HYDROMETEOROLOGICAL DATA AND ITS USEFULNESS IN THE STUDY OF ALGAE BLOOMS IN THE POTOMAC RIVER

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INTRODUCTION

An extensive algae bloom occurred in the tidal freshwater portion of the Potomac River during the summer of 1983. The bloom was characterized by thick surface scums of algae in both the embayments and the mainstem of the river over a 20 mile stretch extending from Piscataway Creek, MD to Quantico, VA (see Figure 1). At times the river gave the appearance of having been painted bright green. This part of the Potomac has experienced large nuisance blooms over the past three decades. The magnitude of the 1983 bloom was indicated by peak chlorophyll-a concentrations in excess of 300 ug/l, with concentrations greater than 100 ug/l persisting for nearly two months at many locations. The species that became increasingly dominant as the summer progressed was identified as the blue-green algae Microcystis aeruginosa (MWCOG 1984).

The magnitude and unmistakable presence of the bloom was the cause of alarm and concern to many in the Washington Metropolitan Area. Recent improvements in Potomac water quality had been observed over the previous decade (GKY 1982; MWCOG 1983), and substantial amounts of money had been spent on pollution abatement. The return of nuisance bloom conditions was not anticipated and it generated much debate about potential causes and the effectiveness of water quality management.

Weather conditions over the summer of 1983 were unusual and thought to be a contributing factor to bloom development. An area of high pressure was anchored over the eastern half of the United States during July. This situation brought many exceptionally clear sunny days, above normal temperatures, light winds, and very little precipitation. These conditions persisted through August and into September. River flow in the Potomac also dropped steadily over the course of the summer. The physical environment appeared to be presenting optimal conditions for the growth of algae, and it was hypothesized that these conditions could to some degree explain the occurrence and the magnitude of the unexpected algae bloom.

The objective of this investigation was to evaluate physical environmental conditions observed during 1983 and to contrast them with the historical record in order to determine the uniqueness of the summer of 1983. Attention was thus directed at a small group of hydrometeorological measures that would tend to affect algal growth. The intent was not to identify the definitive cause of the 1983 bloom and its perpetuation, but to provide some explanation for the occurrence of the Microcystis bloom in terms of especially favorable but unusual conditions within the physical environment. In addition, the evaluation of the joint occurrence of favorable hydrometeorological conditions could be useful in predicting the
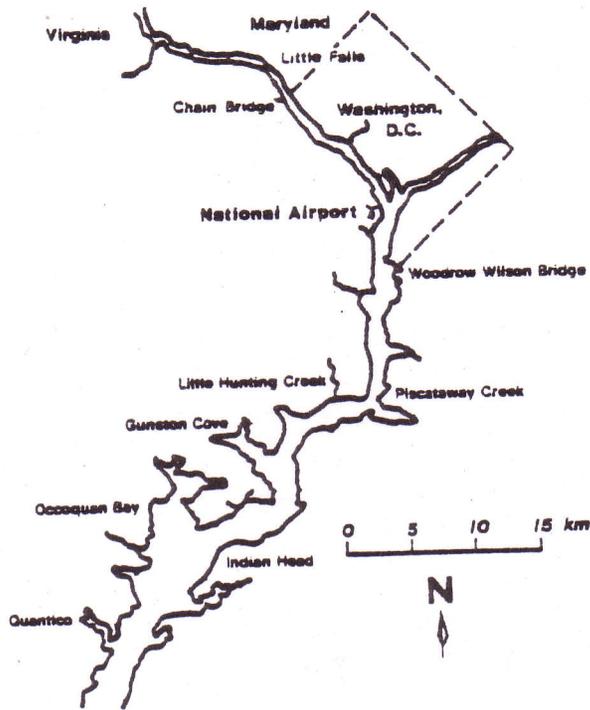
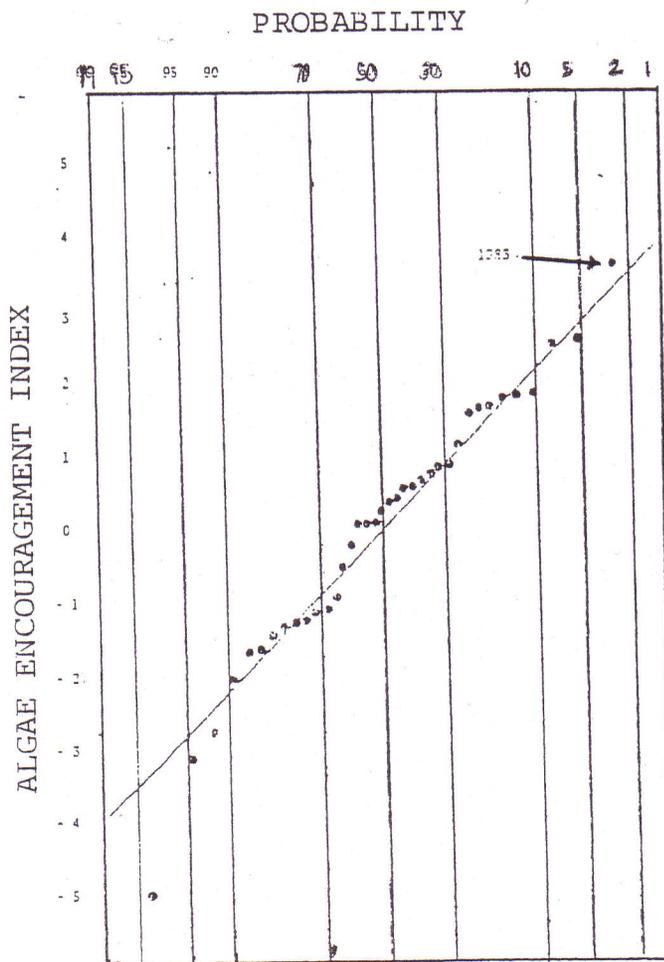# Figure 1. Map of Tidal Freshwater Potomac

