Summer 2005 ecological forecast technical documentation

for

Chesapeake Bay Mainstem dissolved oxygen,
Aquatic grasses, and
Potomac River harmful algal blooms

July 2005

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Dissolved Oxygen Forecast

Introduction

The relationship between spring nutrient loading and summer volume of anoxia is well established in Chesapeake Bay and in other estuaries (Hagy et al. 2004; Rabalais et al. 2002). Spring loads of Nitrogen (N) and Phosphorus (P) fuel spring algal blooms. Excessive N and P loads lead to spring blooms which exceed the grazing capacity of filter feeders. This excess settles on the bottom where it contributes to anoxia in the summer. The relationship is direct; the greater the nutrient load, the greater the summer anoxic volume.

The Chesapeake Bay Program (CBP) will attempt to use the linear model of the summer (June through September mean) anoxic volume vs. spring nutrient load (January through April cumulative) relationship to forecast the summer 2005 anoxic volume. This forecast will be made at the end of April 2005 and then will be updated and refined at the end of May with the January through May 2005 cumulative nutrient load.

The CBP is developing this forecast for two reasons. First, the CBP would like to be more proactive in the reporting of current year DO. Instead of reacting after low DO events occur, the CBP will set the stage for what the expected DO conditions are and then track and update that expectation through the summer. Second, the anoxia versus nutrient load model will help to highlight the relationship between nutrient loading and DO problems as well as elevated spring flows and DO problems.

Methods

1985 through 2004 Chesapeake Bay mainstem DO data were obtained from the CBP water quality data base. The Chesapeake mainstem includes the region of Chesapeake Bay extending from the Susquehanna River to the mouth of Chesapeake Bay not including the tributaries (Figure 1). This dataset contains water column data from ~44 fixed stations (Figure 1).1985 through 2003 below fall line point source total nitrogen (TN) and total phosphorus (TP) load data were obtained from the CBP point source data base for point sources on the northern eastern shore tributaries and the northern western shore tributaries. 1985 through 2005 TN and TP load data from the Susquehanna River were obtained from the USGS.

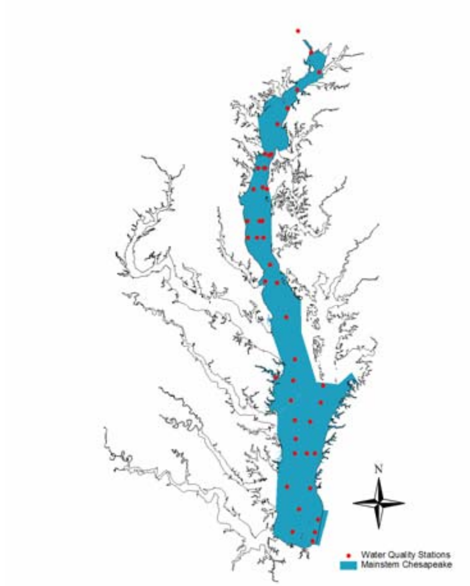


Figure 1. Map of Chesapeake Bay showing monitoring stations used in the forecast development and the portion of the Bay referred to as the mainstem.

To generate the anoxic volume data, dissolved oxygen data from the June through September time period from each year were interpolated cruise by cruise. An inverse distance weighted linear nearest neighbor interpolation was used to interpolate the fixed station data to a 3D grid based on the bathymetry of the mainstem Chesapeake. The cell dimensions of this grid are one kilometer wide by one kilometer long by one meter high for a total of 51,839 cells in the mainstem. From this grid data, the volume, in cubic kilometers with a DO concentration of <=0.2 mg/l was obtained. This gave the anoxic volume for each cruise. From this data the monthly mean anoxic volume was calculated and then ultimately, the June through September or summer mean anoxic volume. These volumes are shown in Table 1.

Cumulative point source TN and TP loads were obtained by summing the total load for each month and then generating a total January through April or Spring load. Unfortunately, there is an approximate 2 year lag between data collection and reporting of results. The 2004 and 2005 spring loads, therefore, had to be estimated based on the monthly load versus time relationships for 1984-2003 for TN and 1986-2003 for TP (Figure 2, 3, & 4). The phosphate detergent ban which was implemented in Maryland in December 1985, District Columbia in September 1985, and Pennsylvania in March 1990 caused a step trend in the data. To eliminate this step trend, the TP point source load versus time model was based on 1986 – 2003 data.

Table 1. Chesapeake Bay mainstem summer anoxic volumes for the past 20 years.

Year	Mean Summer Anoxic (DO<=0.2 mg/l) volume (km3)
1985	.506
1986	1.452
1987	0.590
1988	1.304
1989	1.141
1990	1.221
1991	1.138
1992	0.740
1993	2.488
1994	1.449
1995	0.960
1996	2.213
1997	0.751
1998	1.750
1999	0.460
2000	1.200
2001	0.622
2002	0.000
2003	0.506
2004	1.337

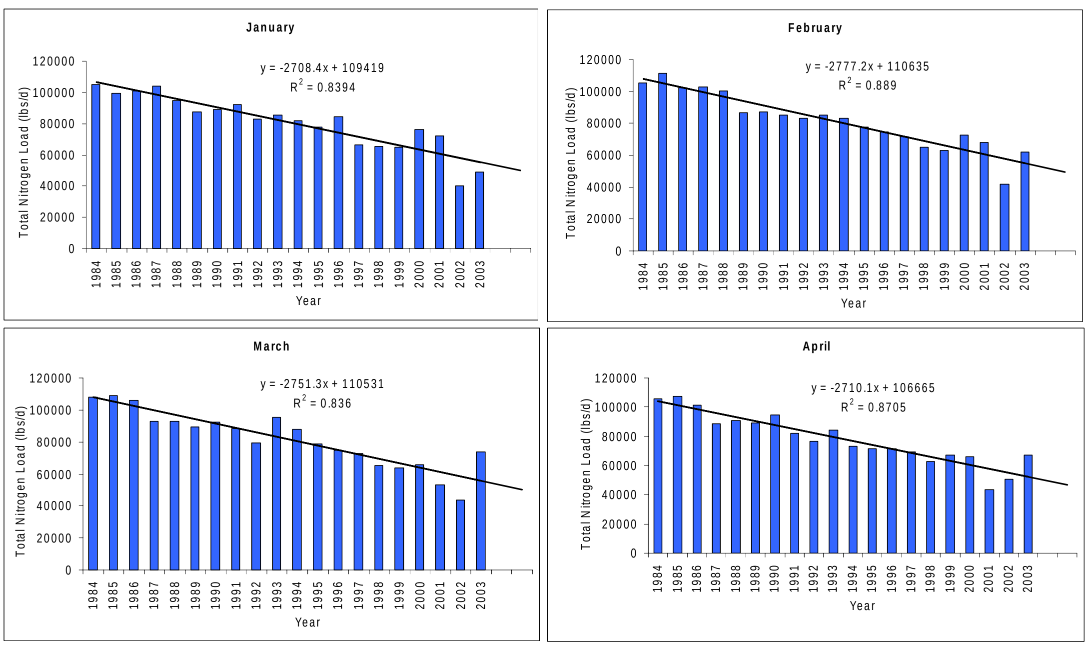


Figure 2. January through April upper Chesapeake Bay point source TN load over the past 20 years. Line fit and equation shown on each graph.

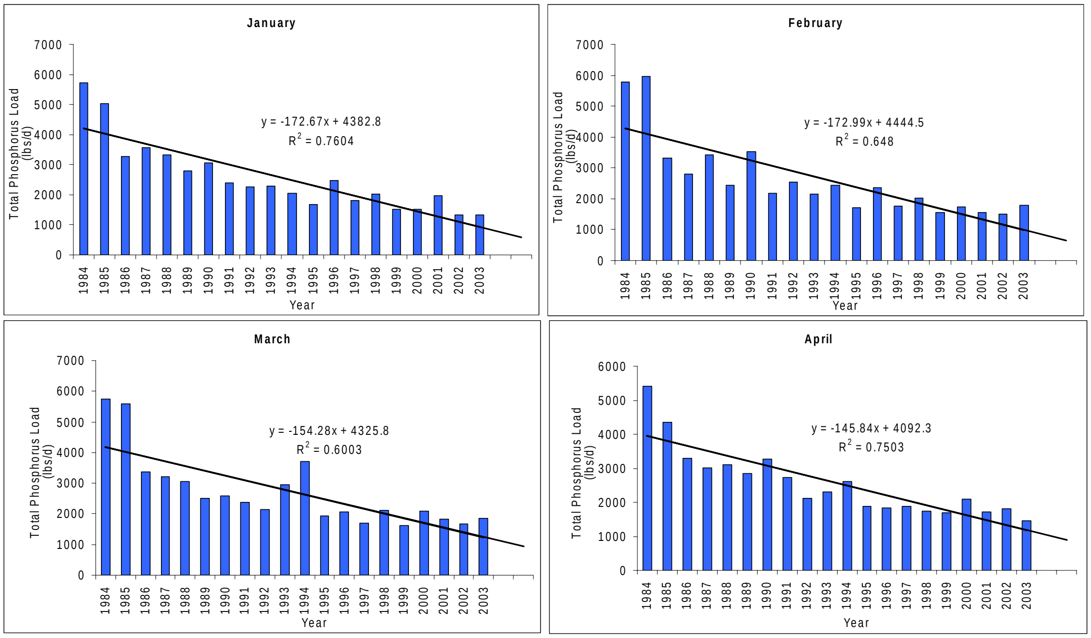


Figure 3. January through April upper Chesapeake Bay point source TP load over the past 20 years. Line fit and equation shown on each graph.

