Virginia Department of Environmental Quality Technical Report
Chlorophyll *a* Numerical Criteria for the Tidal James River
November 30, 2004 (revised 1/12/2005[1])

The tidal James River was listed as impaired under the Clean Water Act by the U.S. Environmental Protection Agency (EPA) in 1999 for violation of Virginia's Water Quality Standards. Existing nutrient and sediment enriched water quality conditions within the entire tidal river were not supporting "balanced" populations of aquatic life protected under Virginia's state water quality standards regulations (9 VAC 25-260-10). These principal water quality impairments, which still persist in the tidal James River, include excessive nutrients that nourish undesirable and nuisance algae, which, in combination with excessive sediments, greatly increase the risk of harmful algae blooms and create extremely poor water clarity conditions for underwater bay grasses.

These water quality conditions in the tidal James River also don't support the desired aquatic life as identified within Virginia's proposed designated use for open-waters in the Chesapeake Bay and its tidal tributaries[2]. While these impaired water quality conditions exist throughout the tidal James, the most visible and evident water quality problems exist in the tidal river below Hopewell and at the mouth of the river near Hampton Roads. These water quality problems have resulted in almost no underwater bay grasses being able to survive anywhere in the tidal river and excessive algae creating bloom conditions favoring nuisance forms and poor quality food (algae) for many aquatic life forms including clams, oysters and menhaden. There is also the increased risk of harmful algal blooms.

This report documents the requirements for a seasonal, river segment specific derivation of numerical chlorophyll *a* criteria for tidal James River. The requirement to derive and adopt numerical chlorophyll *a* criteria for tidal James River is primarily based on the existing Virginia Water Quality Standards Regulation statewide use designation. This current use designation calls for a "balanced, indigenous population of aquatic life in all waters" (9 VAC 25-260-10). The tidal waters of James River do not contain diverse, healthy and balanced populations of many expected aquatic life forms including the base of the food chain which all higher aquatic animals depend upon. These primary producers known as phytoplankton are commonly referred to as algae.

Virginia's existing Water Quality Standards Regulation also requires that substances which nourish undesirable or nuisance aquatic plant life be controlled (9 VAC 25-260-20). Given the tidal James River is listed on the Clean Water Act's 303(d) list of impaired waterbodies, actions must be taken to remove the sources of those water quality impairments.

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[1] Revised with new figure 13 containing an additional year of data (i.e. now is through 2003, previously available only contained through 2002). Text referring to this figure also revised as necessary. Footnotes and last column of Table 11 also corrected.

[2] Virginia Register, Volume 21, Issue 5 November 15, 2004.

Virginia's existing Water Quality Standards Regulation does not provide the quantitative basis for fully defining the water quality conditions necessary to support "a balanced, indigenous population of aquatic life in all waters" within the tidal James River in terms of the phytoplankton community. To determine what pollution reductions must be taken and to provide the scientific basis for the eventual removal of the tidal James River from the list of impaired waters, Virginia's Water Quality Standards Regulation must include numerical chlorophyll *a* criteria derived for and applied specifically to the tidal James River and its aquatic habitats.

BACKGROUND

Existing Virginia Water Quality Regulations

The existing Virginia Water Quality Standards Regulation (9 VAC 25-260-10) contains the requirement for supporting "a balanced, indigenous population of aquatic life in all waters." This statewide use designation clearly intends to maintain not only a balanced population of fish and shellfish, but all aquatic life from the base of the food chain (algae) to up to commercial and recreation fishes. This existing state regulation provides for the "propagation and growth of a balanced, indigenous population of aquatic life which might reasonably be expected to inhabit those waters."

Virginia's existing Water Quality Standards Regulation further require that "substances which nourish undesirable or nuisance aquatic plant life will be controlled" (9 VAC 25-260-20). To meet that requirement, Virginia adopted the Nutrient Enriched Waters (9 VAC 25-260-330-350) and Policy for Nutrient Enriched Waters (9 VAC 25-40) in 1988. These existing regulations also recognized that nutrients were contributing to undesirable growths of aquatic plant life, classified waters as nutrient enriched and imposed phosphorus limits on discharges to waters classified as nutrient enriched. The Chesapeake Bay and its tidal tributaries were all classified as nutrient enriched under these regulations. Chlorophyll *a* was also recognized in the Nutrient Enriched Waters sections of the regulation as an indicator of nutrient enrichment.