Figure 2. Cumulative Frequency Distribution of Index Values

recurrence interval or return frequency for conditions capable of supporting an algae bloom.

METHODS

Hydrometeorological Data

Thirty-seven years of hydrometeorological records spanning the 1949 to 1985 period were evaluated. The specific measures of interest were percent of total possible sunshine, wind speed, and Potomac River discharge. These measures were chosen because they are either directly or indirectly related to algal growth, and long term records were available. Sunlight provides the energy for photosynthesis. Calmness and the minimization of wind-driven surface waves tend to promote light penetration into the water column. This occurs because the angle of incidence remains in an advantageous position over longer periods of time when it is calm (pinsak 1976). Vertical mixing and the resuspension of solids are also minimized during calm periods, and this leads to reduced turbidity and enhanced light penetration. Low levels of discharge play an equally important role since the delivery of suspended solids is lessened during low flow periods (Blanchard and Hahl 1984), and this reduces turbidity. In addition, low levels of discharge increase the retention or "flushing" time of the Potomac, and this provides time for blooms to develop.

Percent of possible sunshine and wind speed were observed at Washington National Airport (See Figure 1), a station immediately adjacent to the tidal Potomac (NOAA, 1949-1985). Both of these measures are observed on a daily basis. The former is derived as a percent from recorded minutes of sunshine and the total possible minutes of sunshine per day of year, and it ranges from 0% to 100 %. Average wind speed is also observed daily and it represents the mean of observed wind velocities in meters per second (m/s) regardless of direction. For Potomac discharge, the streamflow record in cubic meters per second (cms) at Little Falls, MD was utilized (USGS, 1949-1985). The drainage area above this gage is 29,940 km^2 (11,560 mi&s2), which represents nearly 90% of the total drainage to the tidal river.

Observed mean values for these measures for the months of July and August were combined into two-month "summer averages" for each of the 37 years. These months were singled out because they incorporate the greater part of the summer and the period during which nuisance blooms typically develop. From a data availability standpoint this choice was also quite convenient since monthly averages for the measures of interest were readily available in the previously referenced published reports.

Statistical analysis

The complete 37-year record of average summer values for the hydrometeorological measures is summarized in Table 1, along with an Index value described below. The summer averages for percent of total possible sunshine and average wind speed were found to be normally distributed. Potomac discharge had a skewed distribution, but the log of discharges was normally distributed. Discharge was thus replaced by the log of discharge in this analysis. Means and standard deviations were calculated for all three of the measures.

Table 1. Summary of hydrometeorological measures and index values.

