Volumetric Analysis of Dissolved Oxygen Trends in the Chesapeake Bay: Preliminary Findings

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ABSTRACT

Anoxia has long been a problem in Chesapeake Bay. Scientists and both state and federal managers are concerned about the extent of anoxia, its lethal effects on living resources, and associated changes in water and sediment chemistry. This report examines variations in dissolved oxygen from 1950 to the present to determine historical trends and evaluate progress in restoring the health of the Bay.

A three-dimensional interpolator was used to estimate dissolved oxygen, phytoplankton biomass (as chlorophyll *a*), dissolved inorganic nitrogen, and dissolved inorganic phosphorus throughout the Bay. The three-dimensional grids of estimated concentrations were used to construct synoptic views of spatial distributions of water quality and to evaluate inter-relationships among the water quality indicators.

Graphs of water volumes of low concentrations of dissolved oxygen from 1950 to the present reveal an apparent long-term (40-year) degradation in Bay water quality. This trend is weak at best since the historical data are sporadic and year to year variability is great. Trends since 1984 are inconclusive since dissolved oxygen concentrations appear to be controlled largely by complex relationships between spring river flows and the timing and intensity of weather events affecting the Bay stratification. Similarly, there does not appear to be any strong correlation between phytoplankton growth, as measured by chlorophyll *a* levels, and dissolved oxygen concentrations. Since phytoplankton growth and subsequent consumption by bacteria is the major contributor to anoxia, we explored a secondary reason for the lack of correlation. It appears that the total mass of both nitrogen and phosphorus are in excess of those minimum levels needed for growth and reproduction by phytoplankton at all times of the year. Dissolved inorganic nitrogen mass has increased close to

13% over the past six years and is approximately 10 times the level which would limit algal growth. However, the volume of water with nitrogen concentrations at a level which would limit algal growth has also increased dramatically since 1984. Total phosphorus concentrations were reduced by approximately 17% from 1984 through 1989, and dissolved inorganic phosphorus has been reduced by approximately 52% since June 1984. If reductions in dissolved inorganic phosphorus continue at this rate, concentrations will become limiting to phytoplankton growth and improvements in dissolved oxygen in Chesapeake Bay should begin in future years.

INTRODUCTION

This report examines variations in dissolved oxygen from 1950 onward to determine past trends and evaluate progress in restoring the health of the Bay.

One of the signs of the deterioration in water quality in Chesapeake Bay is the amount of life-sustaining dissolved oxygen in the water column. Reductions in dissolved oxygen have been linked to increased nutrients—primarily phosphorus and nitrogen—in the Bay. In the last two decades management actions have been implemented within the watershed to reduce nutrient loadings. Seasonal, annual and longer-term variability of dissolved oxygen in Chesapeake Bay is great, therefore, an extensive and intensive data base is required to differentiate between natural and manmade changes in water quality. The complex interactions among physical and water quality parameters and biological systems are only partly understood and therefore, analyses on a Baywide scale and within a multivariate context are needed to evaluate Bay management progress.

The data on which this analysis is based were uneven in time, space and quality. Data before 1984 were assembled from diverse sources—academic studies, state and federal monitoring, and special programs—all with equally diverse objectives. In 1984, the EPA Chesapeake Bay Program initiated a regular baywide water quality monitoring program. Samples are taken at 50 mainbay stations 20 times each year, with additional samples collected in the nearshore areas and tributaries. These high quality data are a vast resource to aid in the interpretation of Bay water quality dynamics and provide critical information to understand the sporadic historical data.

To analyze the volume of anoxic and hypoxic water in the Bay, we estimated dissolved oxygen concentrations at all Bay locations. In addition, we similarly analyzed other water quality parameters to understand variations in the dissolved oxygen data. Using a three-dimensional (longitude, latitude, depth) inverse distance squared, moving average interpolator, we estimated several water quality indicators within 1 kilometer (longitude) x 1 kilometer (latitude) x 1 meter depth cubes of the Chesapeake Bay (Reynolds and Bahner, 1989). Estimates were obtained for dissolved oxygen (mg/l), phytoplankton biomass (µg/l as chlorophyll *a*), dissolved inorganic nitrogen (mg/l), and dissolved inorganic phosphorus (mg/l). We used the three-dimensional grids of estimated concentrations to construct baywide synoptic views of spatial distributions of water quality and to evaluate interrelationships among the water quality indicators.

METHODS

Description of monitoring data

The data used in these analyses were extracted from the Chesapeake Bay Program historical data base and from the present monitoring program data base. The most extensive records of dissolved oxygen and nutrient concentrations from 1950-1983 were contributed by the Johns Hopkins University Chesapeake Bay Institute, the Virginia Institute of Marine

Science, the U.S. Environmental Protection Agency's Annapolis Field Office, and data collected by Maryland and Virginia as part of their state water quality monitoring programs. The Chesapeake Bay Institute and Annapolis Field Office data sets sometimes included baywide surveys; these, however, were usually interrupted after one or more years once the original objectives were met. The other data sets are, by definition, regionally focused, and differences in parameters and analytical methodologies necessarily confound geographic and temporal trends. During the 30-plus years of this historical record, the methods for measuring dissolved oxygen concentrations and nutrients changed within and between data-collecting organizations. Dissolved oxygen was originally determined using the Winkler titrimetric method and gradually became automated so that oxygen measurements were routinely made directly as in the current monitoring program. The modern meters, however, were usually calibrated against a Winkler titration, so a 1:1 comparability of methodologies was assumed.

The sampling designs of these many studies were geared to their specific objectives. Often only surface samples were collected, or surface, middle, and bottom. Sampling design was almost always fixed-depth, never with respect to local stratification or the depth of a pycnocline as in the current program. The best of the historical data sets includes once-monthly sampling for a year or more. More often, samples collected once or twice per season must be used to represent the entire season. Some of the studies were designed to look directly at oxygen levels in the Bay; others focused on Bay circulation and physical models, or nutrients and eutrophication. Other studies were fixed-station general water quality surveys.

We examined historical dissolved oxygen data from 1950-1983 to determine the spatial and temporal extent of adequate data for analysis. During this period, there was no long-term, continuous monitoring program. We mapped the data for each month to determine which data sets provided adequate spatial coverage. Since 1950, few summers were sampled for all months between May and September—the time period when anoxia exists in the Bay. A time series of data was not available for each year. The next best approach was to use data collected during July, the month sampled most frequently. On limited occasions, June or August data were used to supplement the analysis for those years in which July data were lacking. Lowest dissolved oxygen conditions occurred during July or August each year. We eliminated some years of data because the locations monitored and the depth of the samples did not encompass the "deep trench" of the Bay where the lowest oxygen levels persist. Despite our selectivity, the data from 1950-1983 are sporadic at best and there is little consistency in the locations and frequency of sampling. Marginally sufficient data, therefore, exist for only 25 of the 40 years for Maryland Chesapeake Bay and 18 of 40 years for the Virginia Chesapeake Bay. Hence, the long-term trends are based on observed data taken during July (augmented by June or August data for some years).

The present Chesapeake Bay Water Quality Monitoring Program began in June 1984. In the Maryland portion of the Bay, the Maryland Department of the Environment samples 22 stations, covering the area from the mouth of the Susquehanna River to the Maryland/Virginia border. In the Virginia portion of the Bay, the responsibility of sample collection is shared between the Virginia Institute of Marine Science (20 stations) and Old Dominion University (8 stations) under authority of the Virginia State Water Control Board. The states also fund extensive nearshore and tidal tributary monitoring programs. The data from each of these programs is maintained at the Chesapeake Bay Program Computer Center and comprise the monitoring program water quality data base.

At each monitoring station, scientists measure dissolved oxygen, water temperature, conductivity and pH directly with a Hydrolab probe at 1 to 2-meter depth intervals. Samples

for chlorophyll and nutrient analyses are collected using a submersible pump. These samples are taken at surface (0.5 meter) and bottom (1 meter above the substrate) at all stations and at 1 meter above and below the pycnocline at stratified or typically stratified stations (or at one-third and two-thirds the distance between surface and bottom samples if no pycnocline exists).

The mainstem stations are usually sampled within the same 3-day interval, with some exceptions due to extreme weather in winter and spring. Initially, stations were sampled twice monthly from March through October, and once a month from November through February. In 1988, the once-monthly winter schedule was extended to include October and March.

We used available data from all Bay or tributary monitoring programs collected at 59 Bay and coastal tributary monitoring stations (Figure 1). During the winter months, some data sets did not contain values for mainstem stations or stations lateral to the mainstem due to ice coverage or dangerous seas which prevented sampling. Minimal amounts of data were not reported due to sample loss during handling or chemical analysis. Data sets from January through May 1990 for the Maryland eastern and western embayments were not available for use in these analyses. These missing data are not thought to affect the DO analysis since they generally occur either during the winter when anoxia does not exist or in the shallow areas of the Bay where anoxia also generally does not exist. We treated data below detection as if the value was measured at the reported detection level. We applied no other modifications or filters to the data.

Interpolation procedure

We interpolated the monitoring data using two methods: 1) for each cruise and at each station, we fit a linear regression between each pair of data points so that we could make concentration estimates at each meter from the surface sample down to the bottom sample depth; 2) we then spatially interpolated these linearly interpolated values between samples at each station within the entire Bay volume for each of 57,871 cells measuring 1 kilometer (longitude) x 1 kilometer (latitude) x 1 meter (deep) using the methods reported by Reynolds and Bahner (1989). We computed constituent concentrations in each cell using this nearest four neighbor inverse distance-squared weighting procedure. The 1 kilometer x 1 kilometer x 1 meter lattice represents 7,553 surface grid cells by depth for a total of 57,871 cells for a complete Bay assessment.

RESULTS AND DISCUSSION

Volumetric analysis

The Chesapeake Bay exhibits a cyclical pattern in dissolved oxygen concentrations through the year. During the summer months, oxygen concentrations remain near or above 5 mg/l in the surface mixed layer above the pycnocline, while dropping to hypoxic and anoxic levels below the pycnocline. The pycnocline is the layer of water approximately 6-10 meters from the surface which exhibits rapid change in water density. These same data can be summed to compute the volume of Bay water by concentration range (Appendices 1,2, & 3) or they can be multiplied by model cell volume to compute the mass of oxygen in the Bay (Appendix 4). Figures 2, 3 and 4 respectively show the monthly-mean volume of Maryland Bay water (during July or June-August for those years with adequate data) containing <1.0, <2.4, and <5.0 mg/l. Solid lines between points show data from successive years, whereas dotted lines indicate intervening years of missing values. Also shown is the simple linear regression line signifying the long-term general trend in the data. There is considerable annual variability in the data not modeled by simple linear regression. The data used for this analysis were compiled from several sources and were not collected at the

Chesapeake Bay Monitoring Stations Used in Report

Figure 1.

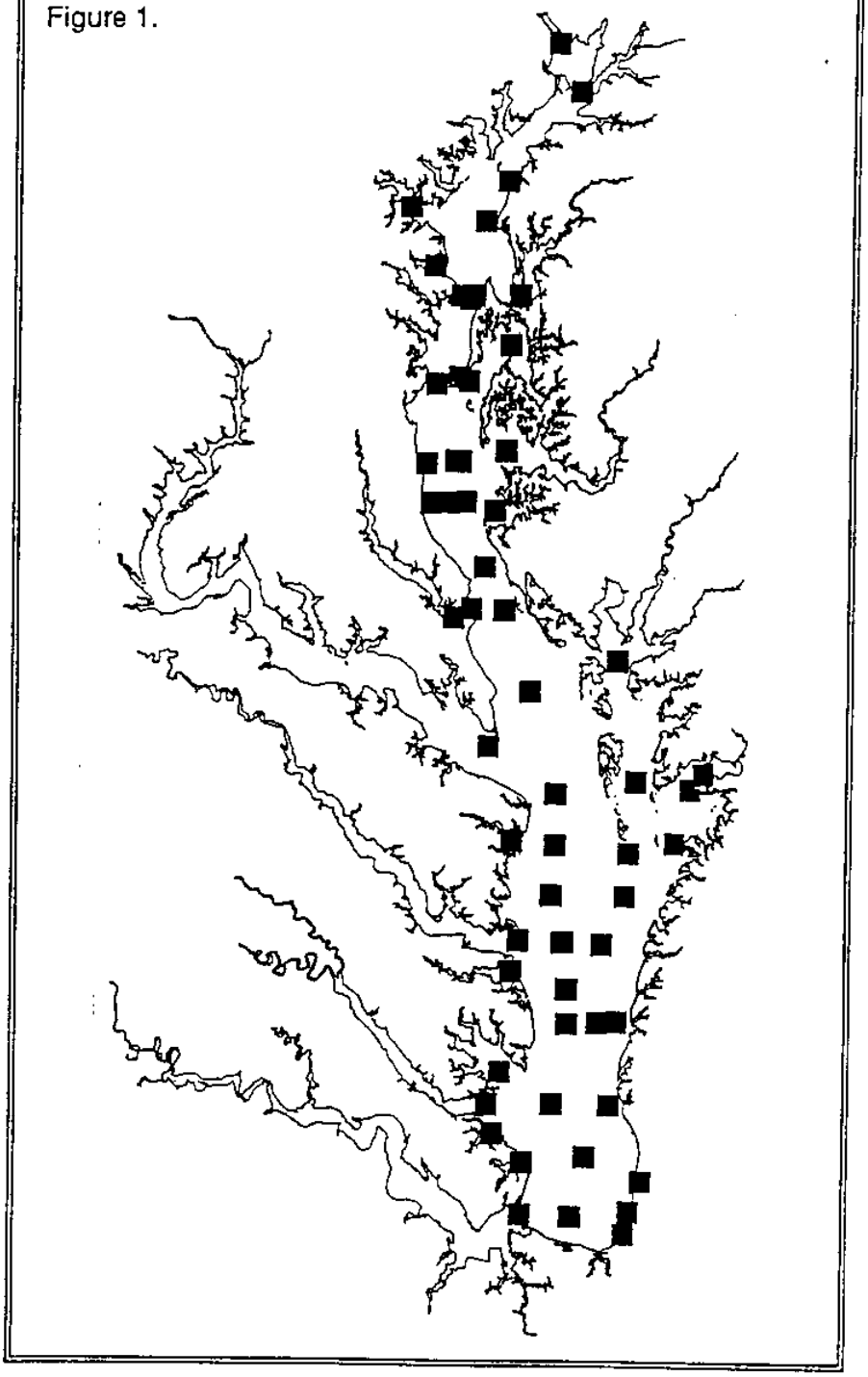


Figure 2. Volume of Maryland Chesapeake Bay with <1 mg/l Dissolved Oxygen Interpolated from July Monitoring Data