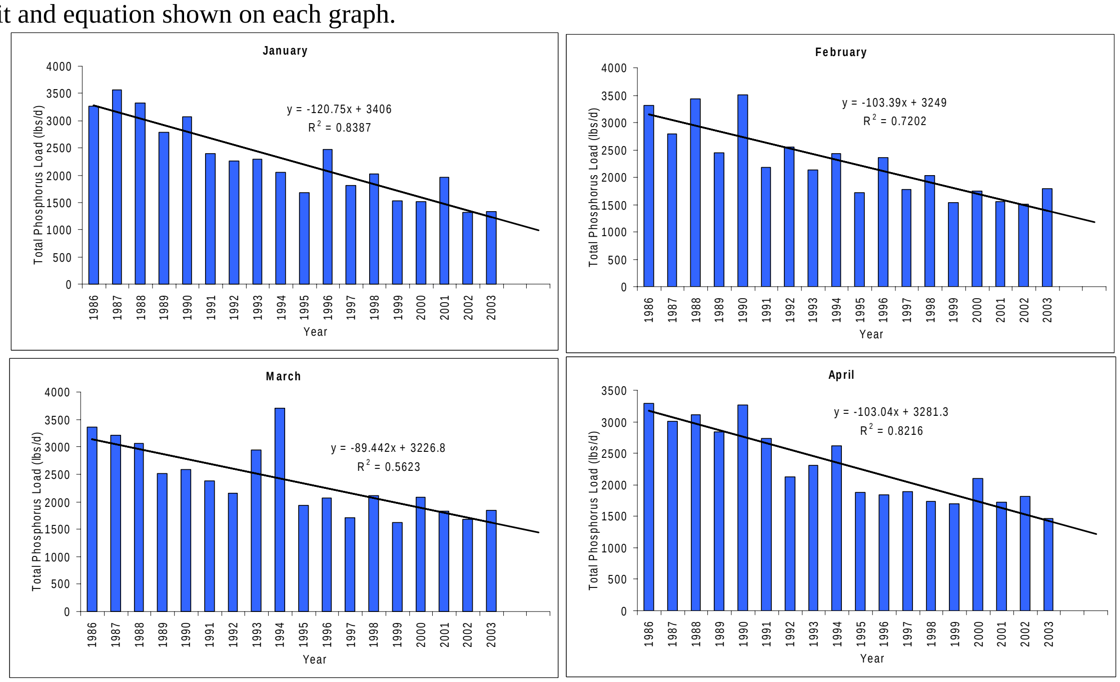


Figure 4. January through April upper Chesapeake Bay point source TP load over the past 18 years (1984 and 1985 removed). Line fit and equation shown on each graph.

Susquehanna TN and TP cumulative spring loads were calculated from monthly TN and TP loads obtained from USGS (U.S. Geological Survey, preliminary data, 2005). January through April TN and TP data were summed for each year to obtain the yearly spring loads.

Point source and Susquehanna load data were then used to generate an algal index value for each spring. The algal index was calculated by summing the TN values with the TP values after the TP values had been scaled by a factor of 10. The TP scaling was done so

TP values would weight equally with the TN values in the regression model. The algal index equation is shown below.

$$\textbf{Algal Index} = (TN_1 + TN_2) + ((TP_1 + TP_2) \times 10)$$

Where:

TN_1 = Susquehanna Spring TN Load

TN_2 = Below Fall Line Point Source Spring TN Load

TP_1 = Susquehanna Spring TP Load

TP_2 = Below Fall Line Point Source Spring TP Load

The calculated spring algal index and mean summer anoxic volume for each year are shown in Table 2.

Table 2. Anoxic and volumes and Algal Indices for each year. The forecast 2005 anoxic volume is shown in red.

Year	Anoxic Volume	Algal Index
1985	0.51	34946406
1986	1.45	51854657
1987	0.59	38126791
1988	1.30	30465393
1989	1.14	28393160
1990	1.22	39402498
1991	1.14	44126799
1992	0.74	28628819
1993	2.49	81568312
1994	1.45	65770854
1995	0.96	26172546
1996	2.21	64652687
1997	0.75	29679092
1998	1.75	60437745
1999	0.46	29866711
2000	1.20	35929355
2001	0.62	25836093
2002	0.00	21452172
2003	0.51	42316327
2004	1.34	42195592
2005	**1.74**	61743176

A linear regression of summer anoxic volume versus spring algal index was then generated (Figure 5). This regression has an r^2 of 0.6988. A plot of the difference between actual and predicted values based on the regression is shown in figure 6. The relationship between anoxic volume and nutrient loading is slightly improved by including May loading data in the regression (figure 7). This regression has an r^2 of 0.7474. Difference between actual and predicted values is in figure 8.

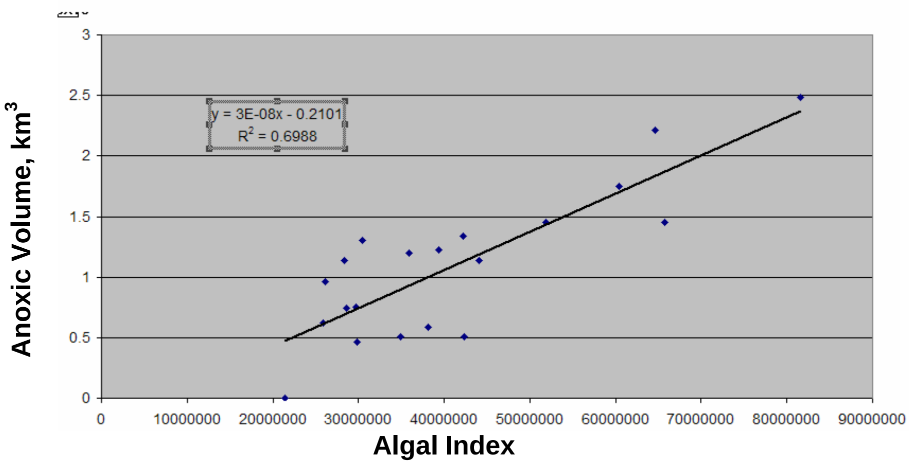


Figure 5. Relationship between summer mainstem Chesapeake Bay Mainstem hypoxic volume and spring TN and TP loading or Algal Index.

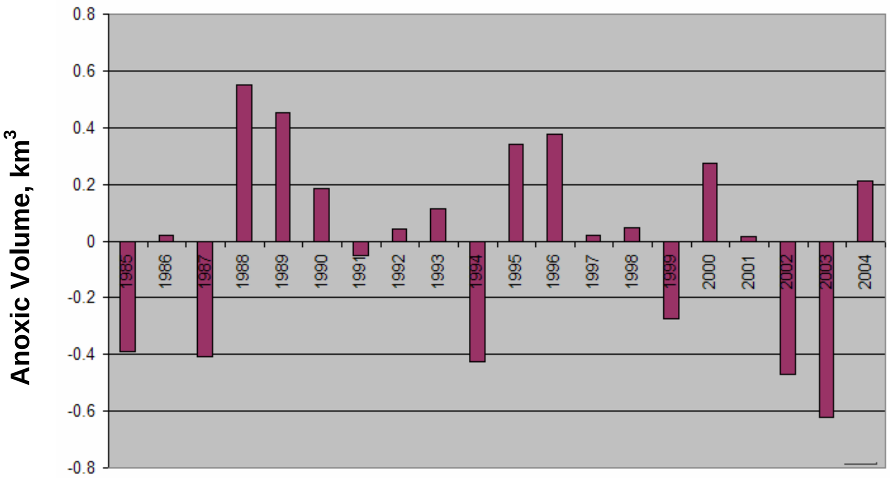


Figure 6. Plot of the difference between actual and predicted values based on the regression of June-September mean anoxic volume and January-April cumulative algal index.