AVERAGE CONDITIONS FOR JULY AND AUGUST

YEAR	Q CMS	LOG Q	WIND M/SEC	% SUN	INDEX
1949	408.12	2.61	2.68	59.65	-0.20
1950	91.13	1.96	4.00	56.80	-1.59
1951	119.06	2.08	3.51	76.95	1.71
1952	124.84	2.10	3.49	69.33	0.75
1953	84.73	1.93	3.49	72.54	1.72
1954	61.68	1.79	4.07	69.10	0.33
1955	440.35	2.64	4.31	54.58	-4.96
1956	217.89	2.34	3.42	57.14	-1.41
1957	45.43	1.66	4.22	67.06	0.16
1958	189.12	2.28	3.60	57.28	-1.63
1959	61.88	1.79	3.33	55.22	0.44
1960	106.99	2.03	4.43	63.76	-2.03
1961	88.02	1.94	3.06	65.44	1.84
1962	65.42	1.82	3.33	67.60	1.88
1963	47.07	1.67	3.64	75.41	2.57
1964	49.42	1.69	4.00	53.01	-1.16
1965	36.14	1.56	3.80	61.89	0.89
1966	17.45	1.24	3.73	66.03	2.65
1967	167.77	2.23	3.46	44.10	-2.73
1968	66.13	1.82	3.44	64.75	1.25
1969	148.03	2.17	3.31	54.54	-0.88
1970	81.87	1.91	3.08	63.83	1.70
1971	124.95	2.10	3.75	64.51	-0.49
1972	328.26	2.52	3.24	59.03	-1.33
1973	153.35	2.19	3.33	63.61	0.13
1974	99.29	2.00	3.22	59.39	0.53
1975	186.18	2.27	2.99	65.62	0.93
1976	89.43	1.95	3.82	71.31	0.67
1977	47.80	1.68	3.80	73.37	1.90
1978	276.40	2.44	3.82	70.64	-1.08
1979	154.17	2.19	3.80	62.93	-1.12
1980	108.66	2.04	4.07	78.24	0.62
1981	91.27	1.96	3.93	69.43	0.14
1982	133.98	2.13	3.29	67.69	0.93
1983	78.65	1.90	2.91	75.93	3.67
1984	254.77	2.41	3.89	54.50	-3.12
1985	92.60	1.97	3.49	50.00	-1.20
1986	67.13	1.83	4.20	50.00	-2.47
1987	78.04	1.89	3.70	60.80	-0.13

PRELIM.

MAX	440.3	2.64	4.43	78.2	
MIN	17.4	1.24	2.68	44.1	
MEAN	135.2	2.02	3.61	63.4	
ST DEV		.29	.40	8.1	

Table 2. Summary of Peak and Summer Avergae Chlorophyll-a Values.

Year	Index	Peak ug/l	Location	n	Sum Avg ug/l	n
1965	.79	88	Nr Piscataway	12	67	36
1966	2.54	141	W.Wilson Br	32	91	179
1968	1.17	139	Nr Gunston	14	76	157
1969	-0.96	104	Hallowing Pt	21	61	201
1970	1.63	107	Possum Pt	10	84	258
1977	1.82	145	Hallowing Pt	14	83	249
1978	-1.12	62	Hallowing Pt	11	45	192
1979	-1.18	58	Hallowing Pt	6	43	274
1980	0.57	82	Hallowing Pt	66	47	517
1981	.07	62	Rosier Bluff	19	53	286
1983	3.63	157	Hallowing Pt	81	78	681
1984	-3.19	66	Possum Pt	7	31	74
1985	-1.30	51	Indian Head	10	24	85

Development of the Index

In order to evaluate the joint occurrence of favorable environmental conditions during 1983, an Algae Encouragement Index (the Index) was conceived and developed. The Index is a simple model based on summer averages for the hydrometeorological conditions as shown in Table 1, with each given an equal weight. The Index was developed in order to evaluate the collective departure of the environmental factors away from individual mean or average conditions for each summer. The Index was calculated in a manner that assigned positive values to conditions thought to favor algal growth such as above normal sunshine, below normal wind, and below normal discharge. Negative values were assigned to conditions which tend to discourage algal growth such as below normal sunshine. Departures from normal were related to the standard deviation for each measure, and the Index (I) for year n was calculated as

$$I_n = \frac{(S_n - \bar{S})}{s_S} + \frac{(\bar{W} - W_n)}{s_W} + \frac{(\bar{LQ} - LQ_n)}{s_{LQ}}$$

where

S = percent sunshine

W = wind velocity in m/sec

LQ = common logarithm (base 10) of discharge in m^3/sec

s_i = standard deviation for each measure i

The calculated Index value (Table 1) provides a common measure of the extent to which hydrometeorological conditions were favorable or unfavorable for the growth of algae for each summer.