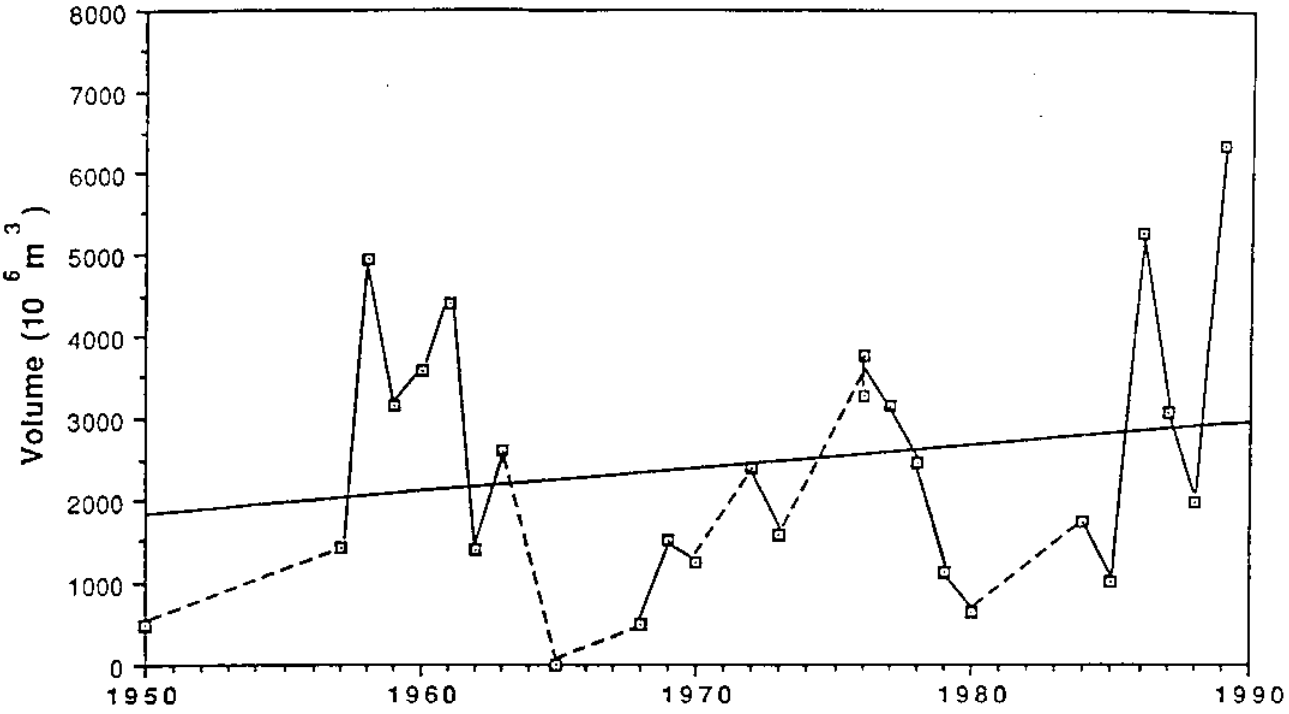


Figure 3. Volume of Maryland Chesapeake Bay with <2.4 mg/l Dissolved Oxygen Interpolated from July Monitoring Data

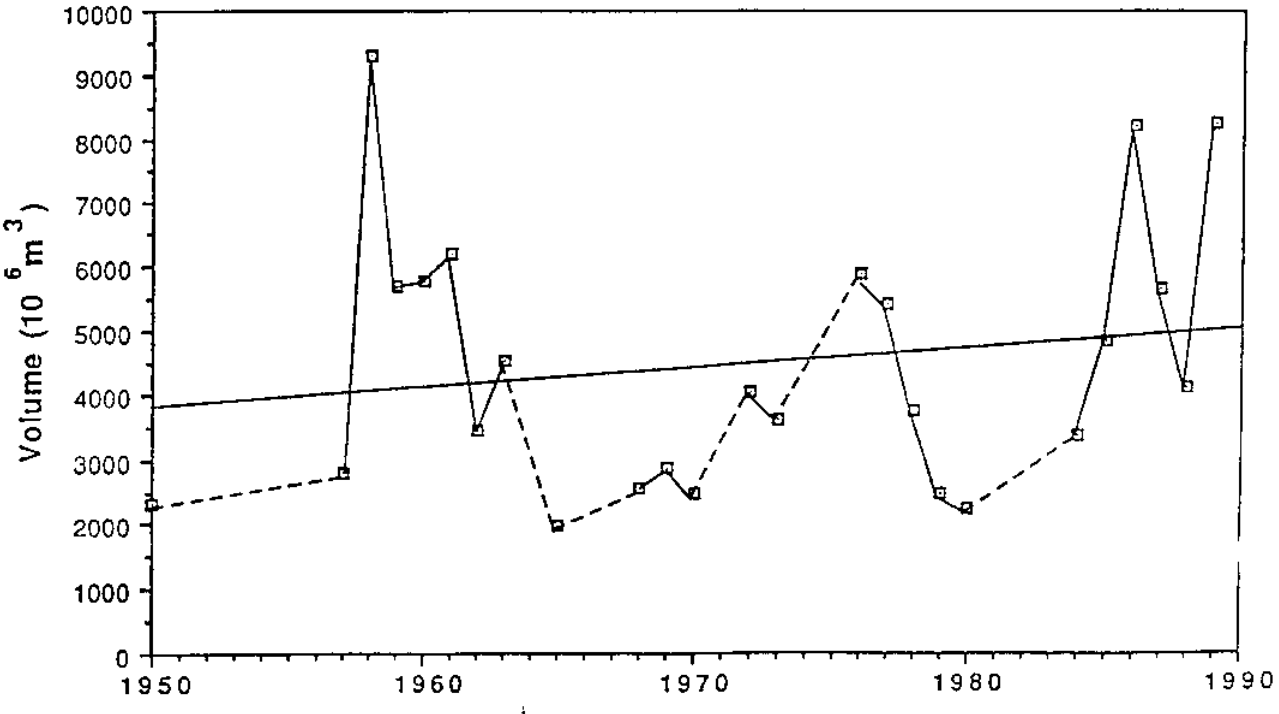


Figure 4. Volume of Maryland Chesapeake Bay with <5.0 mg/l Dissolved Oxygen Interpolated from July Monitoring Data

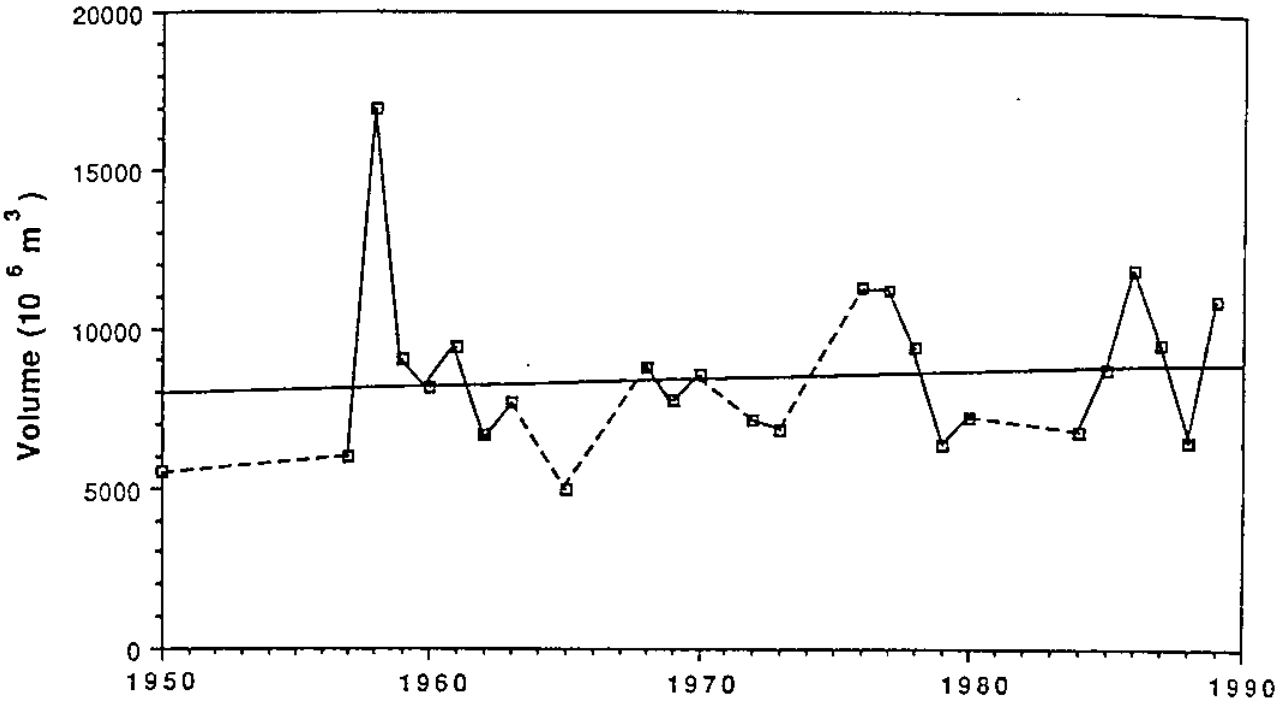
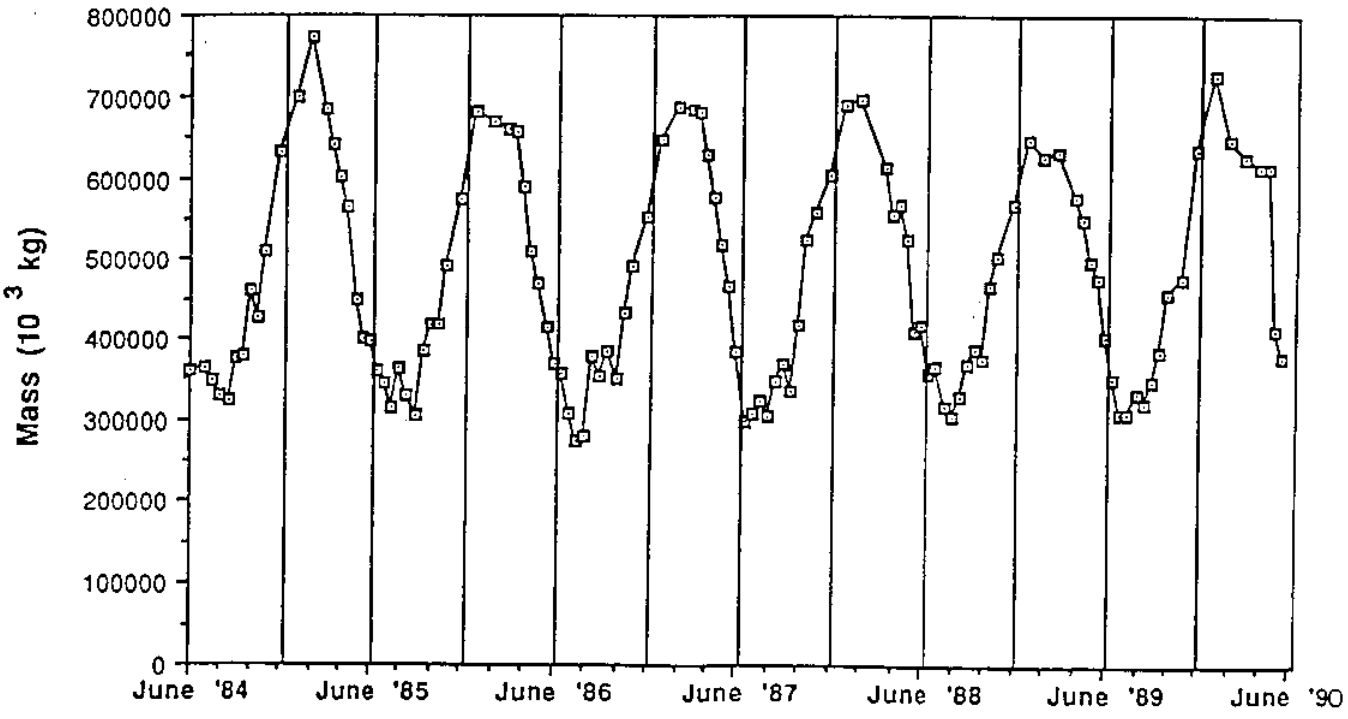


Figure 5. Total Mass of Oxygen in Chesapeake Bay Computed by Volumetric Interpolation of Monitoring Data



same time each year. Therefore, there is considerable sampling variability in the data. The trend lines, however, indicate a general decline of dissolved oxygen in the Bay since 1950.

The current monitoring program data (June 1984-present) were examined in greater detail by interpolating data for each cruise. Figure 5 plots the mass of total dissolved oxygen in Chesapeake Bay for each cruise from June 1984 through May 1990. The annual fluctuations in oxygen mass in the Bay, largely due to temperature, are enormous. Figure 6 shows the volume of Bay water by four concentration ranges below the acceptable level for most living resources. Notice that both the shapes and timing of the peaks vary from year to year. This interannual variability complicated the 40-year trend analysis since no single month provides data representative of the worst annual water quality. Therefore, data from one month should not be used to fully characterize the extent and duration of low dissolved oxygen in a long-term trend analysis. In addition, the 1984 data were truncated because the monitoring program did not begin until the second half of June of that year. The plot shows that a considerable volume of water contained lowered dissolved oxygen prior to June.