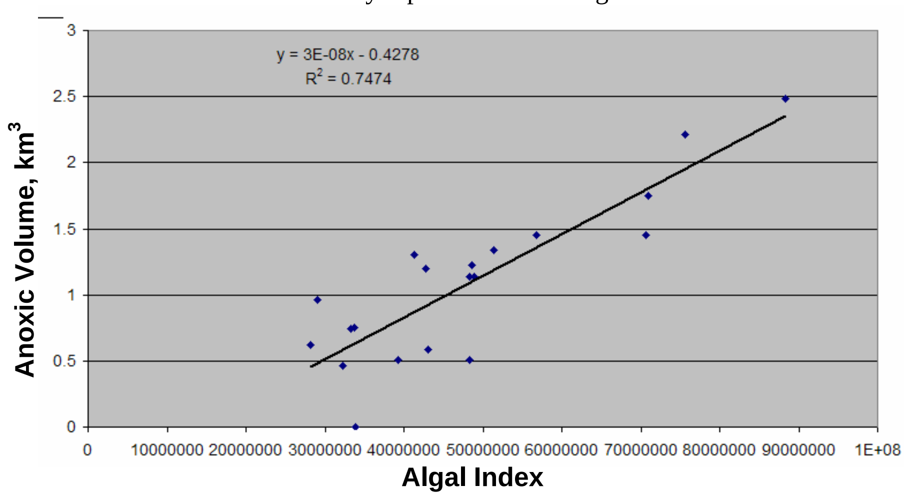


Figure 7. Relationship between summer mainstem Chesapeake Bay Mainstem hypoxic volume and January - May TN and TP loading or Algal Index.

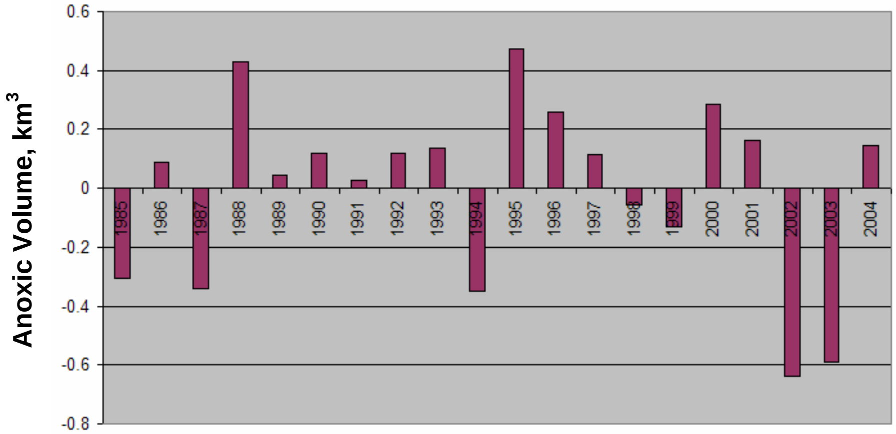


Figure 8. Plot of the difference between actual and predicted values based on the regression of June-September mean anoxic volume and January-May cumulative algal index.

Although the anoxia/loading relationship is stronger with the inclusion of May data, being able to generate a forecast at the end of April outweighs the slight statistical improvement gained by waiting until the end of May. Once the May nutrient loading data are available, the Bay Program will most likely recalculate the forecast and refine the prediction of summer anoxia.

Results and discussion

Based on the nutrient loads delivered to the northern Chesapeake Bay this spring, the Bay Program forecasts that the mean anoxic volume in the Bay this summer will be approximately 1.745 +/- 0.636 cubic kilometers. Relative to previous summers, this volume of anoxia is considered severe. 1998 had very similar spring nutrient loads and summer anoxic volume. A plot of the mean June-September 1998 oxygen distribution is shown in figure 9. Given that prediction is of a mean condition, we would expect some fluctuation around this value through the summer. Factors which will affect the accuracy of this prediction include summer wind mixing, additional and unexpected nutrient loading, and hurricanes/tropical storms. This prediction will be updated and adjusted in the coming months as more information becomes available.

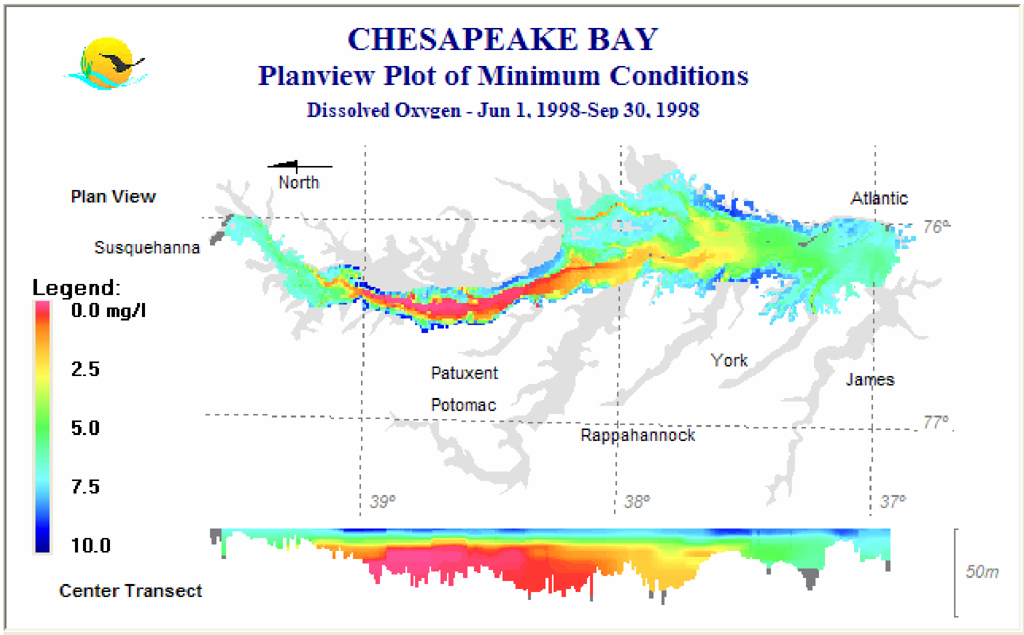


Figure 9. Mean June – September 1998 DO distribution.

References

Hagy, J.D., W.R. Boynton, C.W. Keefe, and K.V. Wood 2004. Hypoxia in Chesapeake Bay, 1950-2001: Long-Term Change in Relation to Nutrient Loading and River Flow. Estuaries 27(4):634-658.

Nancy N. Rabalais, R. Eugene Turner, and William J. Wiseman, Jr. 2002. Gulf of Mexico Hypoxia, A.K.A. "The Dead Zone". Annual Review of Ecological Systems 33:235-263.

Expert panel review of dissolved oxygen forecast

Expert panel

- Dr Michael Kemp (University of Maryland Center for Environmental Sciences)
- Dr Jim Hagy (US Environmental Protection Agency)
- Dr Walter Boynton (University of Maryland Center for Environmental Sciences)

Expert panel review and review rebuttal

(1) **Independent Variables.** The X-axis ("algal index") in the regression model (Fig. 6, 8) in this predictive model is misleading, because it contains several independent factors (river flow, TN and TP concentrations at the fall lines, and point source inputs of TN and TP) lumped together. There is no question that it would be useful for the independent variables to include both climate forces (e.g., flow) and anthropogenic factors (TN, TP inputs and concentrations. However, we already know that flow alone can produce regressions of similar or strength to those in this report (see Fig. 6 in Hagy et al. 2004, $r^2 = 0.75$). Thus, while the "algal index" implies a nutrient effect, the regression is probably

driven primarily by flow, per se. We would like to devise a scheme where nutrient concentrations and loads add significantly to the strength of these regressions, but this needs to be given more thought. We suggest that the use of a multiple regression approach might be more beneficial with separate independent variables for flow and nutrients.