Comparison with Chlorophyll-a data

In order to test the predictive ability of the Index as a means of explaining the occurrence of algae blooms, Index values were evaluated against the observed body of Potomac algae data in the form of chlorophyll-a measurements (References). Chlorophyll-a, a plant pigment, is the most common measure of the overall algae or phytoplankton population. Sufficient amounts of data for the 70 km of the tidal river below the Fall Line were available for thirteen summer periods from the mid-1960's to the present. All mainstem near surface (<1m) observed chlorophyll-a values for calendar summers were included. The sources of data were the Chesapeake Bay Institute (1966), the FWPCA Chesapeake Technical Support Laboratory(Jaworsky et al 1969a, 1969b, 1971), the U.S. EPA Annapolis Field Office (Clark et al. 1978, 1980 and unpublished data), the U.S. Geological Survey (1981, 1984), unpublished data from the State of Maryland and the District of Columbia, and the data base maintained by the Metropolitan Washington Council of Governments for the Potomac Coordinated Monitoring Program (1982-1985). Temporal and spatial differences in the availability of chlorophyll-a data from year-to-year were significant, with the total number of observations ranging from 36 to 681 per summer.

Two measures of the abundance of algae as reflected in the chlorophyll-a observations were chosen for the comparison. In the first, all

observations from the entire 70 km stretch of the tidal river were pooled together for the calculation of a summer average for each year. In the second, the tidal river was linearly subdivided into 16 river segments ranging in length from 3 to 6 km. These segments were originally defined for water quality modeling purposes by Thomann et al. (1974), and they are used herein as a convenient way in which to organize data because most of the principal Potomac sampling stations are centrally located within the segments. All summer chlorophyll-a observations were grouped by segment. Arithmetic means were calculated for each segment, and the highest segment mean for each year was identified as the maximum or peak main channel summer average, which often indicated the peak of a bloom.

RESULTS

The Index was found to have an approximately normal distribution with a mean value of 0.00. The highest Index value of all 37 years was recorded in 1983. This value was over two standard deviations away from the sample mean, and it was substantially greater than that which was calculated for any other year. The calculation of the Index reveals the joint occurrence of very favorable conditions for the growth of algae during 1983. From a strictly hydrometeorological viewpoint, the plot of the cumulative frequency of Index values on a probability scale (Figure 2) suggests a return frequency for the joint occurrence of these conditions on the order of approximately once in fifty years.

Two attempts to correlate the Index values with observed algae conditions were made. In the first, Index values were compared with summer average concentrations for the entire upper 70 km of the tidal Potomac. This relationship is presented in Figure 3, and it shows a close association between the Index and summer average conditions ($r^2 = 0.72$). In all four years in which the summer average was >75 ug/l, the Index was greater than one standard deviation above the mean. With regard to low summer averages, in four of five years with an Index of <-1.0, summer averages were <50 ug/l.

Comparison with the average concentration at the point along the river where the highest or peak concentrations were observed during each summer was also undertaken. As shown in Figure 4, this correlation again suggests a strong association between the Index and observed chlorophyll-a data ($r^2 = 0.66$). The highest observed peak occurred in the year that produced the highest Index value (1983). The three years that registered an Index value greater than one standard deviation above the mean had the highest observed peaks. Further, the five highest peaks all occurred in years that had an Index >1.0. In contrast, in seven of the eight years in which the Index was <1.0, the observed peak concentrations were <100 ug/l.