Another means of examining these data is to compute the number of days in which dissolved oxygen is depleted, multiplied by the volume of water with depleted oxygen for a measure of cubic meter days of depleted oxygen (Figure 7). By integrating the area under each curve, the timing and peakedness of the low dissolved oxygen is lost, but it is somewhat easier to categorize the total extent of low dissolved oxygen over the summer season.

The periodicity evident in Figure 6 is due largely to temperature which affects the amount of oxygen that can be dissolved in water. We assessed the depletion of dissolved oxygen by comparing saturation levels versus those actually measured in the water (Appendices 5 & 6; Figure 8). Conceptually, the difference is the mass of oxygen depleted by biological activity and chemical oxygen demand. Figure 9 shows the mass of oxygen depleted from the Bay during the summer months. Since this analysis represents the difference between the amount possible and that measured, the effects of temperature and salinity annual variability (a measure of flow or rainfall) have been considered.

Examination of the depth at which lowered oxygen concentrations occur indicates that concentrations of <1.0 mg/l exist each summer from the bottom up to the 6 meter depth. The hypoxic water in the 6-7 meter depth layer represents about 2% of the total Bay volume. Up to 4.4% of the Bay volume is similarly hypoxic between 7-11 meters. Up to 10.2% of the Bay volume becomes hypoxic between 11 meters and the bottom. The worst case existed during the last half of July 1986 in which 14.8% of the Bay volume was hypoxic. This hypoxic water accounted for 53% of the water below 11 meters in depth. During 1984-1989, on only two occasions did hypoxic water invade the 4-5 meter layer (less than 0.1% of the Bay volume).

Each summer, 34-44% of the Bay volume contains <5 mg oxygen/l, which is equivalent to the volume of Bay water at depths below 10 and 9 meters, respectively. Since the pycnocline occurs at approximately these depths, it appears that the pycnocline may delineate the volume of water which is depleted in oxygen. Therefore, no change in dissolved oxygen trends should be expected until there is a reduction in biological oxygen demand below the mass of oxygen contained in the sub-pycnocline water.

Relationship of dissolved oxygen and riverine flow

There is a commonly held belief that large riverine flows enhance stratification in the Bay, in turn causing oxygen deprivation below the pycnocline. Based on this belief, we ex-

Figure 6.

Volume of Chesapeake Bay Water Containing Different Levels of Dissolved Oxygen

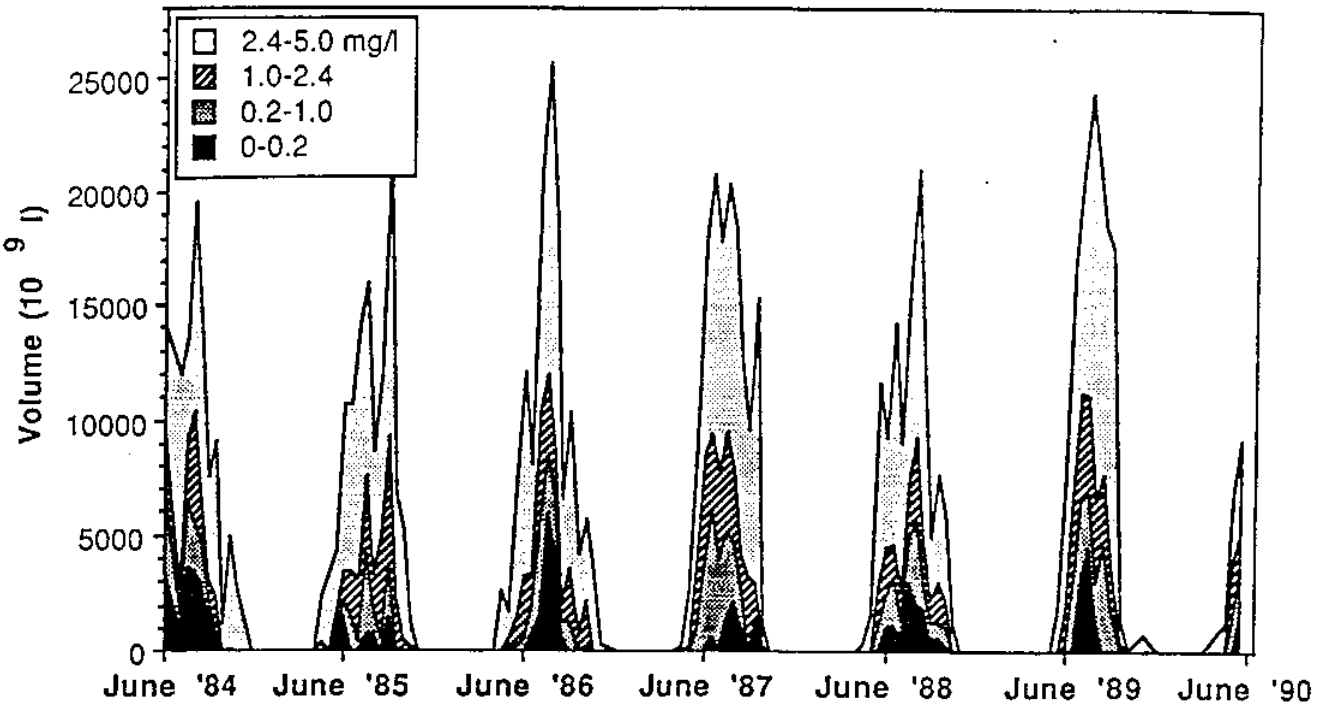


Figure 7. **Cubic Meter Days of Low Dissolved Oxygen**

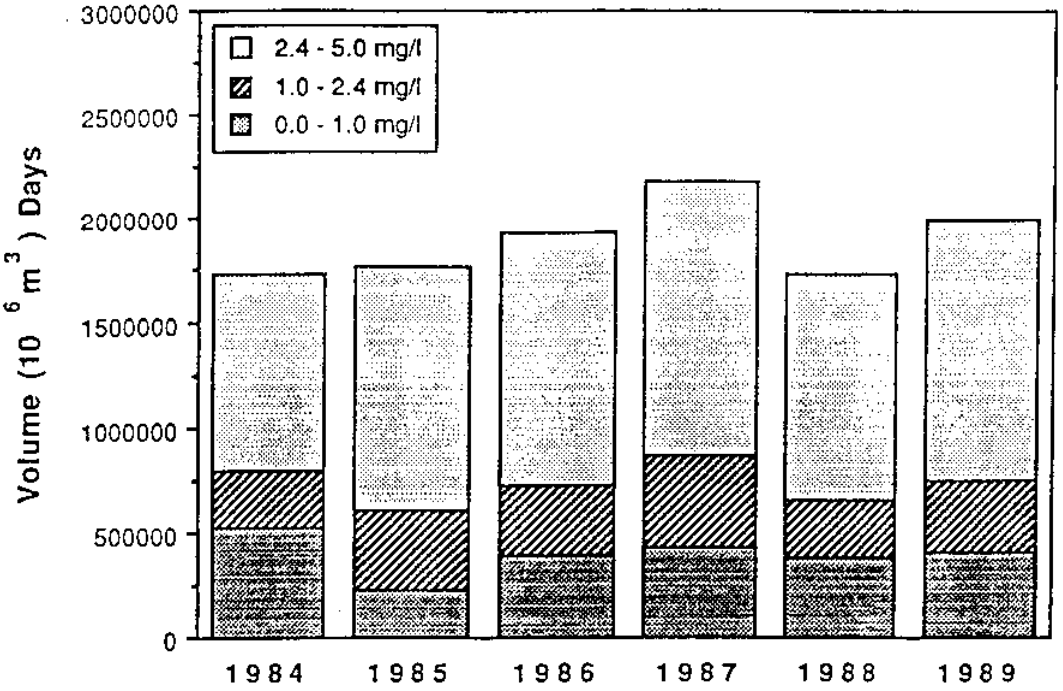


Figure 8. **Observed and Saturated Values for Dissolved Oxygen in Chesapeake Bay**

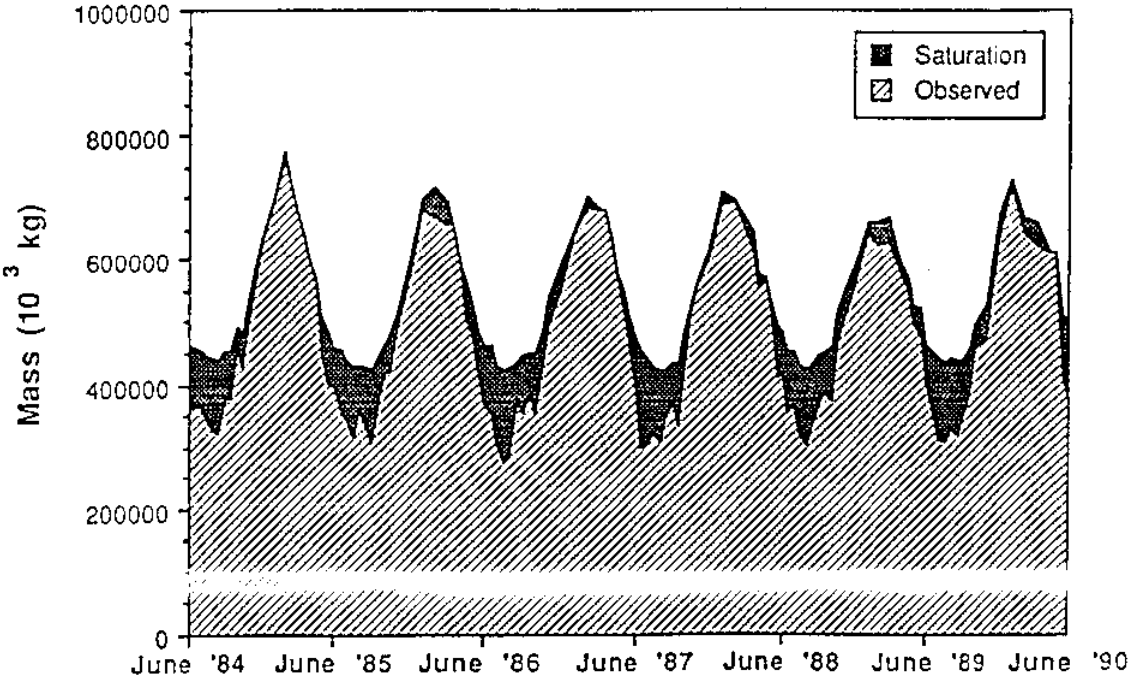
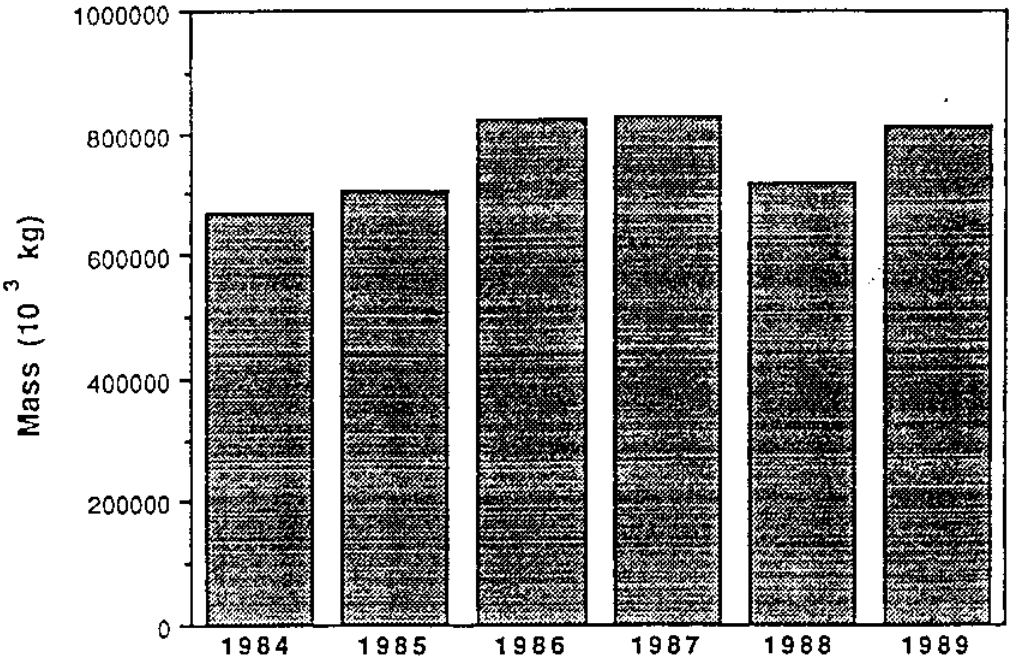


Figure 9. **Dissolved Oxygen Deficit in the Chesapeake Bay Summed for June through September**



amined the Susquehanna River flow, which dominates the Maryland Chesapeake Bay, to determine if flow could be correlated to long term dissolved oxygen trends. Figure 10 is a flow trend plot for 1900-1989. Compared to the 90-year mean, 1961-1969 was a period of considerably reduced flow. The period from 1970-1979 showed flows above average, with the largest spike occurring in 1972 due to Hurricane Agnes. In Figure 11, we overlayed dissolved oxygen (generally measured in July) with the Susquehanna flows summed for the previous July through June period. A visual examination suggests some agreement ([+] indicates agreement; [?] indicates missing data; [-] indicates lack of agreement) between higher flows with lower dissolved oxygen concentrations. However, the association based solely on these data is weak.