We originally had looked at flow alone and got the same relationship you mention above. However, because we are trying to communicate the role of nutrients in determining the volume of anoxia the Bay experiences and because it is the nutrients that flow delivers, not just flow, that causes anoxia, we decided that nutrient loading model made more sense from a communications standpoint than did a flow model. After all, we are trying to manage nutrients, not flow. An earlier iteration of the model was a multiple regression using flow and load (r2 = 0.71). We also used, in various combinations with flow and load, year and previous summer anoxic volume. In the end, however, we were concerned with simplicity of communication and the addition of more variables didn't improve the strength of the model enough to warrant the additional complexity.

(2) **Dependent Variables.** This forecasting scheme should consider using other measures of DO depression rather than only anoxia. We have found that it is sometimes very revealing to contrast predictions of volumes or volume-days of water with DO <0.2, <0.5, <1.0, <2.0, <3.0 mg/L. For the public you might want to keep it simple, but for our own diagnostic purposes we would like to see all of these. In addition, the author's method for computing anoxia volume is suspect; although low DO water was limited in 2002, anoxic volume was not zero (see Jim's comments). It might be easier for citizens to visualize the size of the hypoxic region using area rather than volume, and the two are highly correlated, so this will not affect regressions. It also might make sense to forecast temporal measures of hypoxic water in terms of duration and timing of hypoxic conditions. For example, we have shown that one can predict the timing of initial hypoxia using spring flow, temperature and chlorophyll data (Boynton and Kemp 2000, Hagy et al. 2004). In any case, it is important to include hypoxia in May and September in these analyses, because ecological impacts of hypoxia may be particularly important when in occurs in spring and fall.

We have investigated the model using cutoffs of 0.2, 1.0, 2.0, 3.0 and 5.0. The strongest relationship, by far, was with 0.2. My feeling is that this is because general low DO is strongly controlled by presence or absence of a pycnocline, while anoxia (0.2) is most strongly controlled by nutrient loading. This, obviously, needs further investigation.

The method for computing hypoxic volume uses data from mainstem stations only and at these stations there was no measured anoxia in 2002.

Looking at area rather than volume may be easier to understand and is something we should investigate. One drawback, is that we also need to communicate criteria attainment and the DO criteria are volumetric. Not a roadblock, just something we need to consider.

As part of the early investigative work, look into causes of early onset of hypoxia. Dependent variable was April-May vol <0.2 mg/l. Strongest model was a multiple regression with mean March-April deep water temperature (bottom temp at stations deeper than 11 m) and deep water station stratification as the independent variables ($r2=0.3$) perhaps adding CHL would strengthen this relationship.

(3) **Uncertainty Analysis.** It is important for the forecasts to include some measure of uncertainty or probability to impress upon the public that these forecasts are subject to error. Eventually, we should impress upon the public how this tracking these predictions will help us build more robust models. The public is accustomed to hearing probabilities in forecasts from the weather man. This uncertainty analysis can be very sophisticated or rather simple, but it is absolutely necessary. One way to improve the forecasts is to update them over the course of the late spring and early summer using observations on spring chlorophyll, bottom DO, stratification as factors in updated models; this is similar to an approach used in weather forecasting and storm tracking (see Jim's notes).

Our plan is to update the model through the summer. We will add in May nutrient loading when the data are available so we can refine the model. We were definitely remiss in not including uncertainty and this has been taken care of. FYI the forecasted anoxic volume is 1.745 km3 +/-0.636.

(4) **Collaboration.** We need to get a team of managers and academics, as well as complementary disciplines working on this together to improve forecasts and create a progressively improving exercise. The method of model prediction, observation and analysis of discrepancies between prediction and observation is part of what we call the "scientific method" for hypothesis testing and linking inductive and deductive analyses. Clearly the goals of science and management are completely complementary. To make such an enterprise work in the long run, dependable funding is needed

(5)

We welcome your input and help on future iterations of the model.

Potomac River harmful algal bloom forecast

Overview

Cyanobacteria blooms on the Potomac River in 2004 were among the worst blooms observed since the inception of the water quality monitoring program in 1985. Such blooms may negatively affect living resources by limiting light to submerged aquatic vegetation and dissolved oxygen levels further impacting living resources. Cyanobacteria blooms often include the genus *Microcystis, Anabaena, Aphanizomenon* with species that may produce toxins affecting human health. Do such blooms occur with any level of predictability? Can we forecast bloom conditions for the year ahead?

Patterns of bloom behavior such as the timing of the first bloom sample being collected in the monitoring program, size of the bloom (maximum miles of river detected) and duration of the bloom (1st to last sample collected > 10,000 cells/ml *Microcystis*) were evaluated as they related to environmental conditions prior to each bloom season. The results provided some generalizations upon which we can make some forecasts based on the amount of river flow coming over the fall line ahead of the bloom season.

Methods

Timing of the first bloom sample

Generalizations we observed in the data set were:

1) If we experience a wet year, the first time we collect a bloom sample occurs in June the following year (6 of 6, 100% of the time).
2) If we experience a dry year, there is typically a delay to July or August for when we collect the first bloom sample in the monitoring program.
3) Years with no blooms (1986, 2002) were preceded by moderate to dry years, never by a wet year. (6 wet years were never followed by non-bloom years).

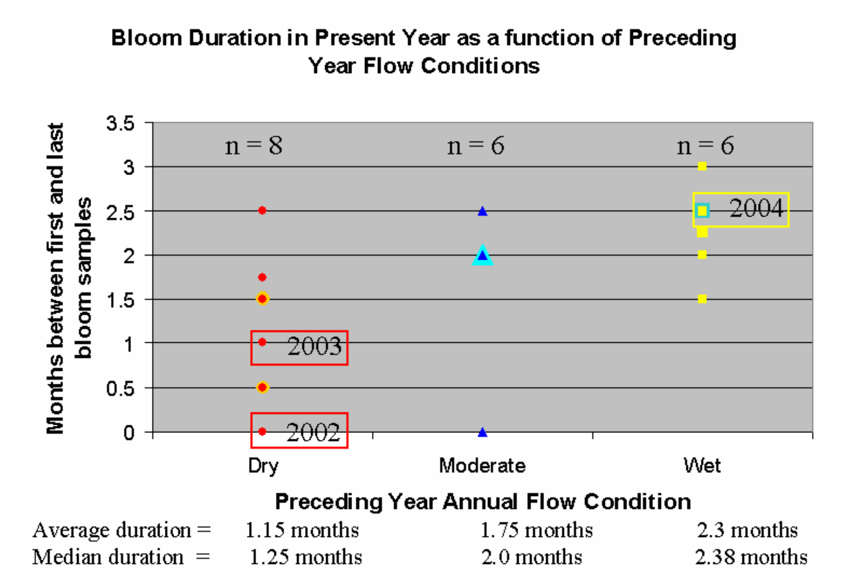
Detection of first bloom sample >10,000 cells/ml during routine monitoring the next year		Preceding Year Annual Flow Condition		
	Month	**Dry**	**Moderate**	**Wet**
	June	1 (12.5%)	3 (50%)	6 (100%)
	July	4 (50%)	2 (33%)	0
	August	2 (25%)	0	0
	No bloom	1 (12.5%) 2002	1 (17%) 1986	0

When we talk about a wet, moderate or dry year, we are talking about a number based on the total sum of water measured coming over the fall line of the Potomac River. In the white paper on flow classification methodology there are actually 7 categories of conditions: Record Dry, Very Dry, Dry, Moderate, Wet, Very Wet and Record Wet. For these analyses, Record Dry or Very Dry or Dry were all grouped into "Dry", the same for Wet, Moderate remains unchanged.