DISCUSSION

Summertime blooms of blue-green algae represent the most serious examples of eutrophic or hypertrophic conditions in the Potomac. These blooms have been recurrent in the Potomac since mid-century. Specific blooms of Microcystis were first reported in the tidal freshwater river in the late 1950's (Stotts and Longwell 1962). Surveys during the 1965 to 1970 period also described large standing crops of Microcystis (Lear and Smith 1976). It was suggested in a report initiated by the Potomac Enforcement Conference of 1969 that the nuisance blue-green algae blooms in

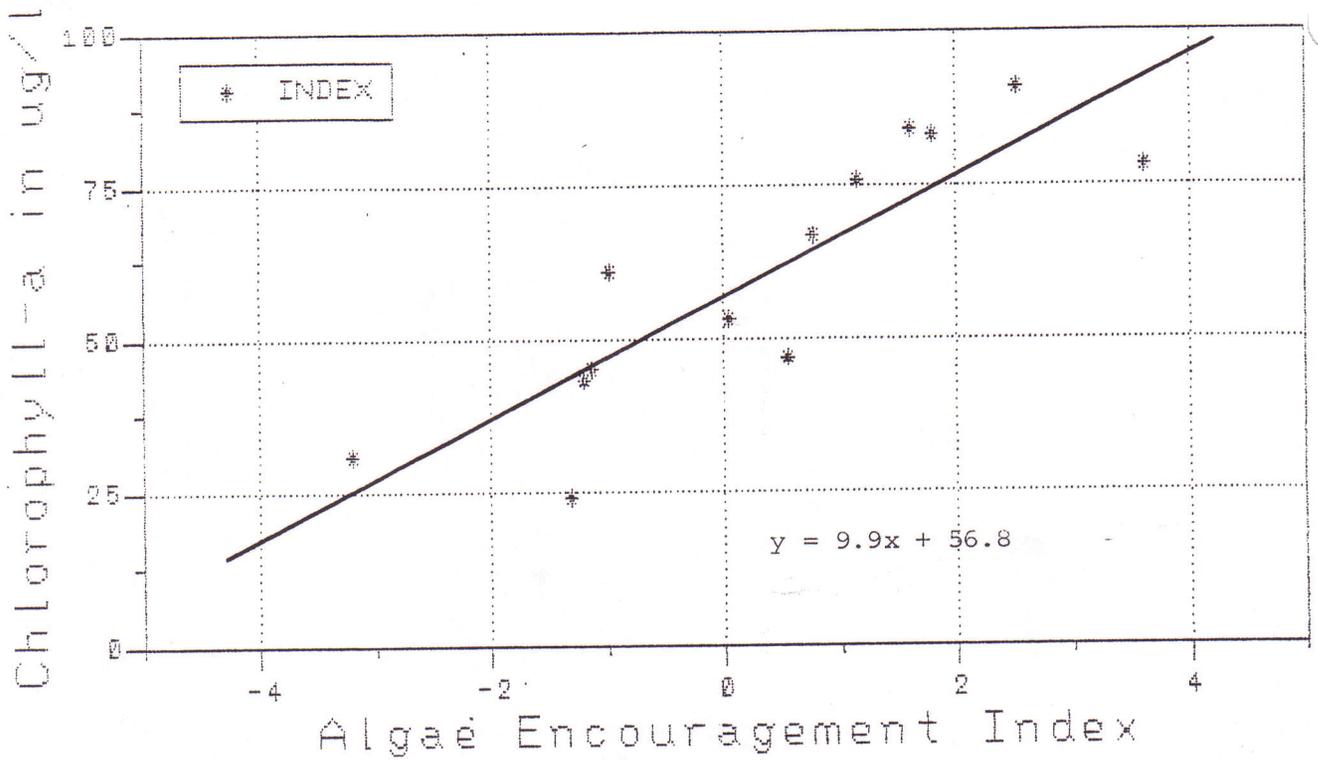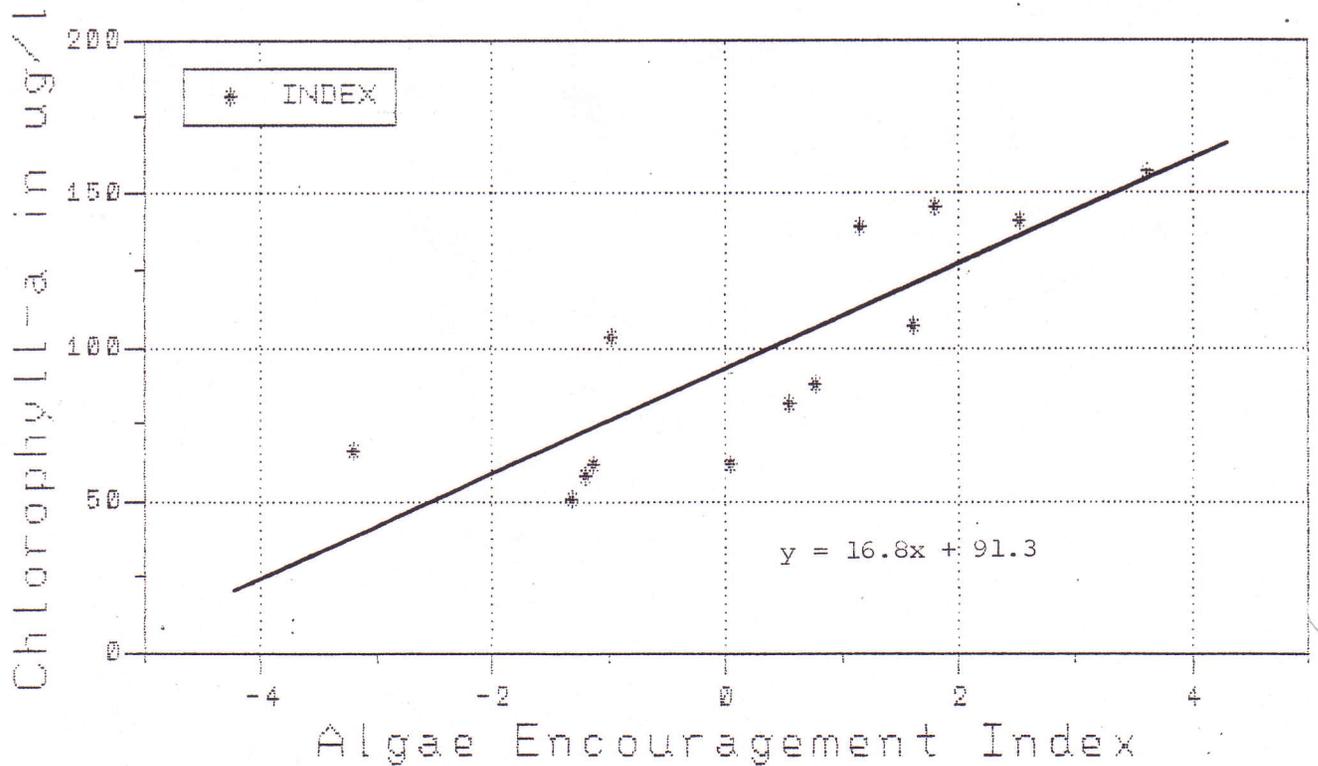Figure 3. Relationship Between Index and Summer Average Chlorophyll-a