Figures 12a and 12b show Susquehanna River flows for 1984-1989. Also shown for reference is the median flow by month for 1950-1989. The height and timing of the peaks was quite different during this short period. In 1984, there were unusually high flows with large peaks in February and April, while 1985 and 1988 had lower flows than average. Comparison of these peak areas with the volume of anoxic water (Figure 7) during those times shows some correlation. Also, there appears to be some correlation between Susquehanna flow pulses (Figures 12a, 12b) and volumes of anoxic and hypoxic water approximately 3 months later in the Bay (Figure 6).

Relationship of dissolved oxygen and chlorophyll *a*

Dissolved oxygen concentration is a function of water density (dictating the capacity for oxygen to dissolve in water), reaeration rate, and the biological and chemical oxygen demand. Phytoplankton, measured as chlorophyll *a* is the largest primary source of carbon in the Bay and the largest potential source for biological oxygen demand when consumed or decayed. Figure 13 shows a plot of mass of chlorophyll *a* for 1984 through 1990. As a second step in determining whether dissolved oxygen trends could be correlated to other monitored parameters, we made comparisons of the mass of chlorophyll *a* in Chesapeake Bay water for 1976 through 1990 (Appendices 7 & 8) with dissolved oxygen. Figure 14 shows a correlation plot of mass of chlorophyll *a* versus mass of dissolved oxygen in the Bay for each cruise from June 1984 through May 1990. The figure indicates that there is no readily apparent correlation between these total mass estimates.

Relationship of dissolved oxygen and nitrogen

We also examined nitrogen concentrations in the Bay to determine how they are changing over time, given that some nitrogen controls have been put in place in the basin. Values of the mass of dissolved inorganic nitrogen were computed for June 1984 through May 1990 (Appendix 9). A plot of these data shows that dissolved inorganic nitrogen concentrations in the Bay have increased by about 13% during the past 6-year period (Figure 15). The line labeled 'Growth Limiting' indicates that mass of dissolved inorganic nitrogen (equivalent to 0.015 mg/l) as used in the Chesapeake Bay two-dimensional model (HydroQual, 1987) below which the lack of nitrogen would limit phytoplankton growth in the Bay. It is apparent from this graph that the mass of nitrogen presently in the Bay is approximately 10 times higher than the levels needed to limit phytoplankton growth. Limiting phytoplankton growth would presumably improve dissolved oxygen concentrations below the pycnocline. The darkened points (labeled 'Sediment Flux') are those in which a large portion of the nitrogen is in the form of ammonia, liberated from the bottom sediments due to overlying anoxic water. During low flow summer months, dissolved inorganic nitrogen concentrations are minimum, even though ammonia concentrations below the pycnocline are fairly high. At other times of the year, nitrate and nitrite concentrations, mainly contributed by the Susquehanna River, dominate the nitrogen distribution in the Bay.

Relationship of dissolved oxygen and phosphorous

We also examined baywide phosphorus concentrations to determine what effect the extensive phosphorus control measures in the basin have had on ambient phosphorus distri-

Figure 10. Susquehanna Annual Flow Deviation About Mean

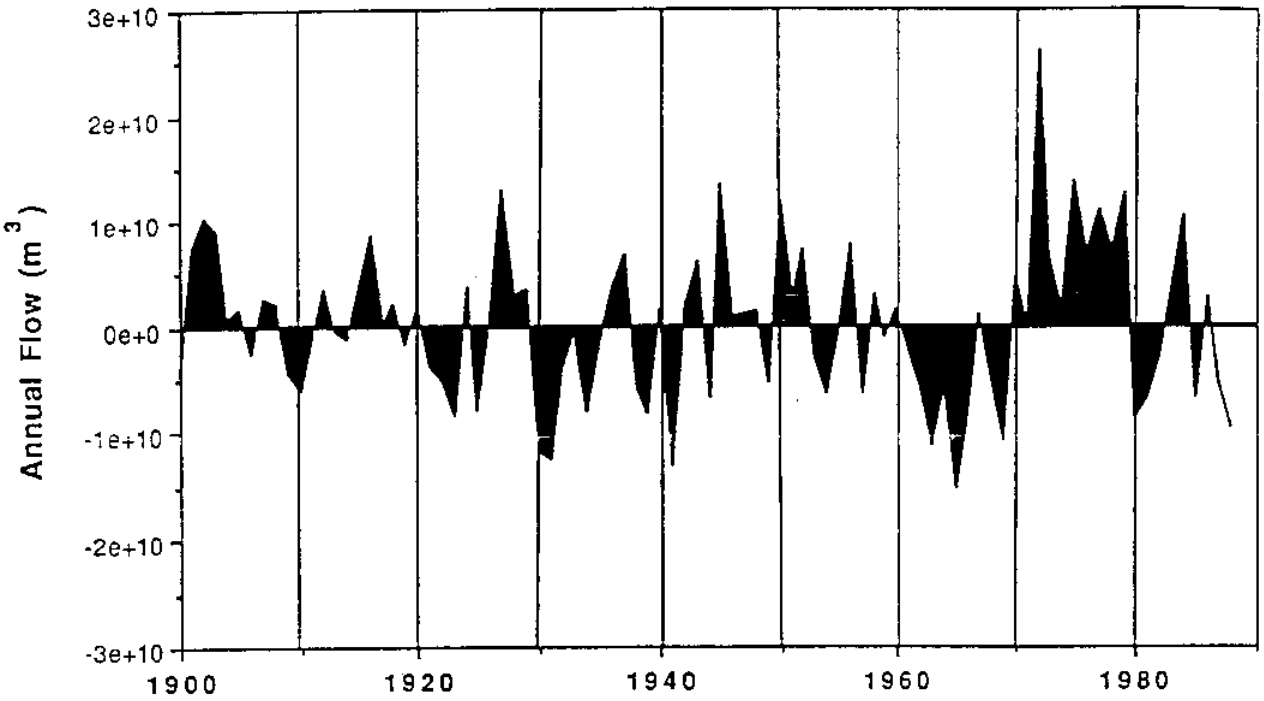


Figure 12.

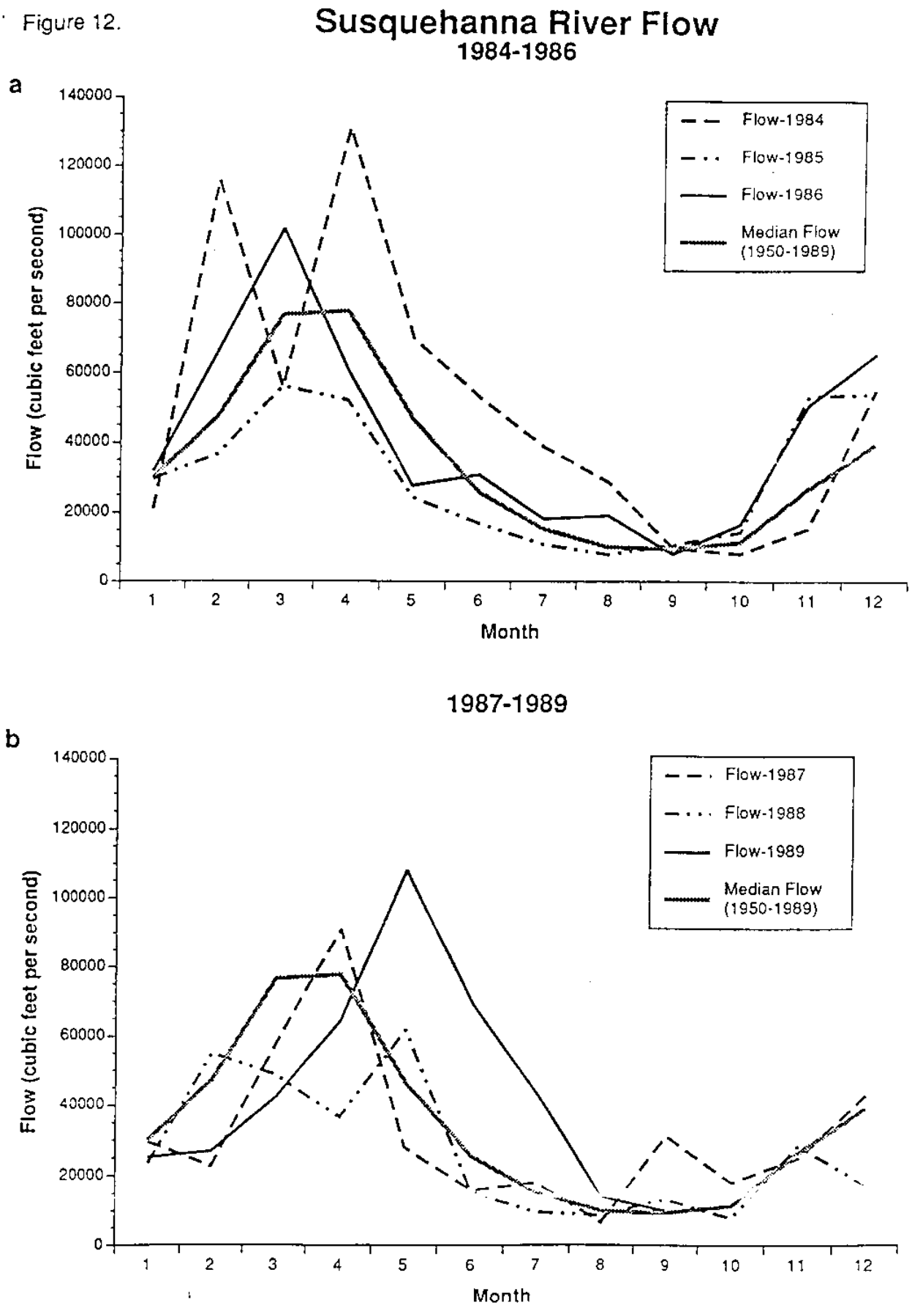

Susquehanna River Flow
1984-1986
a
Flow-1984
Flow-1985
Flow-1986
Median Flow
(1950-1989)
Flow (cubic feet per second)
140000
120000
100000
80000
60000
40000
20000
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
1987-1989
b
Flow-1987
Flow-1988
Flow-1989
Median Flow
(1950-1989)
Flow (cubic feet per second)
Month

Figure 11. **Susquehanna Flow and Maryland Dissolved Oxygen Volume Overlay Flow Equals Sum of July to June Monthly Flows**

