Washington			15.4							Municipal			
	Flow (MGD)		.707	.7	.723	.596	.420	.525	.472	.423	.328	.292	.3	.6
	BOD_5 (lbs/day)		489	461	308	497	490	670	433	551	422	395	336	592

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Activity
38	HRSD-Army Base	5.9							1974			Municipal
	Flow (MGD)			15	16.2	15.7	16.5		14.2			
	BOD_5 (lbs/day)			13010	12025	12832	12935		14685			
38	HRSD - Lambert's Pt.	8.5										Municipal
	Flow (MGD)			26.2	28.0	27.8	32.6		25.4			
	BOD_5 (lbs/day)			26876	24052	22721	31810		27962			
38	HRSD - Western Branch	8.5										Municipal
	Flow (MGD)			2.1	2.1	2.1	2.3		1.8			
	BOD_5 (lbs/day)			2119	1962	1856	2263		2087			
38	City of Portsmouth (Pinner's Point)	10.2										Municipal
	Flow (MGD)			12.9	13.22	12.11	12.95		10.89			
	BOD_5 (lbs/day)			10205	10254	12221	14688		18165			
38	HRSD - Deep Creek	14.6										Municipal
	Flow (MGD)			.52								
	BOD_5 (lbs/day)			274								
38	HRSD - Washington	15.4										Municipal
	Flow (MGD)			.66								
	BOD_5 (lbs/day)			319								

Reach No.	Point Source	Nautical Miles from Bay Reach	1973													Activity
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
38	Carolanne Farms	18.2														
	Flow (MGD)													.6	.65	
	BOD_5 (lbs/day)													124	269	
38	Va. Chemical Inc.	8.8														Chemical Manuf
	Flow (MGD)													1.4	1.2	
	BOD_5 (lbs/day)													642	745	
38	Norfolk Naval Shipyard	12.6														Shipbuilding & Repair
38	Atlantic Creosoling	13.3														Wood Preservation
38	Eppinger & Russell	14.8														Lumber
38	Swift Agricultural Chemical	15.5														Chemical Manuf
38	Smith-Douglas Fertilizer	15.9														Fertilizer
38	Weaver Fertilizer	16.2														Fertilizer
38	VEPCO (Portsmouth)	16.6														Energy Production
38	VEPCO (Norfolk)	13.6														Energy Production
38	Ford Motor Co.	14.9														Auto Assembly

Reach No.	Point Source	Nautical Miles from Bay Reach						1974			Activity
			Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
38	Carolanne Farms	18.2										
	Flow (MGD)			.65								
	BOD_5 (lbs/day)			102								
38	Va. Chemical Inc.	8.8										Chemical Manuf
	Flow (MGD)			1.017								
	BOD_5 (lbs/day)			1247								
38	Norfolk Naval Shipyard	12.6										Shipbuilding & Repair
38	Atlantic Creosoling	13.3										Wood Preservation
38	Eppinger & Russel	14.8										Lumber
38	Swift Agricultural Chemical	15.5										Chemical Manuf
38	Smith-Douglas Fertilizer	15.9										Fertilizer
38	Weaver Fertilizer	16.2										Fertilizer
38	VEPCO (Portsmouth)	16.6										Energy Production
38	VEPCO (Norfolk)	13.6										Energy Production
38	Ford Motor Co.	14.9										Auto Assembly

Reach No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Activity
38	City of Colonial Heights	73.1							1973							Municipal
	Flow (MGD)														1.7	
	BOD_5 (lbs/day)														2844	
38	City of Petersburg	76.6														Municipal
	Flow (MGD)									5.5	4.4	4.2	3.7	4.3	6.5	
	BOD_5 (lbs/day)									5000	3926	4168	3456	3550	6072	
38	Lone Star (Puddledock)	74.4														Sand & Gravel
38	City of Suffolk	23.6														Municipal
	Flow (MGD)			2.1		2.29	1.70	1.34	1.33	1.20	1.14	.85	.81	.77	.96	
	BOD_5 (lbs/day)			963		1605	806	1697	1057	561	1054	666	1050	938	650	
38	Yates E.S.	25.4														
	Flow (MGD)				1.14	.85		.77	.96							
	BOD_5 (lbs/day)				1054	666		939	650							
39	Birchwood Gardens	4.3														Municipal
	Flow (MGD)															
	BOD_5 (lbs/day)															
39	HRSD - Oceana Naval Air St.	0.0														Municipal
	Flow (MGD)			.9	.9	.9	1.1	1.07	1.0	.8	1.1	1.3	1.3	1.4	1.5	
	BOD_5 (lbs/day)			83	180	98	183	214	92	160	404	542	651	1005	826	

each No.	Point Source	Nautical Miles from Bay Reach	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Activity
38	City of Colonial Heights	73.1							1974			Municipal
	Flow (MGD)							1.6	1.5			
	BOD_5 (lbs/day)							2569	2145			
38	City of Petersburg	76.6										Municipal
	Flow (MGD)			7.5	6.8	6.2	5.4	5.3	4.9			
	BOD_5 (lbs/day)			7381	5501	6412	7296	6011	5313			
38	Lone Star (Puddledock)	74.4										Sand & Gravel
38	City of Suffolk	23.6										Municipal
	Flow (MGD)			1.09	1.195	1.34	1.35		.760			
	BOD_5 (lbs/day)			544	568	1218	1068		482			
38	Yates E.S.	25.4										
	Flow (MGD)											
	BOD_5 (lbs/day)											
39	Birchwood Gardens	4.3										Municipal
	Flow (MGD)			.55								
	BOD_5 (lbs/day)			161	163	142	168	164	173	147	151	
39	HRSD - Oceana Naval Air St.	0.0										Municipal
	Flow (MGD)			921	340	411	638	531	445	320	73	
	BOD_5 (lbs/day)											

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
39	HRSD Chesapeake-Elizabeth	0.0	1973	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (MGD)		12.5	14.0	14.8	13.7	12.1	12.2	12.5	12.6	10.1	11.1	8.2	9.6
BO_5 (lbs/day)		4796	6422	8887	9141	7266	7529	7506	9043	9271	7684	5543	6489

Reach No.	Point Source	Nautical Miles from Bay Reach		Activity
39	HRSD Chesapeake-Elizabeth	0.0	1974	Municipal

	Comp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Flow (MGD)		11.5							
BOD_5 (lbs/day)		8728							