Duration of the *Microcystis* bloom

We looked at the time of the bloom that passed between the first bloom sample and the last bloom sample of the year regardless of the station that detected it. The bloom duration increased as the amount of flow in the previous year increased:

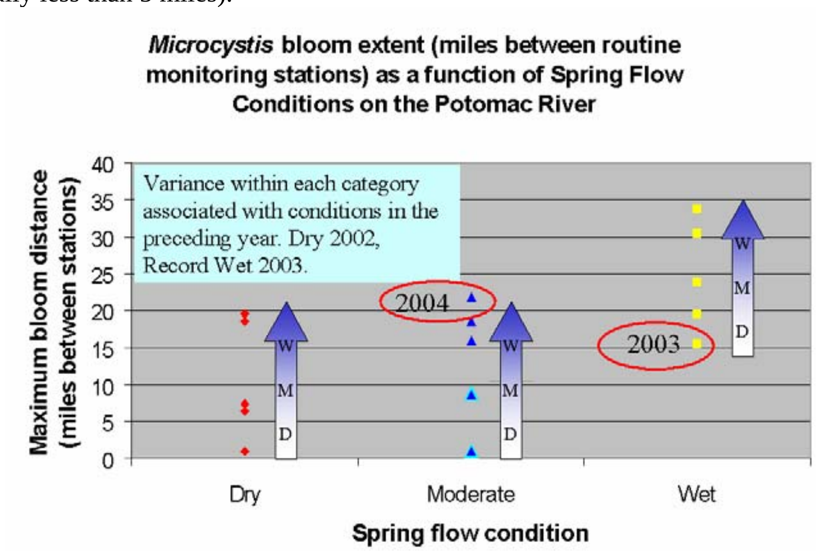
		Preceding year	
	DRY	MODERATE	WET
Subsequent year			
Average duration =	1.15 months	1.75 months	2.3 months
Median duration =	1.25 months	2.0 months	2.38 months



Extent of the bloom

The distance over the water that we detect a bloom on the worst case day of our sampling program was more closely related to the spring flow conditions (March, April and May) rather than the flow conditions from the year before.

1) Wet spring conditions were related to blooms detected over 15 or more miles of the Potomac.
2) Dry springs tend to result in short stretches of river showing blooms (average of 7.4 miles but generally less than 5 miles).



Year	Bloom distance (miles)	Spring	Preceding Year
2002	0	D	D
1990	1	**D**	M
2000	6.4	**D**	D
1995	7.4	**D**	**W**
1999	18.5	**D**	**W**
1985	19.5	**D**	**W**
Mean	**8.8**		
1986	0	**M**	**M**
1992	1	**M**	**D**
1997	1	**M**	**W**
2001	8.6	**M**	**D**
1989	8.8	**M**	**D**
1988	16	**M**	**M**
1991	18.5	**M**	**M**
2004	21.8	**M**	**W**
Mean	**9.4625**		
2003	15.4	**W**	**D**
1996	15.4	**W**	**D**
1993	19.5	**W**	**M**
1987	23.8	**W**	**D**
1998	30.4	**W**	**M**
1994	33.8	**W**	**W**
Mean	**23.05**		

Results and discussion

The general forecast model for the Potomac river *Microcystis* blooms

Using the relationships we uncovered for timing, duration and extent of the bloom, we have a general model that uses the total annual flow from the previous year to predict timing and duration of the bloom, and combine total annual flow with additional information about the spring conditions right before the summer season of interest to understand the probable extent of the bloom.

Annual Flow for the previous year	**Bloom levels first detected in the monitoring program**	**Bloom duration**	**Bloom Extent: Prediction modified by spring flow condition**	
			Spring flow	**Bloom extent**
DRY	**Early-mid summer or no bloom**	**Short (1.25 months)**	**DRY**	**Short (< 10 miles)**
			MODERATE	**Short**
			WET	**Moderate (10-20 miles)**
MODERATE	**Early summer or no bloom**	**Moderate (2 months)**	**DRY**	**Short**
			MODERATE	**Moderate**
			WET	**Long (>20 miles)**
WET	**Late spring to early summer**	**Long (>2 months)**	**DRY**	**Moderate**
			MODERATE	**Moderate**
			WET	**Long (> 20 miles)**

Note “Moderate” is likely to be “Long” be affected by small sample size having 1 high value and 1 low value.

What to expect for *Microcystis* blooms in 2005?

2004 began as an average year but progressed toward being wet. Because last year was a wet year, this suggests that

1) **Blooms will occur**: We will detect bloom conditions (at least one sample >10,000 cells/ml) on the Potomac River
2) **Expect it to start early**: We can expect to collect our first bloom sample during late spring/early summer (June).
3) **Expect bloom concentrations to be long lasting**: The bloom patterns in relation to a previously wet year suggest we will experience a long bloom season this summer (average of 2.5 months with a range of 1.5 to 3 months where we detect bloom level samples during routine monitoring).
4) **Blooms will be detected over more than 10 miles of river**: Depending on spring flow conditions we can expect to see bloom conditions stretching over more than 10 miles of the river, most likely greater than 15 miles (moderate to long extent of river coverage).

Expert panel review of harmful algal bloom forecast

Expert panel

- Dr Judy O’Neil (University of Maryland Center for Environmental Sciences)
- Dr Hans Pearl (University of North Carolina)
- Dr. Wayne Carmichael (Wright State University)

Expert panel review and review rebuttal – Dr Judy O’Neil

I have read the draft report entitled above, which seeks to develop a predictive capacity for the timing, duration, extent and relative bloom magnitude of the cyanobacterium *Microcystis* in the Potomac River for Summer 2005. The predictive capacity presented is based solely on physical parameters (i.e. annual flow of the preceding year, spring flow, or a combination of the two). Working with just these parameters alone, the authors have come up with a reasonable prediction with what they had to work with. I applaud the efforts to try and develop a better understanding of these harmful algal blooms which have potential deleterious effects on the ecosystem as well as humans and pets.

1) <u>Timing</u>: Onset of the first bloom sample can reasonably be predicted by the annual flow conditions of the previous year. The 7 categories of flow conditions have been simplified to wet, moderate or dry. (The criteria for each of these should be presented in a table for easy reference). Based on the monitoring data to date:
   a) a “wet” year will result in the first bloom sample in June;
   b) a “dry” year will result in the first bloom sample in July or August;
   c) a “moderate” or “dry” year can sometimes result in zero blooms.

   Perhaps studying the differences in other measured chemical, physical or biological parameters between the “dry” or “moderate” years that yield blooms, to those years that don’t yield blooms, would help pinpoint factors triggering *Microcysitis* blooms.

As this is a first attempt to utilize our 20 year monitoring data set to forecast bloom conditions, your comments are well received. The discharge model behaved best when looking at bloom conditions relative to the wettest preceding years, there is a fair amount of variability related to the drier conditions that needs an enhanced model to improve overall predictability. Chemical, physical and biological parameters will be reviewed to improve forecasting accuracy in future analyses.

2) <u>Duration</u>: The amount of time between first bloom sampled and last bloom sampled, increased as the amount of annual flow in the previous year (i.e. more flow = longer duration of bloom in summer).

a) a "wet" year will result in an average duration of ~2.3 months;
b) a "dry" year will result in an average duration of ~1.2 months;
c) a "moderate" year will result in an average duration of ~1.8 months.

Investigating what other factors persist during these bloom periods that are related to flow input may improve predictive capacity and give insight into factors that maintain growth or persistence of the blooms.

The driest conditions tended to separate well from the wettest conditions in forecasting. We are discussing mechanisms that might occur to affect duration of a bloom that will allow us to pursue improvements to the forecast.

3) Extent: The distance of river area covered by bloom appears to be better predicted by Spring flow conditions (March, April and May) than total flow conditions for the previous year as above.
   a) "wet" spring conditions yielded blooms that extended in excess of 15 miles on the Potomac
   b) "dry" spring conditions yielded blooms that extended an average of ~ 7 miles, but generally less than 5 miles.

   Investigating what is transported in the spring-flow (i.e. snow-melt etc) that is different than in the average annual flow, might give clues into what effects the extent and maintenance of the bloom over specific geographic locations.

The combination of considering spring river discharge paired with previous year conditions produced a clearer gradient of bloom extent based on the two season conditions versus one. Spring alone did well separating forecasting results of wet compared with moderate or dry spring conditions, but the pattern was improved with the two-season approach in our estimation. We agree that additional parameters such as chemical composition of nutrients delivered will be a good direction to go for upgrading the further analysis in the forecasting effort.

4) Relative Bloom Magnitude: The authors state that this criteria, is the most difficult category to predict. Given the variability in any harmful algal bloom abundance even spatially let alone temporally this is a given. However, even if it is a bit like a "Farmer's Almanac" forecast, it is the best that can be done with the physical data, and just as weather forecasts come with certain implicit unknowns and uncertainty, it is just the nature of the process. So, based on past years empirical data, and the fact that 2005 certainly seems to fall in a "wet" year, a prediction for the summer of 2005 of:
   a) *Microcystis* blooms with concentration values greater than 10,000 cells/ml;
   b) Blooms starting early (i.e. June);
   c) Blooms extending greater than 10-15 miles;
   d) Blooms persisting for ~ 2 months;

   are not unreasonable predictions.