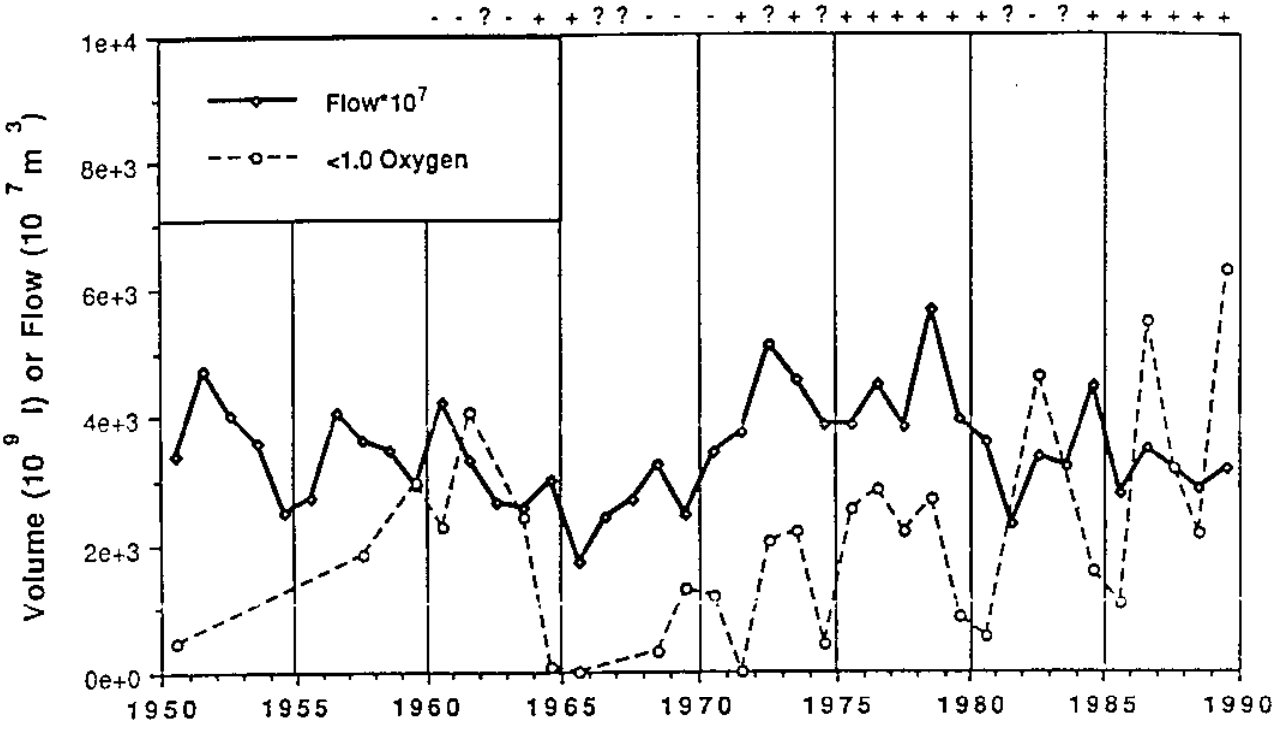


Figure 13. **Plot of Mass of Chlorophyll in Chesapeake Bay**

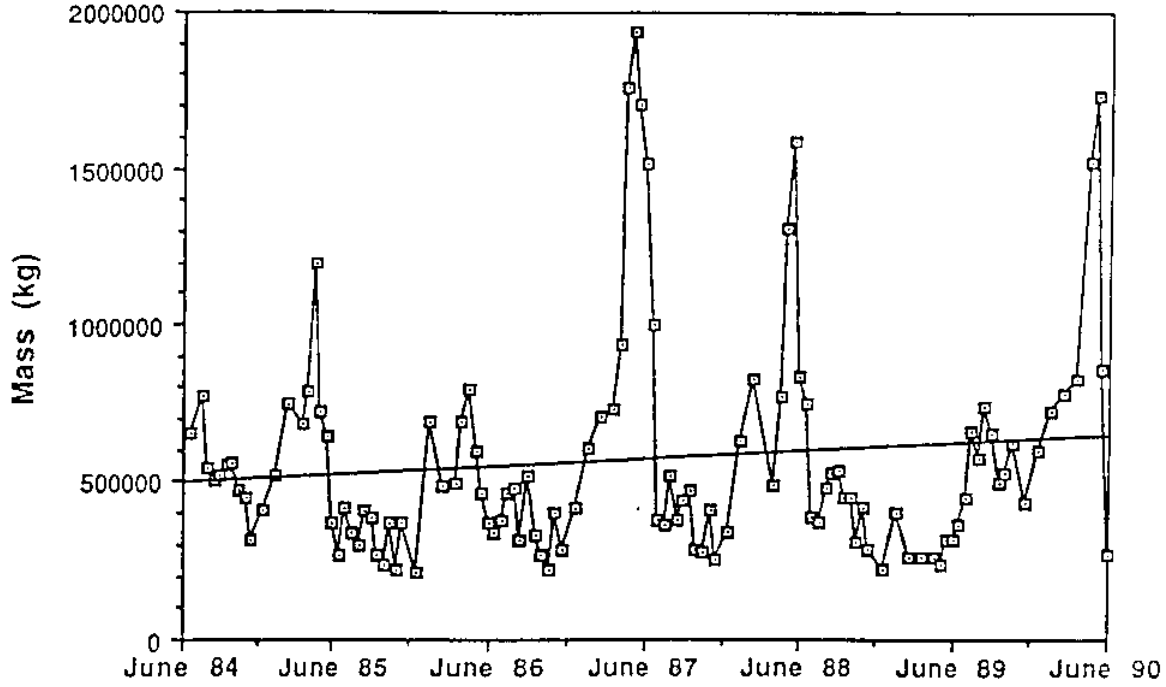


Figure 14. **Correlation of Mass of Chlorophyll to Dissolved Oxygen for Chesapeake Bay, June 1984 - May 1990**

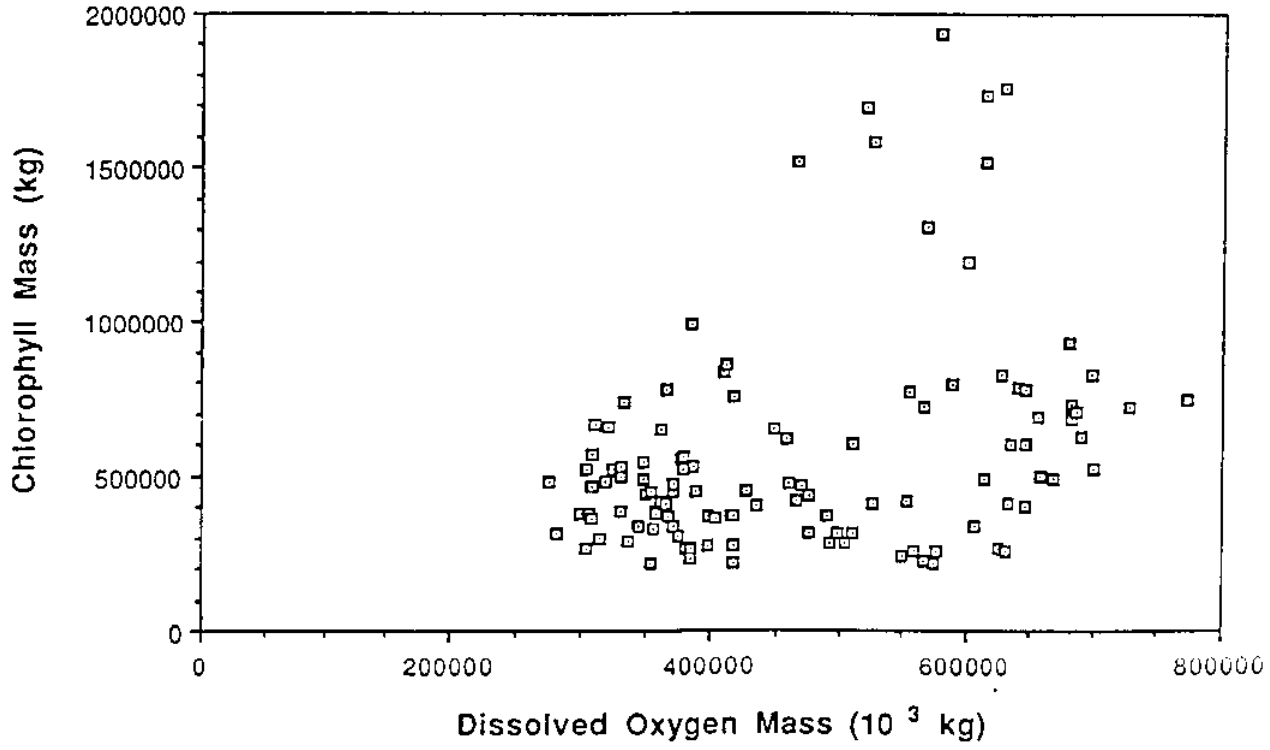


Figure 15. **Plot of Mass of Dissolved Inorganic Nitrogen Measured vs Phytoplankton Growth Limiting**

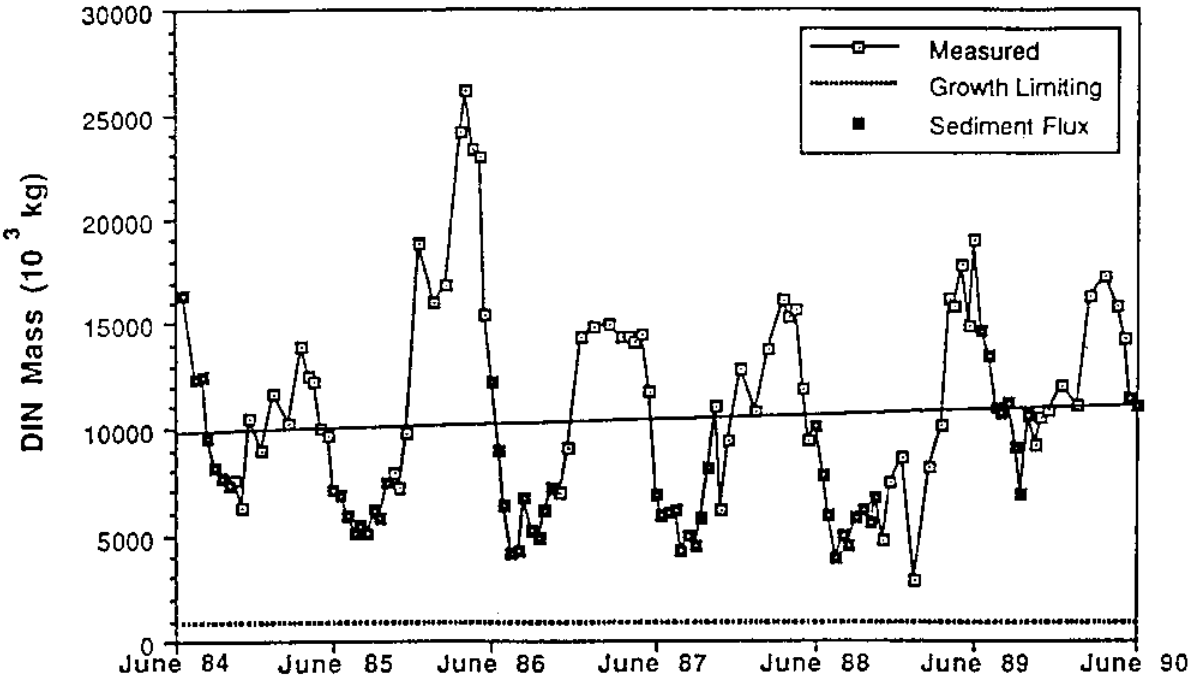
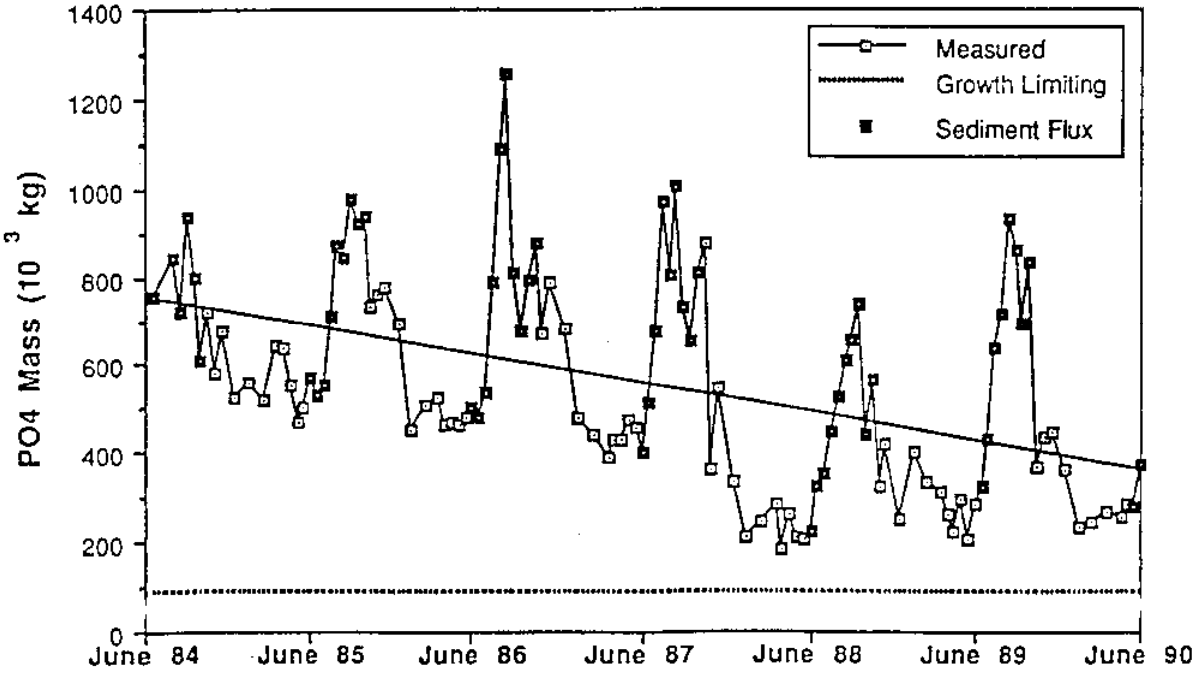


Figure 16. **Plot of Mass of Dissolved Inorganic Phosphorus Measured vs Chlorophyll Growth Limiting**



butions. Values of the mass of dissolved inorganic phosphorus were computed for June 1984 through May 1990 (Appendix 10). A plot of these data shows that dissolved inorganic phosphorus concentrations in the Bay have decreased by approximately 52% during the past 6 years (Figure 16). The line labeled 'Growth Limiting' indicates that mass of dissolved inorganic phosphorus (equivalent to 0.0015 mg/l) as used in the Chesapeake Bay two-dimensional model (HydroQual, 1987) below which the lack of phosphorus would limit phytoplankton growth in the Bay. Measured concentrations presently in the Bay during late spring are approaching those concentrations which would limit phytoplankton growth. If the current trend continues, phosphorus concentrations should begin to limit the phytoplankton population likely resulting in improved dissolved oxygen concentrations below the pycnocline. Special consideration must be given to ambient concentrations of phosphorus from nearshore Atlantic Ocean seawater and to detection limits for measuring phosphorus in water, since these factors may alter the trend as concentrations decline. The darkened points (Figure 16), labeled 'Sediment Flux', are those in which a very large load of phosphorus is liberated from the bottom sediments due to overlying anoxic water. This load approximately doubles or triples the mass of dissolved inorganic phosphorus in the Bay during the summer.

CONCLUSIONS

An examination of available data for dissolved oxygen for the month of July revealed apparent degradation in Bay water quality between 1950 and the present. Data between 1950 and 1983 were sporadically collected, most commonly during the months of July and August. Interpretation of trends was complicated by the considerable annual and interannual variability due to temperature and weather effects.

There is some evidence to indicate that Susquehanna River flow affects dissolved oxygen concentrations in Maryland Chesapeake Bay. The velocity and volume of fresh water determine the occurrence and strength of the pycnocline, which acts as a barrier to reaeration of the water below during summer months.

Preliminary examinations of the mass of chlorophyll *a* and dissolved oxygen indicated no simple correlation, even though phytoplankton are the primary source of carbon which ultimately causes depletion of oxygen within the Bay. It is believed that the established nutrient controls are not yet affecting phytoplankton growth and consequently dissolved oxygen concentrations have not improved.

Dissolved inorganic nitrogen has increased by approximately 13% during the past 6 years. Its total mass is approximately 10 times higher than that needed to limit phytoplankton growth. Sediments supply large quantities of ammonia during periods of anoxia, however, the major source of inorganic nitrogen during the year is nitrate and nitrite nitrogen from the Susquehanna River. In contrast, the volume of Bay water with plankton growth-limiting concentrations of dissolved inorganic nitrogen (<0.015 mg/l) has increased from 4% in July 1985 to 7.5% in June 1986, 15% in June 1989, and finally 39% in May 1990. This rise seems to indicate that nitrogen limitation on phytoplankton growth may be increasing, although the total mass of dissolved inorganic nitrogen in the Bay is also increasing. Further work is needed to determine whether these nitrogen limiting conditions are located in areas of the Bay that might have a significant effect on algal populations.