$y = 9.9x + 56.8$

Figure 4. Relationship Between Index and Peak Chlorophyll-a

$y = 16.8x + 91.3$

the Potomac were associated with large increases in phosphorus and nitrogen loadings from wastewater plants (Jaworski et al. 1971). Since 1970 only two major blooms have occurred. A large bloom of the blue-green algae Oscillatoria was observed during 1977 (Clark and Roesch 1978). However, there was no surface scum associated with the Oscillatoria, and the visual and nuisance impacts were not as great as with similar high concentrations of Microcystis. The 1983 bloom represented a particularly severe outbreak of Microcystis with much attendant surface scumming. Representative spatial plots of summer mean chlorophyll-a concentrations for the bloom years of 1966, 1977, and 1983 from Chain Bridge at the head of the tidal Potomac to Quantico (km 66) are presented in Figure 5.

In spite of recent major reductions in phosphorus loadings to the Potomac due to the implementation of advanced waste treatment, nutrient limitations do not appear to prevent blooms from happening, especially beyond the 30 km mark. Previous studies have pointed out this rather constant fertility and overenrichment (Thomann and Fitzpatrick 1982), and the light limited nature of the Potomac (Cohen 1983). Given the fact that sufficient quantities of nutrients to support bloom levels of algal growth have been available in all recent years, but that nuisance blooms have occurred rather intermittently, it would appear that physical environmental conditions are indeed influential in determining whether or not a bloom will occur. This suggests that factors such as sunlight, turbidity and residence time may be the chief determinants, and that large blooms are likely to occur only when all are simultaneously in an optimal state for algal growth. The need for these physical conditions to be optimized at the same time is paramount for the success of a bloom. For example, sunlight must be accompanied with low levels of turbidity in order for light penetration to be maximized. Paerl (1983) has previously noted the importance of physical factors in determining blue-green algal bloom potential in the lower Neuse River in North Carolina.