As we all know harmful algal blooms are indeed complex, multi-faceted problems which are inherently difficult to understand, predict or solve. It is always an ongoing iterative process and I believe you have a good first step. Future improvements on the predictive capacity could potentially be gained by additional inclusion of physical parameters (e.g. water temperature, light penetration, photoperiod, wind speed and direction, stability of the water column); chemical parameters (e.g. pH, salinity, inorganic and organic nutrients) and biological interactions (e.g. grazer interactions, phytoplankton, bacterial and viral community interactions). Some of these interactions may lead to a better understanding of the factors influencing the potential toxicity of the *Microcystis* as well. Given the severe nature of *Microcystis* toxins (including hepatotoxins), particularly to children and small animals, and the fact that 40% of the bloom samples in the Potomac indicate toxicity levels above the safe threshold for children by Australian standards, I agree with the statement that it would seem "that children would have a reasonable high probability of coming in contact with toxin concentrations of concern in obvious bloom waters", and education efforts etc. as well as involvement of human health officials is warranted. The precautionary principal is always prudent when human health is involved.

We have integrated our monitoring efforts with those of the Department of Health and Mental Hygiene and the Department of the Environment to keep these essential agencies abreast of potential environmental and human health issues as they arise with toxicity in algae. All information is shared as results come back and interagency press releases produced, warning citizens and officials of water quality conditions. We know bloom samples appear to show 100% toxicity and provide cautions to the public because levels of toxicity vary and we have not as yet been able to predict levels of toxin at any one place and time. Educational materials have been posted on the web, press agencies have covered the bloom events and included the health warnings our interagency team has published. County health agencies have closed beaches appropriately when the findings suggest toxin levels that may be of concern have been identified. Safety thresholds for toxins have an added layer of safety. The safety threshold is a precautionary number, not a bright line between safe and unsafe. As the concentration increases, the risk of adverse effects increases and we continue to express cautionary notes in as many forums as possible to help educate the public on the potential health risks associated with exposure to such blooms. Possible bloom related health effects that arrive in a physicians office are required to be reported to DHMH and are tracked to expand our data and knowledge regarding these issues.

Expert panel review and review rebuttal – Dr Hans Pearl

Overview

Historically (that is going back to the early eighties….1983 and 1985 come to mind), the individual years that have the highest potential for blooms are those that exhibit high winter-spring runoff, followed by sudden and persistent drought conditions in the summer). This has been well documented for the Neuse, which in the mid-eighties had parallel (to the Potomac) severe Microcystis blooms (Christian et al. 1986, Paerl et al. 1987). I would put my money on this scenario as the most likely sequence to cyano bloom development in either system, with the prior wet year followed by a moderate to dry year scenario being the second most likely sequence.

We felt the same pattern likely too be true and believe it holds in most cases in our region. However, in 2004, we experienced a relatively wet summer coincident with the worst bloom conditions in 20 years. This went counter to the summer drought requirement we thought maybe needed. There may be some underlying changes in the nutrient delivery in the basin for example that have impacted the bloom characteristics. Further analyses are underway in this regard.

Timing of the first bloom sample

Report comment: "If we experience a wet year, the first time we collect a bloom sample occurs in June the following year (6 of 6, 100% of the time)."
Review comment: This should probably be modified to also reflect the within year scenario outlined above

Under review also as mentioned above due to the unusual conditions in 2004 that did not follow the expected summer pattern for significant blooms on the river.

Report comment: When we talk about a wet, moderate or dry year, we are talking about the a number based on the total sum of water measured coming over the fall line of the Potomac River.
Reviewer comment: I prefer using discharge instead of flow. Discharge (i.e. Cu m per second) is more useful as it can be directly related to nutrient loading if you know the concentrations. Flow could mean speed or volume (it is less specific). You could use flow, but maybe define what you want it to mean first.

Thank you Hans, I think we have been careful to use flow instead of discharge since we often refer to discharge at point sources and didn't want that confusion. For the future though we can clear up this concern as you suggested.

Extent of the bloom

Report comment: "Extent of the bloom."
Review comment: Extent could mean time or space. Clarify this first

In the text we reference extent in miles and duration for time.

Review comment: In the Neuse, the overall magnitude of the summer bloom was also directly related to the amount of spring FW discharge, as long as it was followed by a dry, low discharge period. My guess is that this rule of thumb might apply to the Potomac as well, but it would depend on residence time vs. discharge (what are typical spring vs. summer residence time numbers for the Potomac?).

I don't have those residence time numbers off hand, that is something we as a group around Chesapeake Bay have discussed, having a set of metrics like residence time to aid everyone in exploring relationships of interest. We will keep this idea ready for further analyses efforts. Good suggestion.

Forecasting relative bloom magnitude

Report comment: "We do not have a mechanistic underpinning for this relationship yet"
Review comment: I don't think this is entirely true**.** Look at the work of the Potomac Nutrient Commission in the mid 1980's (of which I was a member, along with Scott Nixon, Jay Taft and Norb Jaworski), that pretty much laid out the relevant scenarios.

Our goal is to look at other past and present models such as those you suggest. We acknowledge there have been several fine efforts to look at controls on bloom conditions on the Potomac since the 1970's. We would like to review those efforts this year to glean additional information about mechanisms influencing the bloom dynamics. I am aware of a moderately complicated physiological model for Microcystis out of Australia based on carbohydrate balances I believe. So we have ahead of us some work to make these comparisons and better appreciate what is known about the detailed, mechanistic underpinnings linking the physical, chemical and biological dimensions of bloom characteristics.

What to expect for *Microcystis* blooms in 2005?

Report comment: "expect bloom to start in early spring**"**
Reviewers comment: Why? I don't follow the rationale here.

Actually it's early summer based on the relationship that 100% of years following a wet year we have had our first bloom sample in the monitoring program. Years following moderate and dry conditions were much more variable about the time of first detecting but last year was classified as a wet year by statistical standards and therefore we are predicting the June start time for picking up bloom concentrations in our monitoring program.

Report comment: Expect bloom concentrations to be long lasting
Reviewers comment: I think this is very risky as far as predictions go. What if it turns out that this is a wet summer?

Last year was a wet summer and the bloom lasted approximately 2.5 months. This ran counter to the drought idea which, as you point out, is a good rule of thumb but apparently not set in stone based on our experiences.

Report comment: "Average sample results will be greater than 10,000 cells/ml for the year."
Reviewers comment: I don't like the idea of setting a cell No. standard. You're boxing your self in here. Why not simply deal with "bloom conditions" (i.e. visible discoloration and surface accumulations).

We have pulled this prediction from our work from now. We agree, the number means something for us but is less valuable as a public communication metric

Expert panel review and review rebuttal – Dr Wayne Carmichael

(Supplemental to the comments made by Hans Pearl)

1) The Draft Adobe file forecast page says Microcystis has bloomed in the Potomac since the 60's. Could this be placed in perspective--i.e. are the blooms worse now--more intense--toxic? If they have been there for 40 years why worry about forecasting for them now?

2) Microcystis almost always produces some level of Microcystin toxins when blooming -(but toxin levels are highly variable)- and confirmed toxicities are rare--or not reported. Are there any forecast statements that could be made about toxin production and blooms?

Aquatic grass forecast

Overview

Aquatic grasses populations are highly dynamic in terms of spatial and temporal variability and species composition. Light availability has been identified as a major control on the distribution of submersed aquatic macrophytes in the Chesapeake Bay. Light availability at depth is affected directly by the presence of TSS and phytoplankton (chlorophyll a) in the water column and by epiphytes and sediment accumulations upon the leaf surface. Increasing nutrient loading increases epiphytic algae and phytoplankton; increases in phytoplankton cause an increase in TSS as well. Light availability is also closely related to weather variables such as available sunshine and wind, the latter of which causes resuspension in shallow areas.

In order to develop a robust forecasting model for aquatic grass communities in the Chesapeake Bay, we examined the relationships among water quality and other variables, and fluctuations in submerged aquatic vegetation (i.e., area coverage, % change from previous year, and density) from 1985 to 2004 for three SAV community types, corresponding to low, medium, and high salinity regimes. Unfortunately, this approach did not yield relationships that were strong enough to form the basis of the forecast. The final approach used to generate the forecast relied on expert interpretations of past aquatic grass area changes, available aquatic grass habitat and winter/spring water quality (salinity, temperature and clarity). The forecast was also aided by recent field observations from members of the forecast team. So that a public record of the broad-scale correlation approach is retained, the methods and results are provided below. seems completely redundant with the previous sentence – or did I misunderstand?