The most important finding of this study is that dissolved inorganic phosphorus concentrations have decreased by approximately 52% over the past six years. Bahner and Reynolds (1990) reported earlier that total phosphorus was reduced by 17% from 1984 through

1989. Dissolved inorganic phosphorus concentrations are approaching that level required to limit phytoplankton growth (<0.0015 mg/l). If current trends of phosphorus reduction continue at the current levels, improvements in dissolved oxygen concentrations below the pycnocline should be observed in future years. If this scenario evolves and anoxia is not as prevalent, the extremely high summer concentrations of dissolved inorganic phosphorus seen in previous years should not materialize due to reduced nutrient flux from the sediments. These diminished concentrations should aid in further recovery of the Bay since the following year cycle would begin with lower initial phosphorus concentrations.

ACKNOWLEDGEMENTS

We appreciate the extensive support provided by Marcia Olson, CSC, in preparing the historical data used in this reprt. We also appreciate the work done by Nina Fisher, Ellen Horvath, and Susan Phelps, CSC, in manuscript preparation.

Appendix 1

Dissolved oxygen volume (10^9 l) by concentration range in Maryland waters (1950-1989)

Date (YYMM)	DO concentration range (mg/l) 0-0.2	0.2-1.0	1.0-2.4	2.4-5.0	>5.0	Total
5007	1	483	1823	3198	19292	24797
5707	389	1029	1374	3184	18821	24797
5808	948	3981	4377	7673	7818	24797
5907	0	3139	2545	3373	15740	24797
6007	540	3032	2207	2402	16616	24797
6107	8	4398	1788	3230	15373	24797
6207	0	1384	2063	3250	18100	24797
6307	0	2618	1901	3166	17112	24797
6507	0	8	1950	3027	19812	24797
6807	19	459	2084	6250	15985	24797
6907	630	897	1352	4916	17002	24797
7007	237	1017	1219	6091	16233	24797
7207	1315	1077	1639	3157	17609	24797
7306	628	956	2031	3227	17955	24797
7606	1372	1890	1178	2381	17976	24797
7607	1652	2116	2105	5421	13503	24797
7707	8	3157	2259	5819	13554	24797
7807	814	1634	1309	5684	15356	24797
7907	525	600	1346	3909	18417	24797
8007	0	625	1622	4995	17555	24797
8407	918	816	1635	3407	18021	24797
8507	104	886	3866	3852	16089	24797
8607	1145	4093	2988	3572	12999	24797
8707	214	2852	2594	3826	15311	24797
8807	710	1274	2143	2338	18332	24797
8907	3092	3255	1890	2681	13879	24797

Appendix 2

Dissolved oxygen volume (10^9 l) by concentration range in Virginia waters (1950-1989)

Date (YYMMDD)	DO concentration range (mg/l) 0-0.2	0.2-1.0	1.0-2.4	2.4-5.0	>5.0	Total
500701	0	15	132	3404	28406	31957
520701	0	0	335	15625	15997	31957
580801	0	23	1849	12125	17960	31957
590701	0	5	485	1886	29581	31957
600701	0	1071	1047	8464	21375	31957
610701	0	344	551	4684	26378	31957
650701	0	0	77	1142	30738	31957
680701	0	149	444	5309	26055	31957
690701	0	0	308	316	31333	31957
700701	0	278	568	7587	23524	31957
790701	0	0	150	8109	23698	31957
800701	0	0	154	4653	27150	31957
840701	312	1119	2202	1295	27029	31957
850701	0	6	1822	5390	24739	31957
860701	0	843	2876	9958	18280	31957
870701	0	111	2179	5293	24374	31957
880701	0	81	2091	6169	23616	31957
890701	38	2667	3721	4044	21487	31957

Appendix 5 (continued)

Volume of water (10^9 l) in Chesapeake Bay at DO saturation level

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
861201	0	26445	30619	807	0	57871
870101	0	3	55977	1891	0	57871
870201	0	0	46532	11339	0	57871
870301	0	0	56316	1555	0	57871
870316	0	0	57871	0	0	57871
870401	0	1632	56239	0	0	57871
870416	0	41880	15991	0	0	57871
870501	0	54639	3232	0	0	57871
870516	0	57871	0	0	0	57871
870601	0	57871	0	0	0	57871
870616	31	57840	0	0	0	57871
870701	28147	29724	0	0	0	57871
870716	46813	11058	0	0	0	57871
870801	55139	2732	0	0	0	57871
870816	54571	3300	0	0	0	57871
870901	36973	20898	0	0	0	57871
870916	35160	22711	0	0	0	57871
871001	0	57620	251	0	0	57871
871016	0	57753	118	0	0	57871
871101	0	48161	9710	0	0	57871
871201	0	4233	52794	844	0	57871
880101	0	0	40346	17525	0	57871
880201	0	0	45485	12386	0	57871
880316	0	0	57853	18	0	57871
880401	0	33008	24863	0	0	57871
880416	0	39360	18511	0	0	57871
880501	0	57749	122	0	0	57871
880516	0	57800	71	0	0	57871
880601	0	57871	0	0	0	57871
880616	1149	56722	0	0	0	57871
880701	5629	52242	0	0	0	57871
880716	37324	20547	0	0	0	57871
880801	53565	4306	0	0	0	57871
880816	44173	13698	0	0	0	57871
880901	2774	55097	0	0	0	57871
880916	23	57848	0	0	0	57871
881001	2115	55756	0	0	0	57871
881016	0	57325	546	0	0	57871
881101	0	48667	9204	0	0	57871
881201	0	18711	38619	541	0	57871
890101	0	0	56122	1749	0	57871
890201	0	0	55966	1905	0	57871
890301	0	0	57871	0	0	57871
890401	0	19424	38447	0	0	57871
890416	0	36600	21271	0	0	57871
890501	0	56165	1706	0	0	57871

Appendix 5 (continued)

Volume of water (10^9 l) in Chesapeake Bay at DO saturation level

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
890516	0	55426	2445	0	0	57871
890601	239	57632	0	0	0	57871
890616	13232	44639	0	0	0	57871
890701	25603	32268	0	0	0	57871
890716	28460	29411	0	0	0	57871
890801	11803	46068	0	0	0	57871
890816	16068	41803	0	0	0	57871
890901	15490	42381	0	0	0	57871
890916	84	57787	0	0	0	57871
891001	0	57626	245	0	0	57871
891101	0	54693	3178	0	0	57871
891201	0	0	53671	4200	0	57871
900101	0	0	21503	36368	0	57871
900201	0	363	53428	4080	0	57871
900301	0	0	54885	2986	0	57871
900401	0	17587	40284	0	0	57871
900416	0	30467	27404	0	0	57871
900501	0	57871	0	0	0	57871
900516	0	57871	0	0	0	57871

Note: (1) Saturation level is determined by water density.

(2) These values could exist if biological activity and chemical oxygen demand were not present. Notice that there are no values below 5 or above 15 mg/l. Dates are in YYMMDD format where DD=01 indicates data from the first two weeks of the month and DD=16 indicates data from the last two weeks of the month.

Appendix 6

Mass (10^3 kg) of dissolved oxygen in Chesapeake Bay at saturation

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
840601	24365	437409	0	0	0	461775
840701	558	453135	0	0	0	453693
840716	30218	416477	0	0	0	446695
840801	80123	362147	0	0	0	442270
840816	165815	273300	0	0	0	439115
840901	46080	407461	0	0	0	453541
840916	1450	452764	0	0	0	454215
841001	0	489159	0	0	0	489159
841016	0	478296	0	0	0	478296
841101	0	426842	113202	0	0	540044
841201	0	39365	568003	10625	0	617993
850101	0	0	551554	143170	0	694724
850201	0	0	342788	388224	0	731012
850301	0	1059	654135	25	0	655219
850316	0	30289	580270	7631	0	618190
850401	0	299046	287049	0	0	586095
850416	0	462061	73661	0	0	535722
850501	0	510671	0	0	0	510671
850516	0	482526	0	0	0	482526
850601	8430	451497	0	0	0	459927
850616	5184	448661	0	0	0	453844
850701	144039	293827	0	0	0	437866
850716	336509	90016	0	0	0	426525
850801	264957	166292	0	0	0	431249
850816	341615	83809	0	0	0	425424
850901	400603	22490	0	0	0	423093
850916	40317	404896	0	0	0	445212
851001	8603	451854	0	0	0	460457
851016	0	475997	111	0	0	476108
851101	0	502260	6426	0	0	508686
851201	0	231804	352050	8513	0	592368
860101	0	409	594504	100591	0	695503
860201	0	0	369985	346143	0	716128
860301	0	0	671932	23005	0	694937
860316	0	0	650399	0	0	650399
860401	0	200809	386205	0	0	587014
860416	0	364535	201082	0	0	565618
860501	0	523634	0	0	0	523634
860516	0	482991	0	0	0	482991
860601	5155	455674	0	0	0	460829
860616	32768	428155	0	0	0	460923
860701	282112	148666	0	0	0	430778
860716	375555	48588	0	0	0	424143
860801	366312	60337	0	0	0	426649
860816	212733	222314	0	0	0	435047
860901	71029	373459	0	0	0	444488
860916	45724	402837	0	0	0	448562
861001	48051	400849	0	0	0	448900
861016	0	486090	1658	0	0	487748
861101	0	496078	43528	100	0	539706

Appendix 6 (continued)

Mass (10^3 kg) of dissolved oxygen in Chesapeake Bay at saturation

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
861201	0	257636	324638	10353	0	592626
870101	0	30	622357	24882	0	647269
870201	0	0	555983	144529	0	700512
870301	0	0	654367	19677	0	674044
870316	0	0	640723	0	0	640723
870401	0	16236	593052	0	0	609289
870416	0	394754	165118	0	0	559872
870501	0	510960	32876	0	0	543836
870516	0	508338	0	0	0	508338
870601	0	475739	0	0	0	475739
870616	232	455627	0	0	0	455859
870701	208620	228059	0	0	0	436679
870716	343140	84179	0	0	0	427319
870801	401747	20781	0	0	0	422527
870816	396867	25069	0	0	0	421936
870901	272088	160332	0	0	0	432419
870916	258298	173587	0	0	0	431886
871001	0	474528	2527	0	0	477055
871016	0	501279	1205	0	0	502484
871101	0	457272	99785	0	0	557057
871201	0	41571	564725	10919	0	617214
880101	0	0	484123	226340	0	710463
880201	0	0	529329	159080	0	688408
880316	0	0	644099	228	0	644327
880401	0	317750	258657	0	0	576406
880416	0	378534	188388	0	0	566922
880501	0	530801	1221	0	0	532022
880516	0	491436	724	0	0	492160
880601	0	482706	0	0	0	482706
880616	8579	447561	0	0	0	456140
880701	41971	407146	0	0	0	449117
880716	274804	156855	0	0	0	431659
880801	390106	32952	0	0	0	423058
880816	324857	105218	0	0	0	430075
880901	20683	424120	0	0	0	444804
880916	172	448419	0	0	0	448592
881001	15804	443153	0	0	0	458957
881016	0	506432	5595	0	0	512028
881101	0	454905	95524	0	0	550429
881201	0	183070	408264	6980	0	598314
890101	0	0	637867	23161	0	661028
890201	0	0	637927	25006	0	662932
890301	0	0	670042	0	0	670042
890401	0	190520	403325	0	0	593845
890416	0	350562	219074	0	0	569636
890501	0	509814	17143	0	0	526956
890516	0	496897	25488	0	0	522385

Appendix 6

Mass (10^3 kg) of dissolved oxygen in Chesapeake Bay at saturation

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
840601	24365	437409	0	0	0	461775
840701	558	453135	0	0	0	453693
840716	30218	416477	0	0	0	446695
840801	80123	362147	0	0	0	442270
840816	165815	273300	0	0	0	439115
840901	46080	407461	0	0	0	453541
840916	1450	452764	0	0	0	454215
841001	0	489159	0	0	0	489159
841016	0	478296	0	0	0	478296
841101	0	426842	113202	0	0	540044
841201	0	39365	568003	10625	0	617993
850101	0	0	551554	143170	0	694724
850201	0	0	342788	388224	0	731012
850301	0	1059	654135	25	0	655219
850316	0	30289	580270	7631	0	618190
850401	0	299046	287049	0	0	586095
850416	0	462061	73661	0	0	535722
850501	0	510671	0	0	0	510671
850516	0	482526	0	0	0	482526
850601	8430	451497	0	0	0	459927
850616	5184	448661	0	0	0	453844
850701	144039	293827	0	0	0	437866
850716	336509	90016	0	0	0	426525
850801	264957	166292	0	0	0	431249
850816	341615	83809	0	0	0	425424
850901	400603	22490	0	0	0	423093
850916	40317	404896	0	0	0	445212
851001	8603	451854	0	0	0	460457
851016	0	475997	111	0	0	476108
851101	0	502260	6426	0	0	508686
851201	0	231804	352050	8513	0	592368
860101	0	409	594504	100591	0	695503
860201	0	0	369985	346143	0	716128
860301	0	0	671932	23005	0	694937
860316	0	0	650399	0	0	650399
860401	0	200809	386205	0	0	587014
860416	0	364535	201082	0	0	565618
860501	0	523634	0	0	0	523634
860516	0	482991	0	0	0	482991
860601	5155	455674	0	0	0	460829
860616	32768	428155	0	0	0	460923
860701	282112	148666	0	0	0	430778
860716	375555	48588	0	0	0	424143
860801	366312	60337	0	0	0	426649
860816	212733	222314	0	0	0	435047
860901	71029	373459	0	0	0	444488
860916	45724	402837	0	0	0	448562
861001	48051	400849	0	0	0	448900
861016	0	486090	1658	0	0	487748
861101	0	496078	43528	100	0	539706

Appendix 6 (continued)