The occurrence of blooms in the Potomac is certainly a complicated phenomena related to many factors including spring runoff, sediment phosphorus release, and other chemical and biological processes. However, the Index demonstrates that physical environmental conditions are extremely important in determining whether or not an algae bloom is likely to occur. Further, the Index suggests that the magnitude of a bloom is liable to increase the more favorable these physical environmental conditions are. Since the individual and joint frequency of occurrence of hydrometeorological conditions upon which the Index is based is known, predictions of the frequency with which blooms will occur due primarily to environmental conditions are possible. Use of the Index to predict the frequency or return period of high chlorophyll-a or "bloom-like" conditions is possible. For example, the regression in Figure 4 implies that peak main channel summer average concentrations in excess of 100 ug/l can be expected in years in which the Index equals or exceeds +0.5. The cumulative frequency graph in Figure 2 indicates the likelihood of the Index exceeding +0.5 in any given year is roughly 40%. This suggests that two years out of five would be expected to have environmental conditions favorable enough to encourage and support a peak summer average concentration equal to or greater than 100 ug/l. Taking this a step further, chlorophyll-a levels can be expected to exceed 125 ug/l once in ten years.

Application to summer average conditions can also be made. The probability graph (Figure 2) indicates there is a 50% chance that the Index for a given year will be greater than or less than 0.0. Similarly, one-in-ten year conditions could be expected to produce an Index of 2.0. Applying this to chlorophyll-a levels and the regression in Figure 3, summer average concentrations for the entire 70 km stretch of the upper Potomac can be expected to exceed 50 to 55 ug/l in one of every two years. Further, a summer average >75 ug/l can then be expected once in ten years.

Use of the Index to make predictions of chlorophyll-a concentrations should be valuable to water quality managers, especially those concerned with the development of chlorophyll-a goals or standards for the Potomac.

Figure 5. Summer Average Chlorophyll-a Values for 1966, 1977 and 1983
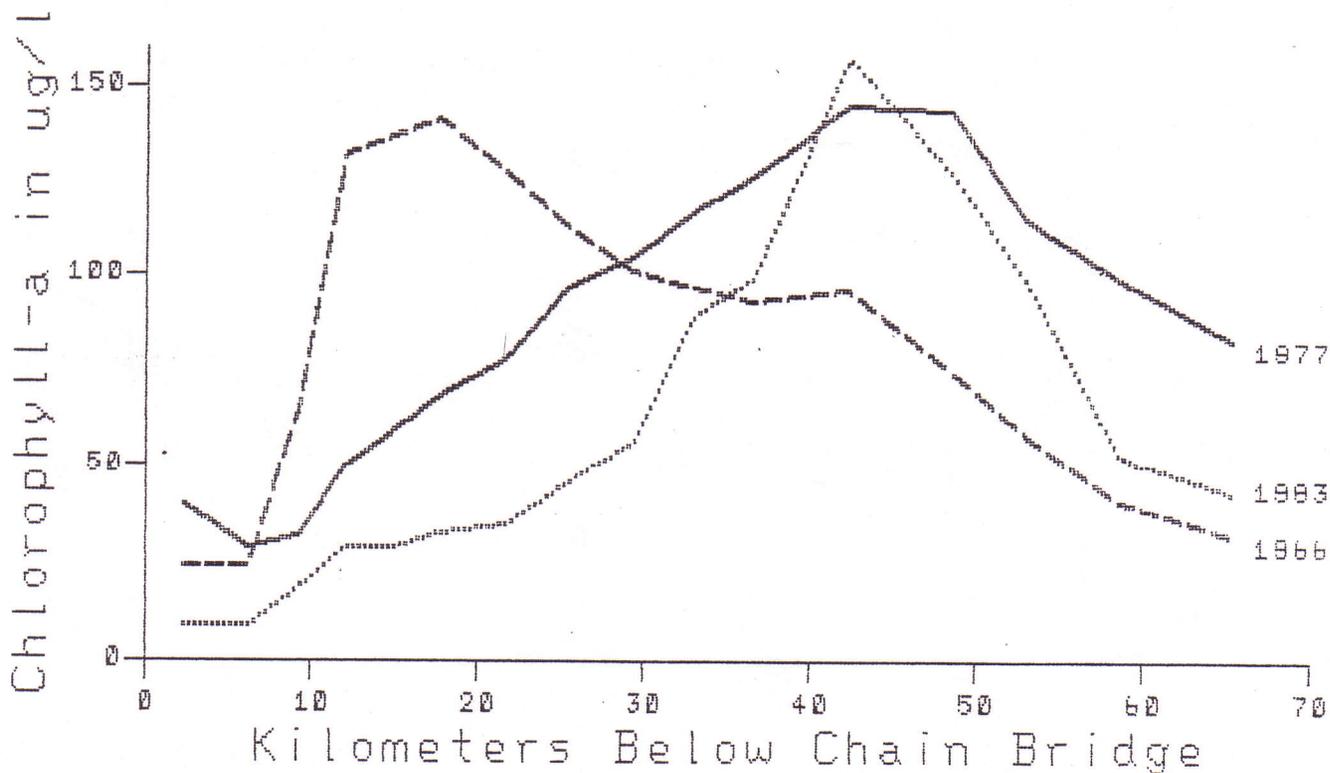
BLANCHARD, S.F.; AND D.C. HAHL. 1984. Transport of dissolved and suspended material by the Potomac River at Chain Bridge at Wahsington, D.C., water year 1978-81. U.S.G.S. Water Supply Paper 2233B.