Correlating aquatic grass community types with environmental and water quality variables

Methods

Relationships were determined for area coverage (AC), percent change, and density of aquatic grass for the three community types (freshwater species, *Ruppia*, and *Zostera*) with a number of independent variables. Area coverage and density data for SAV were obtained from the Virginia Institute of Marine Science; other data were obtained from the Chesapeake Bay Program's CIMS database, the USGS River Input Monitoring Program (RIMP), the National Climate Data Center (NCDC), and Fisher et al. (2003). Data used to calculate the relationships were averaged over the growing season (April – October) of the previous year and spring (March – April) of the actual year from which SAV data were derived.

Results & Discussion

Based on a study by Moore et al. (2000), major community types of submerged aquatic vegetation (SAV) were separated into salinity zones that approximate their distributions within Chesapeake Bay (Figure 1). The area coverage of aquatic grass in these three zones from the period of 1985 – 2004 indicates that there is a general increase in the abundance of aquatic grass species in the low-salinity zone (i.e., upper Bay and tributaries), whereas those of the mid- and high salinity zones of the bay show no obvious trends and have high variability (Figure 2).

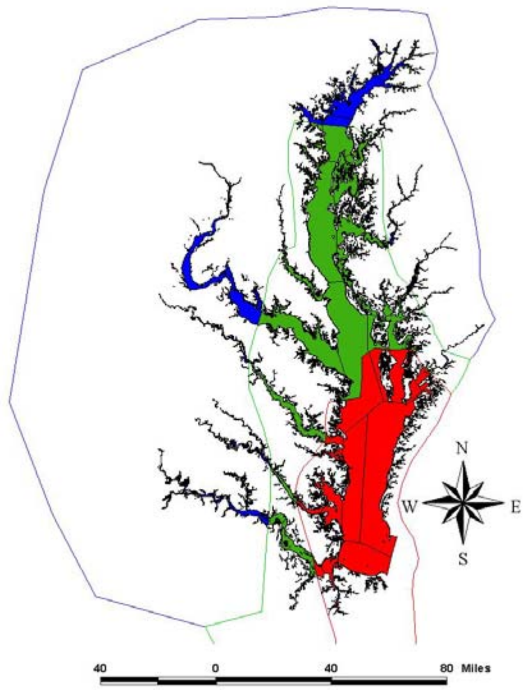


Figure 1: Locations of the major aquatic grass community types in Chesapeake Bay. Community types based on salinity tolerance of species present - low, medium, and high salinities are indicated by blue, green, and red, respectively.

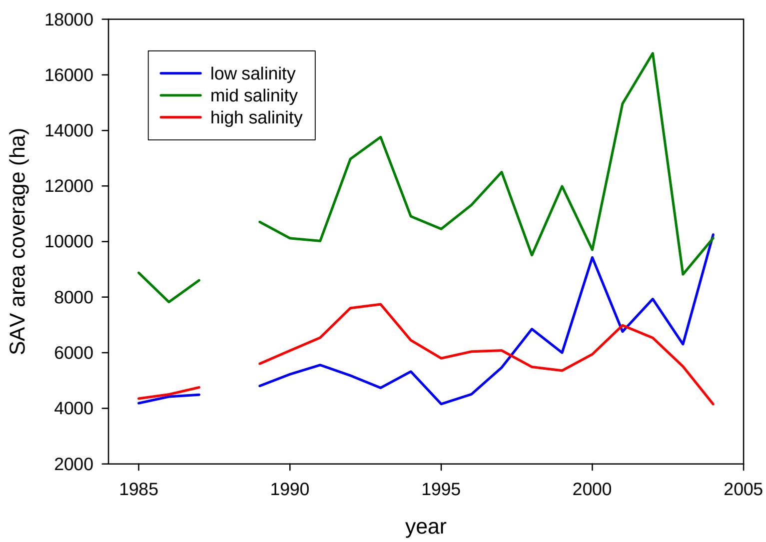
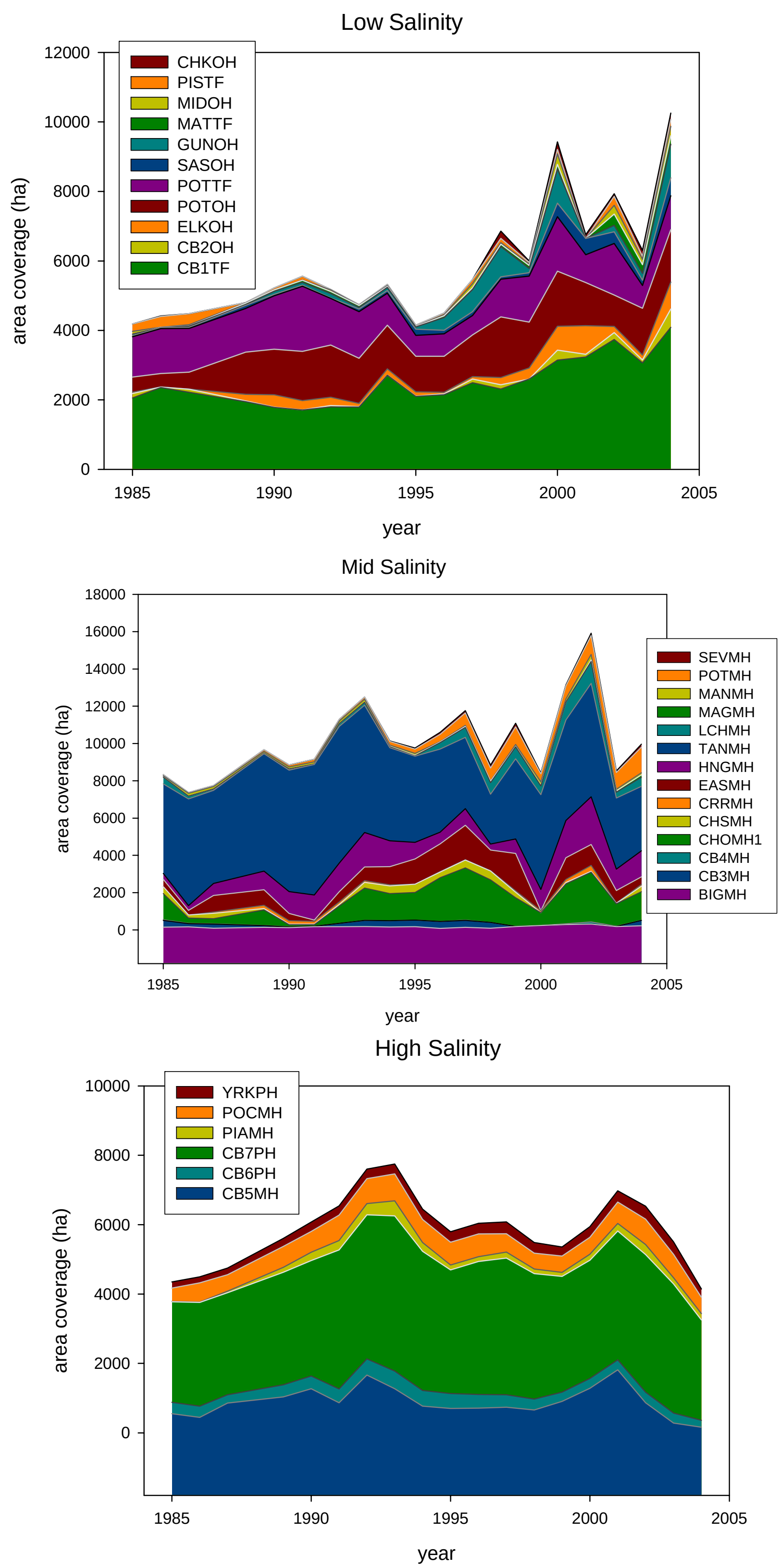


Figure 2: Changes in aquatic grass area coverage for the three salinity zones over the past 20 years.

There was a relatively large increase in the area coverage of aquatic grass in the low-salinity zone in 2004, compared to a moderate increase in the mid-salinity zone, and a moderate decrease in the high-salinity zone. The cumulative area of individual segments within each salinity zone indicates that certain SAV beds are responsible for most of the aquatic grass coverage in their respective salinity zone (Figures 3a - 1c). For instance, aquatic grass in the CB1TF segment (i.e., Susquehanna Flats), on average, is responsible for about 43% of the aquatic grass area in the low-salinity zone.



Figures 3a - c: Time series of the total area of SAV indicating the contribution from each Bay segment within the three salinity zones (i.e., low, medium, and high). See appendix for map of segments.