Mass (10^3 kg) of dissolved oxygen in Chesapeake Bay at saturation

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
861201	0	257636	324638	10353	0	592626
870101	0	30	622357	24882	0	647269
870201	0	0	555983	144529	0	700512
870301	0	0	654367	19677	0	674044
870316	0	0	640723	0	0	640723
870401	0	16236	593052	0	0	609289
870416	0	394754	165118	0	0	559872
870501	0	510960	32876	0	0	543836
870516	0	508338	0	0	0	508338
870601	0	475739	0	0	0	475739
870616	232	455627	0	0	0	455859
870701	208620	228059	0	0	0	436679
870716	343140	84179	0	0	0	427319
870801	401747	20781	0	0	0	422527
870816	396867	25069	0	0	0	421936
870901	272088	160332	0	0	0	432419
870916	258298	173587	0	0	0	431886
871001	0	474528	2527	0	0	477055
871016	0	501279	1205	0	0	502484
871101	0	457272	99785	0	0	557057
871201	0	41571	564725	10919	0	617214
880101	0	0	484123	226340	0	710463
880201	0	0	529329	159080	0	688408
880316	0	0	644099	228	0	644327
880401	0	317750	258657	0	0	576406
880416	0	378534	188388	0	0	566922
880501	0	530801	1221	0	0	532022
880516	0	491436	724	0	0	492160
880601	0	482706	0	0	0	482706
880616	8579	447561	0	0	0	456140
880701	41971	407146	0	0	0	449117
880716	274804	156855	0	0	0	431659
880801	390106	32952	0	0	0	423058
880816	324857	105218	0	0	0	430075
880901	20683	424120	0	0	0	444804
880916	172	448419	0	0	0	448592
881001	15804	443153	0	0	0	458957
881016	0	506432	5595	0	0	512028
881101	0	454905	95524	0	0	550429
881201	0	183070	408264	6980	0	598314
890101	0	0	637867	23161	0	661028
890201	0	0	637927	25006	0	662932
890301	0	0	670042	0	0	670042
890401	0	190520	403325	0	0	593845
890416	0	350562	219074	0	0	569636
890501	0	509814	17143	0	0	526956
890516	0	496897	25488	0	0	522385

Appendix 6 (continued)

Mass (10^3 kg) of dissolved oxygen in Chesapeake Bay at saturation

Date (YYMMDD)	DO concentration range (mg/l) 5-7.5	7.5-10	10-12.5	12.5-15	>15	Total
890601	1779	461499	0	0	0	463278
890616	98079	350638	0	0	0	448717
890701	189670	250991	0	0	0	440661
890716	210205	225925	0	0	0	436131
890801	87438	355357	0	0	0	442795
890816	118667	319338	0	0	0	438005
890901	114574	325222	0	0	0	439796
890916	630	457465	0	0	0	458095
891001	0	490798	2472	0	0	493269
891101	0	498198	33135	0	0	531333
891201	0	0	619828	54910	0	674738
900101	0	0	257084	470441	0	727525
900201	0	3616	611801	52480	0	667898
900301	0	0	621987	39018	0	661004
900401	0	172467	428650	0	0	601117
900416	0	294053	285247	0	0	579300
900501	0	510758	0	0	0	510758
900516	0	498572	0	0	0	498572

Note: (1) Saturation level is determined by water density.

(2) These values could exist if biological activity and chemical oxygen demand were not present.

Dates are in YYMMDD format where DD=01 indicates data from the first two weeks of the month and DD=16 indicates data from the last two weeks of the month.

Appendix 7

Mass (kg) of chlorophyll in Maryland Chesapeake Bay water (1976-1989)

Chlorophyll concentration range (ug/l)

Date (YYMM)	0-5	5-10	10-15	15-20	20-25	>25	Total
7606	23382	86630	71858	12243	2165	338	196617
7703	57965	64155	25723	0	0	0	147844
7704	0	29449	196446	37856	18949	69771	352471
7706	54115	55864	20902	20279	1515	0	152674
7707	2026	24154	36165	35953	31205	1086442	1215946
7708	28	90083	53522	71216	44558	76912	336320
7709	43761	64959	15266	11269	12114	28583	175952
7710	31028	104138	14650	3716	0	0	153532
7711	40042	90897	0	0	0	0	130939
7803	47977	46535	6273	3353	122	0	104261
7804	17784	0	0	0	0	0	17784
7806	33507	60164	82341	935	0	0	176947
7807	30181	79061	40424	13634	761	0	164061
7808	20243	64860	53906	80199	14259	10398	243867
7809	27544	93129	23417	20953	8786	41358	215188
7810	27589	74570	46718	18768	6602	15190	189436
7904	68406	2909	2672	5492	5103	46912	131493
7905	1169	19256	3280	5479	9454	1036391	1075030
7906	38489	62073	16096	30498	30640	11289	189085
7910	54558	33821	5841	0	0	0	94220
8004	8403	127995	53617	4239	0	0	194254
8005	5	8292	19825	42295	130898	510871	712186
8006	10921	59348	136257	19798	6452	59308	292084
8007	29276	77332	9187	12803	17808	117424	263830
8010	0	8095	49253	59380	148755	400584	666066
8105	2173	35548	138528	17472	28986	208761	431468
8203	47247	20	0	0	0	0	47267
8204	28836	86390	22786	45	0	0	138056
8206	29788	54591	56	0	0	0	84435
8304	30481	80887	60007	5441	2963	1447	181226
8403	41454	58933	1614	0	0	0	102001
8404	55290	35232	3857	0	0	0	94379
8405	49335	46356	3764	0	0	0	99454
8406	18311	80400	47201	6084	5817	190320	348132
8407	15954	38928	105813	54043	21811	24792	261341
8408	11510	102277	40093	37649	8398	18114	218040
8409	14909	63618	76985	61772	27590	20406	265281
8410	25486	79863	53445	6267	2420	22427	189907
8411	35590	81569	8912	0	0	0	126070
8412	13687	139620	28004	0	0	0	181311
8501	0	14870	275847	0	0	0	290717
8502	0	46182	213789	37334	2069	1718	301093
8503	867	33111	128297	104543	55189	47203	369209
8504	156	9333	5497	37215	151869	447985	652055
8505	8690	70427	68497	35743	30856	157471	371683
8506	23096	83236	48497	9901	1070	71669	237469
8507	35576	45898	26591	9722	8699	56605	183090
8508	33618	64898	50471	12481	7519	12216	181202

Appendix 7 (continued)

Mass (kg) of chlorophyll in Maryland Chesapeake Bay water (1976-1989)

Date (YYMM)	Chlorophyll concentration range (ug/l) 0-5	5-10	10-15	15-20	20-25	>25	Total
8509	59186	39918	1482	0	0	0	100586
8510	58690	29944	16816	8842	7564	18013	139869
8511	37384	80714	20459	0	0	0	138557
8512	52934	1909	0	0	0	0	54843
8601	17414	134751	7493	0	0	0	159658
8602	1534	129442	83360	10849	241	0	225427
8603	6694	134921	58131	1294	107	0	201147
8604	2360	16076	158187	131849	33037	15935	357444
8605	33283	61268	19302	21518	23827	99710	258909
8606	18704	115637	30477	496	480	0	165795
8607	25649	82079	22108	9629	9079	39050	187594
8608	19743	103371	32286	4002	3745	25064	188210
8609	52267	56297	13270	1639	1533	0	125005
8610	42072	64544	11873	3246	699	0	122434
8611	34007	95026	27421	1713	0	0	158167
8612	17190	29363	48386	57563	51646	158092	362241
8701	16897	129943	42684	0	0	0	189525
8702	1359	99831	82981	36289	21390	13235	255085
8703	33	82796	85106	68591	36131	40916	313572
8704	1063	17139	26453	36240	165780	338452	585126
8705	9	6546	65906	93151	69478	368415	603505
8706	9363	58138	35843	76812	80870	103457	364484
8707	18409	82466	54324	20359	8566	109974	294097
8708	27033	67334	33235	35017	19100	21306	203024
8709	19268	82093	64345	17267	13144	11194	207311
8710	26772	89655	45656	19010	0	0	181093
8711	28626	32419	44419	16454	6468	427	128813
8712	29382	88320	31069	16007	4569	0	169346
8801	5152	131659	70416	3365	0	0	210591
8802	4246	62115	138547	37960	33492	14657	291018
8803	453	52021	174958	33932	29800	25080	316243
8804	2387	49978	39714	35142	71789	314409	513419
8805	462	16968	44215	55847	66602	473960	658053
8806	13447	40572	118435	77262	24228	9449	283394
8807	12498	105219	53652	27781	11044	0	210194
8808	16299	92200	19963	17880	16800	144901	308044
8809	12273	66464	105123	58874	1683	0	244417
8810	17424	129870	10185	0	0	0	157479
8811	89585	13514	0	0	0	0	103099
8812	49646	29086	27459	7285	0	0	113476
8901	35423	80724	52492	5068	0	0	173706
8902	54075	70432	17203	0	0	0	141710
8903	74597	22125	6479	0	0	0	103201
8904	69007	25607	0	0	0	0	94614
8905	33664	77910	45212	23708	323	0	180816
8906	19923	89240	49975	25708	2085	0	186931
8907	18155	30028	62108	99771	63523	15843	289429

Appendix 8

Mass (kg) of chlorophyll in Chesapeake Bay water (1984-1990)

Chlorophyll concentration range (ug/l)

Date (YYMMDD)	0-5	5-10	10-15	15-20	20-25	>25	Total
840601	37564	199667	105578	88441	65917	156755	653922
840701	22030	107342	209931	159622	104208	172444	775577
840716	36266	162886	190871	109204	36361	11044	546631
840801	38914	190576	179830	55697	21067	15413	501496
840816	23867	222413	212127	47598	14169	2833	523006
840901	20677	205323	284399	30249	4629	9039	554316
840916	30145	244670	118144	47264	30065	90770	561058
841001	48451	253714	97216	42469	10095	18254	470199
841016	47306	250069	102491	35096	10865	2408	448236
841101	103622	186235	21520	1141	0	0	312518
841201	58268	258645	93212	513	0	0	410639
850101	13131	251027	259021	0	0	0	523179
850201	0	103355	445539	164331	9885	22207	745316
850301	19913	163812	214737	117103	73871	94646	684082
850316	19797	95520	192676	227724	187529	64251	787496
850401	15096	31770	77421	175744	246583	648517	1195132
850416	45250	35624	51859	136931	135005	316485	721153
850501	76314	155436	64848	31150	16427	304408	648584
850516	93015	116258	71702	22118	5409	61931	370433
850601	112373	144538	10950	1925	1038	254	271078
850616	80726	186755	58982	16720	1484	74142	418808
850701	108779	122558	24189	10186	10671	60294	336677
850716	85325	138234	26062	17755	13886	14156	295418
850801	63387	199718	101135	38910	4461	710	408321
850816	89070	171256	47202	23349	6820	49100	386797
850901	103998	132128	19355	4433	4552	3877	268343
850916	97597	124030	9900	2993	1265	603	236387
851001	84294	161068	78934	15228	10811	22542	372878
851016	138282	41859	6560	4273	3596	22456	217026
851101	77651	183141	88844	14582	1327	4134	369680
851201	131344	81763	1887	483	0	0	215478
860101	13754	160946	215493	150996	113218	36137	690543
860201	13969	290121	153090	32766	1963	103	492012
860301	18931	286993	159200	24866	6956	1869	498815
860316	14232	99811	340423	166888	62969	9245	693569
860401	16040	113615	213257	220409	112368	116325	792014
860416	25097	148962	273106	130029	18575	5556	601325
860501	104543	118360	29477	14097	24032	175339	465848
860516	113243	145304	27429	22843	27265	32979	369063
860601	71972	240925	14272	3035	1864	7363	339432
860616	81794	196163	56739	13867	2307	27048	377919
860701	68978	164307	105731	36999	7764	79191	462970
860716	74013	160382	66715	34403	13158	133832	482502
860801	83689	167677	19291	7299	5210	33353	316519
860816	23580	258737	167318	30492	31097	10954	522178
860901	99697	179939	38354	4273	4295	804	327363
860916	122599	92302	9256	3104	3036	34009	264306
861001	123295	68024	16305	8720	1888	776	219008
861016	53709	210287	114288	25596	308	0	404187

Appendix 8 (continued)

Mass (kg) of chlorophyll in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	Chlorophyll concentration range (ug/l) 0-5	5-10	10-15	15-20	20-25	>25	Total
861101	105249	145136	32540	1528	0	0	284453
861201	105024	67031	41272	47135	43959	109904	414326
870101	15804	165162	326818	89662	3237	3885	604568
870201	1435	177593	257508	145297	83107	45483	710423
870301	4624	176603	231931	169580	81607	64767	729112
870316	126	61119	285010	262924	178837	146073	934090
870401	2261	13856	29483	26932	148527	1536982	1758041
870416	5307	23348	36060	88413	158006	1625972	1937105
870501	2255	11398	73394	157683	155928	1297201	1697858
870516	3182	21042	70908	152008	251925	1015299	1514364
870601	9866	111190	150010	150871	196832	380652	999421
870616	64712	235843	64583	14050	1845	55	381089
870701	70570	210728	63014	9226	6046	3248	362832
870716	60273	169199	104308	60279	32091	89990	516140
870801	93710	158449	39635	17977	18031	50610	378412
870816	68076	208175	90536	24035	9091	44387	444299
870901	32617	248917	123542	48096	15503	5863	474539
870916	108421	90864	28895	14739	10899	33007	286825
871001	101951	116166	46985	7104	149	0	272354
871016	49730	282847	62404	11176	2106	1153	409415
871101	125012	75310	28634	15180	9237	913	254286
871201	96153	191976	26584	16947	6073	2611	340343
880101	9814	216486	256422	89174	22004	33157	627057
880201	7946	67902	287275	279787	120681	61931	825521
880316	36954	219321	223891	9439	0	0	489605
880401	39807	98775	114675	180160	196324	138583	768323
880416	22438	87422	78844	133550	124039	864304	1310598
880501	25342	35679	90401	117952	111253	1199622	1580249
880516	46140	94952	79484	95816	99891	417140	833423
880601	42107	127474	121982	156526	142138	161714	751942
880616	60241	201927	86735	12733	7621	14645	383903
880701	72862	203638	48855	11475	4514	30386	371730
880716	50182	170132	142510	65303	33168	22673	483967
880801	66985	165901	111575	23097	11821	145193	524572
880816	37688	172636	171793	86573	41473	21952	532114
880901	63413	179376	157115	36157	14019	2419	452498
880916	73342	159928	92634	102633	24149	0	452686
881001	96994	196141	14087	152	0	0	307373
881016	30778	322587	64079	730	513	0	418686
881101	139799	141662	0	0	0	0	281461
881201	157886	36544	19733	7506	0	0	221668
890101	53309	244866	92554	7871	0	0	398600
890201	144314	97941	20123	0	0	0	262378
890301	140403	118405	720	0	0	0	259529
890401	146228	106224	7602	733	0	0	260787
890416	164508	67878	4699	0	0	0	237085
890501	123409	134159	58231	1042	0	0	316841
890516	111541	125859	44244	16153	8451	6023	312272
890601	63643	229519	57326	13272	982	0	364742