CLARK, L.J. AND S.E. ROESCH 1978. Assessment of 1977 water quality conditions in the upper Potomac Estuary. EPA 903/9-78-008, U.S. EPA Annapolis Field Office, Annapolis, MD.

CLARK, L.J.: S.E. ROESCH AND M.M. BRAY 1980. Assessment of 1978 water quality conditions in the upper Potomac Estuary. EPA 903/9-80-002, U.S. EPA Annapolis Field Office, Annapolis, MD.

COHEN, R.H. 1983. Phytoplankton productivity, growth and light in the freshwater tidal Potomac. Estuarie 6: 30-xx.

GKY AND ASSOCIATES, INC. 1982. A decade of progress: tidewater Potomac Clean-up. A report to the Environmental Protection Agency. Springfield, VA.

JAWORSKI, N.A.;D.W. LEAR AND J.A. AALTO 1969a. A technical assessment of current water quality conditions and factors affecting water quality in the upper Potomac Estuary. FWCA, CTSL Tech. Report 5, Annapolis, MD.

JAWORSKI, N.A. 1969b. Nutrients in the upper Potomac river basin. FWPCA, CTSL Tech. Report 15, annapolis, MD.

JAWORSKI, N.A.; L.J. CLARK; AND K.D. FEIGNER. 1971. A water Resource-Water Supply Study of the Potomac Estuary. CTSL, Tech. Rept. 35. U.S. Environmental Protection Agency, Annapolis, MD.

LEAR, D.W.; AND SMITH, S.K. 1976. Phytoplankton of the Potomac Estuary. Proceedings of symposium on the Potomac Estuary: biological resources. Interstate Commission on the Potomac River Basin. Alexandria, VA.

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS. 1983. Potomac River water quality 1982: conditions and trends in Metropolitan Washington. Washington, DC.

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS. 1984. Potomac River water quality in 1983: condiitons and trends in metropolitan Washington. Washington, D.C.

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS. 1982-1985. Potomac Coordinated Monitoring Program Data Base. Washington, D.C.

NOAA 1949-1985. Local Climatological Data. National Climate Center, Asheville, NC.

PAERL, H.W. 1983. Factors regulating nuisance blue-green algal bloom potentials in the lower Neuse River, N.C. Report N. 188. WRRI, The University of North Carolina.

STOTTS, V.D.; AND J.R. LONGWELL. 1962. Potomac River Biological Investigation 1959. Supplement to Tech. Appendix, Part VII of the Report on the Potomac River Basin Studies. U.S. Dept. of Health, Educational Welfare. Annapolis, MD.