Relationships of area coverage (AC), percent change and density of SAV for the three community types (freshwater species, *Ruppia*, and *Zostera*) with a number of different independent parameters were commonly weak (i.e., $r^2<0.3$; Table 1). There was a significant relationship ($r^2=0.56$; $p<0.05$) for the area coverage of SAV and below fall line (BFL) point source (PS) inputs because of the inverse relationships of increasing AC for freshwater species and decreasing PS loading over the last two decades. However, the cause and effect of this relationship is tenuous since nutrient loading from PS is at most 20% (for N), compared to 60% for river inputs, which do not show a strong relationship. The relationships are no stronger using the water quality parameters and other variables during the growing season of the year of actual aquatic grass growth, which we could not use in a forecasting model.

Table 1: Relationships of area coverage (AC) for the three predominant SAV community types associated with low, medium, and high salinities (i.e., freshwater species, *Ruppia*, and *Zostera*, respectively). Coefficients of determination (highlighted in blue) are of SAV area coverage versus the variable indicated in the column heading.

previous year's all rivers Flow (km^3) total	all rivers Flow (km^3) Mar & Apr	previous year's Apr-Oct PAR (uE/m2.d)	previous year's growing season Chl a (ug/L)	Previous year's Nitrogen PS loads lbs y^{-1}	
0.13	0.004	0.13	0.00007	0.56	low salinity
0.02	0.001	0.03	0.009	0.08	Mid salinity
0.05	0.001	0.002	0.07	0.005	high salinity

Previous year's Phosphorus PS loads lbs y^{-1}	January - April TN load (all rivers) kg	January - April TP load (all rivers) kg	previous year's growing season Salinity	previous year's growing season Secchi (m)	
0.3	0.05	0.007	0.26	0.005	low salinity
0.19	0.004	0.0006	0.004	0.0004	Mid salinity
0.16	0.008	0.013	0.003	0.02	high salinity

previous year's growing season TSS (mg/L)	previous year's FW spps Ave surf H2O temp Apr-Oct °C	rate of temp change - spring °C day^{-1}	Wind speed at BWI mph	
0.01	0.18	0.12	0.19	low salinity
0.03	0.02	0.0001	0.00003	Mid salinity
0.12	0.16	0.05	0.09	high salinity

The lack of strong relationships suggests that the geographical area being incorporated into this analysis may be too large and that aquatic grass beds may be responding more to localized drivers than the composite from various locations. For example, there is a relatively large hydrochemical variability in the tributaries that is muted when data are pooled in the analysis. Moreover, there is a study by Carter et al. (1994) for the upper Potomac where they showed that SAV growth is influenced by TSS, Secchi depth, wind speed, and flow on a localized scale, although this was for a shorter time period (1980 to 1989) and the extended data set used in our analysis (i.e., 1985 – 2004) may not have similar relationships.

References

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Forecasting changes aquatic grass distribution during the 2005 growing season

This year's forecast is based on interpretation and analysis of two datasets in conjunction with expert knowledge and field observations. The datasets used were average spring water quality and long-term trends in aquatic grass area. Because this year's forecasts were largely interpretive, the forecasts are very general, only indicating whether an increase, decrease or no change in aquatic grass distribution is expected. The goal of the forecast team is to further develop the forecasting methods so that more robust and empirical approaches can be used for future forecasts. As discussed above, this will most likely entail conducting multivariate analyses at relatively small geographic detail.

Low salinity community group forecast

An overall increase in the area of low-salinity aquatic grasses is forecast for the 2005 growing season. This prediction is largely based on two factors:

1) Water quality conditions during spring favored the growth of low salinity species, with low salinity (i.e., only slightly higher than the long-term average) and lower water clarity recorded (Table 2). Poor water clarity tends to favor the low salinity community types as many species have growth forms that enable them to grow close to the water surface, where light levels are higher, and water clarity has little influence. Moreover, the area of the Bay with favorable low-salinity levels was increased this spring, as indicated by below-average salinities in those regions classified as medium salinity community types (Table 3).

Table 2. Average spring water quality conditions for all low-salinity segments of the Bay.

Aquatic grass community	Variable	Long-term average (March-May - 1985-2004)	Past spring average (March – May 2005)
Low	Salinity (PPT)	0.08	0.5
	Clarity (m)	0.71	0.45
	Temperature (^{o}C)	12.5	12.5

2) A gradual increase in aquatic grasses area occurred on Susquehanna flats over the past 10 years (Figure 4). Susquehanna Flats accounts for approximately 40% of the total area for the low salinity community group. It is predicted that the aquatic grasses on the Flats will continue to increase in area and density in 2005.

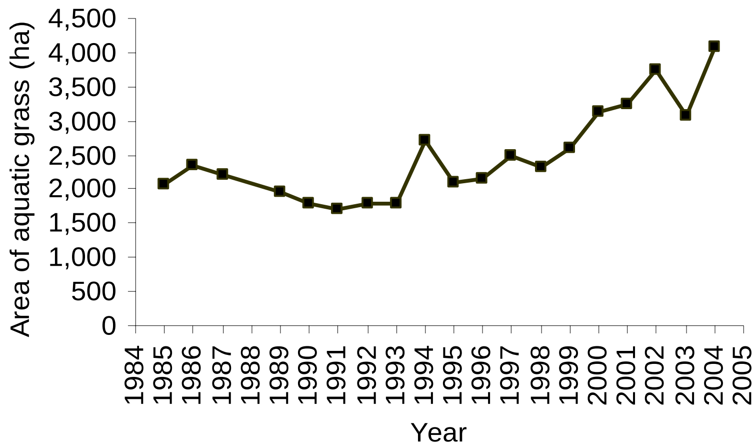


Figure 4. Area of aquatic grass on Susquehanna Flats for the past 20 years.

Medium salinity community group forecast

No overall change in the area of medium-salinity aquatic grasses is forecast for the 2005 growing season. This forecast is partially based on water clarity and water temperature being below the long-term average this spring, restricting expansion of medium salinity aquatic grass beds (Table 3).

Table 3. Average spring water quality conditions for all medium-salinity segments of the Bay.

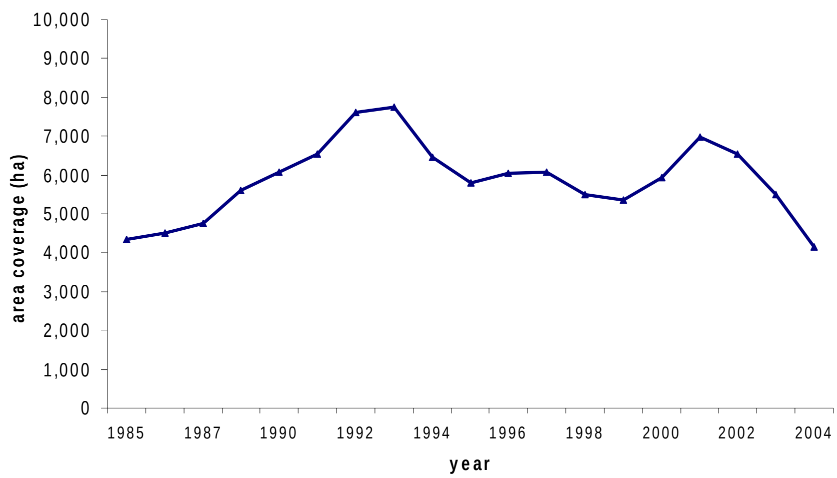
Aquatic grass community	Variable	Long-term average (March-May - 1985-2004)	Past spring average (March – May 2005)
Medium	Salinity (PPT)	11.0	7.5
	Clarity (m)	1.8	0.9
	Temperature (^oC)	12.1	11.3

High salinity community group forecast

A small overall increase in the area of high-salinity aquatic grasses is forecast for the 2005 growing season. Figure 5 illustrates the recent decline in the area of this community group due to Hurricane Isabel in 2003 and above average river loads in 2004. While the below-average spring water clarity and temperature are likely to limit recovery from these events (Table 4), if the summer conditions are favorable (good clarity and warm waters) it is predicted that a small increase in aquatic grass area will occur.

Table 4. Average spring water quality conditions for all high-salinity segments of the Bay.

Aquatic grass community	Variable	Long-term average (March-May - 1985-2004)	Past spring average (March – May 2005)
High	Salinity (PPT)	16.3	17.5
	Clarity (m)	1.9	1.2
	Temperature (^oC)	12.5	9.7



-Figure 5. Area of aquatic grass on Susquehanna Flats for the past 20 years.