Appendix 8 (continued)

Mass (kg) of chlorophyll in Chesapeake Bay water (1984-1990)

Chlorophyll concentration range (ug/l)

Date (YYMMDD)	0-5	5-10	10-15	15-20	20-25	>25	Total
890616	59847	181380	131073	42135	18900	17721	451057
890701	30851	121794	189671	197068	88176	36436	663996
890716	34194	135407	210801	139307	39531	12730	571971
890801	25623	103937	232629	183670	75794	120950	742602
890816	29578	148413	241890	80330	43581	111435	655227
890901	41635	251439	131223	46610	15028	6963	492898
890916	20745	236714	215377	51263	4278	0	528377
891001	16475	195035	211004	188726	6360	1510	619111
891101	33508	322023	73228	1391	0	0	430150
891201	3772	252700	258268	55859	27478	704	598780
900101	5407	161810	263155	193329	47617	52265	723584
900201	13584	77948	333175	174207	115853	65334	780100
900301	10833	62996	249165	339134	144024	17668	823822
900401	7388	34627	70078	101221	139132	1167321	1519767
900416	16510	36687	60265	101069	105560	1414782	1734872
900501	33912	94073	101005	70213	78344	479271	856818
900516	132883	95863	28222	8744	931	0	266644

Appendix 9

Mass (10^3 kg) of dissolved inorganic nitrogen in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	DIN concentration range (mg/l) 0.0-0.015	0.015-0.05	0.05-0.1	0.1-0.5	>0.5	Total
840601	0	0	90	13867	2452	16409
840701	0	181	864	6780	4557	12382
840716	0	313	1580	4717	5841	12449
840801	0	573	1329	4835	2850	9586
840816	0	347	1841	4440	1487	8114
840901	0	546	1573	4530	966	7615
840916	0	424	1806	4104	943	7277
841001	0	254	2140	4109	988	7491
841016	0	1096	965	2990	1161	6213
841101	0	0	844	7687	1940	10471
841201	0	46	2701	3222	2963	8931
850101	0	5	1058	8058	2471	11592
850201	0	376	583	9062	254	10276
850301	0	360	758	7842	4959	13919
850316	0	434	710	6286	5085	12514
850401	0	363	926	5964	4943	12197
850416	0	521	1005	5870	2637	10032
850501	0	341	754	7234	1288	9617
850516	0	730	748	4834	798	7110
850601	0	770	956	4053	1059	6838
850616	20	764	1125	2859	1134	5902
850701	27	812	1198	2551	505	5093
850716	25	771	1209	3150	239	5393
850801	18	696	1113	3117	132	5076
850816	0	329	1852	3683	256	6120
850901	23	628	981	3993	94	5719
850916	0	147	1499	5561	213	7420
851001	0	190	1032	6014	671	7907
851016	0	246	1837	4349	803	7235
851101	0	243	1102	6888	1581	9814
851201	0	0	0	12851	5988	18839
860101	0	79	920	9776	5260	16035
860201	0	176	483	9402	6743	16804
860301	0	79	234	9694	14113	24120
860316	0	20	220	10118	15759	26117
860401	1	100	302	9196	13655	23254
860416	1	104	246	10982	11579	22912
860501	1	161	531	11687	3030	15412
860516	8	207	591	10110	1338	12254
860601	52	293	854	7099	622	8920
860616	11	1186	679	3095	1325	6296
860701	52	992	1109	1919	72	4145
860716	24	870	1449	1864	75	4282
860801	16	603	1300	4336	416	6671
860816	16	773	1538	2361	441	5129
860901	1	886	1399	2286	272	4844
860916	0	127	2462	3382	118	[illegible]

Appendix 9 (continued)

Mass (10^3 kg) of dissolved inorganic nitrogen in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	DIN concentration range (mg/l) 0.0-0.015	0.015-0.05	0.05-0.1	0.1-0.5	>0.5	Total
861001	0	128	2121	4417	533	7199
861016	1	253	1980	4260	477	6971
861101	0	69	1667	5184	2100	9020
861201	0	4	146	10187	4056	14392
870101	0	16	943	8506	5357	14822
870201	7	191	791	9060	4916	14966
870301	7	204	590	9261	4315	14377
870316	14	342	690	8214	5082	14341
870401	78	248	643	7075	6039	14083
870416	57	454	616	5739	7597	14463
870501	78	231	543	7249	3645	11745
870516	91	587	534	4755	828	6795
870601	95	784	461	3782	794	5916
870616	68	534	1517	2837	1048	6004
870701	58	480	1200	3956	453	6146
870716	67	968	718	2055	481	4288
870801	33	679	1577	2417	260	4966
870816	39	791	1439	1957	249	4475
870901	29	691	1111	3498	484	5814
870916	3	197	1571	5095	1290	8156
871001	1	46	311	8786	1961	11104
871016	6	861	928	3007	1373	6174
871101	0	170	1481	5675	2081	9406
871201	0	5	654	8544	3603	12806
880101	17	311	939	6835	2680	10782
880201	87	348	587	6860	5836	13718
880316	0	326	1065	6092	7854	15337
880401	15	355	947	5418	8882	15618
880416	84	529	443	5094	5738	11888
880501	84	632	560	4885	3229	9389
880516	52	750	293	5115	3854	10065
880601	64	678	594	4596	1802	7733
880616	25	908	857	3143	995	5928
880701	36	1003	585	1761	555	3940
880716	48	641	1291	2684	296	4959
880801	56	852	856	2348	398	4510
880816	37	998	792	2746	1213	5786
880901	5	801	1134	2966	1244	6151
880916	42	684	1228	2806	742	5503
881001	8	529	1557	3564	1077	6735
881016	16	1161	453	2335	685	4650
881101	1	823	1033	3834	1749	7440
881201	0	207	1843	4270	2240	8560
890101	12	1213	547	763	284	2819
890201	32	544	768	4294	2523	8161
890301	0	104	1361	8695	0	10159

Appendix 9 (continued)

Mass (10^3 kg) of dissolved inorganic nitrogen in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	DIN concentration range (mg/l) 0.0-0.015	0.015-0.05	0.05-0.1	0.1-0.5	>0.5	Total
890401	2	150	475	8434	6693	15755
890416	9	158	529	8259	8801	17756
890501	0	110	560	10833	3345	14848
890516	0	38	558	10170	8170	18936
890601	92	194	506	7504	6250	14546
890616	70	472	603	4567	7681	13393
890701	49	510	577	6235	3570	10941
890716	55	431	891	5447	3850	10673
890801	42	377	808	6366	3544	11137
890816	17	437	882	5681	1993	9011
890901	14	647	922	4095	1140	6818
890916	4	39	1209	6776	2512	10539
891001	18	120	1516	5556	2023	9232
891101	28	618	423	6145	3659	10874
891201	8	284	1265	7119	3278	11955
900101	6	154	882	8099	1952	11093
900201	65	377	743	4652	10385	16221
900301	80	261	495	5342	10952	17130
900401	107	264	331	5778	9289	15769
900416	148	216	506	4778	8562	14209
900501	258	147	351	4682	5927	11364
900516	58	510	505	5444	4492	11009

Appendix 10

Mass (10^3 kg) of dissolved inorganic phosphorus in Chesapeake Bay water (1984-1990)

Date	DIP concentration range (mg/l)						
(YYMMDD)	0-0.0015	0.0015 -0.005	0.005-0.01	0.01-0.05	0.05-0.1	0.1-1.0	Total
840601	0	0	0	754	0	0	754
840701							
840716	0	0	143	647	50	3	843
840801	0	0	162	540	16	0	718
840816	0	0	136	768	32	0	936
840901	0	0	146	590	60	0	796
840916	0	0	179	428	0	0	606
841001	0	0	144	576	0	0	720
841016	0	0	185	394	0	0	579
841101	0	0	186	489	0	0	675
841201	0	0	202	321	0	0	523
850101	0	0	211	348	0	0	558
850201	0	0	208	310	0	0	517
850301	0	35	133	470	3	0	641
850316	0	59	82	494	2	0	637
850401	0	53	74	424	1	0	551
850416	0	53	264	149	0	0	466
850501	0	26	137	338	0	0	502
850516	0	9	84	475	0	0	568
850601	0	21	133	375	0	0	530
850616	0	15	142	394	0	0	551
850701	0	6	105	600	0	0	711
850716	0	19	81	753	17	0	869
850801	0	18	79	682	64	0	843
850816	0	0	41	934	1	0	977
850901	0	14	69	748	88	0	918
850916	0	16	58	840	23	0	937
851001	0	4	97	627	5	0	733
851016	0	21	113	604	18	0	757
851101	0	14	75	678	6	0	773
851201	0	0	98	596	0	0	694
860101	0	50	268	135	0	0	453
860201	0	48	74	386	0	0	509
860301	0	49	69	408	0	0	526
860316	0	44	83	337	0	0	465
860401	0	44	99	322	0	0	466
860416	0	53	54	356	0	0	463
860501	0	30	122	329	0	0	482
860516	0	34	53	415	0	0	502
860601	0	57	87	324	11	2	480
860616	0	20	142	374	0	0	536
860701	0	15	77	604	70	18	784
860716	0	6	71	935	70	2	1085
860801	0	4	76	775	380	20	1255
860816	0	16	53	690	51	0	810
860901	0	32	77	566	0	0	675
860916	0	29	83	679	0	0	790
861001	0	26	61	787	0	0	873

Appendix 10 (continued)

Mass (10^3 kg) of dissolved inorganic phosphorus in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	DIP concentration range (mg/l) 0-0.0015	0.0015 -0.005	0.005-0.01	0.01-0.05	0.05-0.1	0.1-1.0	Total
861016	0	28	89	552	0	0	669
861101	0	28	67	684	7	0	786
861201	0	38	87	557	0	0	682
870101	0	62	104	316	0	0	482
870201	0	50	138	250	0	0	438
870301	0	75	108	208	0	0	391
870316	0	67	127	234	0	0	428
870401	0	62	121	249	0	0	432
870416	0	44	139	290	0	0	473
870501	0	51	110	297	0	0	457
870516	0	50	161	188	0	0	399
870601	0	5	209	299	0	0	513
870616	0	24	120	516	15	0	676
870701	0	1	74	798	99	0	972
870716	0	28	87	590	100	0	805
870801	0	29	91	686	198	0	1004
870816	0	55	132	418	126	1	732
870901	0	75	112	448	18	0	654
870916	0	46	111	615	36	0	808
871001	0	10	115	742	10	0	877
871016	0	85	177	99	0	0	360
871101	0	37	204	306	0	0	547
871201	2	108	88	135	0	0	333
880101	12	127	54	17	0	0	210
880201	16	77	109	41	0	0	243
880316	0	160	25	1	0	0	186
880401	0	113	95	56	0	0	264
880416	0	117	84	12	0	0	213
880501	12	96	92	4	0	0	204
880516	12	93	65	52	0	0	222
880601	10	72	125	115	1	0	324
880616	5	62	173	108	0	0	349
880701	1	52	233	160	0	0	445
880716	2	76	99	345	1	0	523
880801	3	60	101	421	23	1	609
880816	5	66	77	449	54	0	651
880901	0	54	67	608	7	0	737
880916	6	66	114	252	0	0	438
881001	1	67	91	406	0	0	565
881016	14	78	97	133	0	0	322
881101	3	59	167	188	0	0	417
881201	7	84	74	88	0	0	253
890101	0	62	222	116	0	0	400
890201	0	113	150	67	5	0	334
890301	0	96	177	40	0	0	313
890401	12	101	86	26	0	0	296
890410	10	74	121	90			

Appendix 10 (continued)

Mass (10^3 kg) of dissolved inorganic phosphorus in Chesapeake Bay water (1984-1990)

Date (YYMMDD)	DIP concentration range (mg/l) 0-0.0015	0.0015 -0.005	0.005-0.01	0.01-0.05	0.05-0.1	0.1-1.0	Total
890501	20	71	84	31	0	0	207
890516	14	76	95	101	0	0	286
890601	14	55	120	135	0	0	324
890616	4	78	117	229	0	0	428
890701	1	62	123	410	38	0	635
890716	6	46	99	455	107	0	712
890801	0	32	130	666	105	0	933
890816	0	27	142	650	38	0	857
890901	5	47	112	470	59	0	693
890916	0	14	173	641	4	0	832
891001	6	89	87	187	0	0	369
891101	0	103	119	225	0	0	447
891201	0	142	82	105	32	0	362
900101	0	144	85	5	0	0	234
900201	0	152	67	28	0	0	248
900301	0	136	104	29	0	0	269
900401	0	134	72	52	0	0	258
900416	0	136	108	40	0	0	284
900501	1	146	72	58	0	0	277
900516	0	116	90	168	0	0	374