Chesapeake Bay Water Quality Restoration Commitment

Virginia was one of seven signatories to the *Chesapeake 2000* agreement in June 2000. One of the principal goals of that agreement and the larger Chesapeake Bay Program state-federal-local partnership is "achieve and maintain water quality conditions necessary to protect aquatic living resources of the Chesapeake Bay and its tidal tributaries" (Chesapeake Executive Council 2000). Towards that goal, the jurisdictions with tidal waters agreed to use their best efforts to adopt new or revised water quality standards consistent with these necessary water quality conditions.

EPA Water Quality Criteria Guidance

In the federal guidance document *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (*Regional Criteria Guidance*), published in April 2003, EPA recommended water quality criteria, tidal water designated uses and criteria attainment assessment protocols specific for Chesapeake Bay and its tidal rivers (USEPA 2003a). Developed over a four year process involving all seven watershed jurisdictions and over a hundred individual scientists, agency managers and technical staff, publication of this *Regional Criteria Guidance* document addressed the Chesapeake 2000 commitment to "define the water quality conditions necessary to protect aquatic living resources" (Chesapeake Executive Council 2000).

Open-Water Designated Use

The EPA guidance contained a recommended open-water designated use description focusing on fish and shellfish and includes waters that support the "survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting open-water habitats" (USEPA 2003b). It is clear from the numerous references in the existing Virginia Water Quality Standards Regulation calling for balance in all aquatic life, prohibition of undesirable aquatic plant growth and use of chlorophyll *a* as an indicator of eutrophication, that Virginia's existing narrative criteria provides equal if not more encompassing protection than EPA's open-water designated use recommendation.

In spite of Virginia's current narrative, there are still many indications that this open-water designated use is not being met. This is particularly apparent in the tidal James River as is documented below.

Chlorophyll a Criteria

Given the independent scientific peer review feedback that the scientific information presented within the *Regional Criteria Guidance* document did not support EPA's publication of a single set of baywide chlorophyll *a* criteria, EPA recommended states to adopt a narrative chlorophyll *a* criterion across all their tidal waters (see insert). EPA further recommended state derive and adopt site specific numerical chlorophyll a criteria where needed to address algal-related impairments. Specifically, the *Regional Criteria Guidance* document stated that:

> "The EPA expects states to adopt narrative chlorophyll *a* criteria into their water quality standards for all Chesapeake Bay and tidal tributary waters. The EPA strongly encourages states to develop and adopt site-specific numerical chlorophyll *a* criteria for tidal waters where algal-related impairments are expected to persist even after the Chesapeake Bay dissolved oxygen and water clarity criteria have been attained."
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> "The site-specific nature of impairments caused by the overabundance of algal biomass supports state adoption of the EPA-recommended narrative criteria, with application of site-specific numeric criteria for localized waters addressing local algal-related impairments."

<u>EPA recommended Chesapeake Bay chlorophyll a narrative criteria.</u>

Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences–such as reduced water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions–or otherwise render tidal waters unsuitable for designated uses.

Source: USEPA 2003a.

Proposed Water Quality Standards Regulation

Virginia's existing Water Quality Standards Regulation narrative criteria have been in place since the late 1960s and yet the tidal James has the most 'unbalanced' phytoplankton community compared to Virginia's other tidal waters with numerous observations of over-abundances of 'undesirable' plant life. Continuing with a narrative criteria approach to the tidal James River ecosystem will not provide the technical basis for the implementing the necessary nutrient loading reduction actions needed to restore balance to that ecosystem. Narrative criteria are extremely difficult, if not impossible, to implement and enforce. Therefore, it has been determined by Virginia Department of Environmental Quality and the EPA that Virginia needs numerical criteria for chlorophyll *a* applied to the tidal James River. These numerical criteria are needed to quantify the water quality conditions necessary for the protection already required within the narrative criteria within the existing Virginia Water Quality Standards Regulation.

While the Chesapeake Bay and other major tidal tributary waters may also have algal-related impairments due to eutrophication, EPA and the seven watershed jurisdictions have determined that numerical chlorophyll *a* criteria are not required for these other tidal waters at this time. Based on extensive evaluation of Chesapeake Bay water quality monitoring data and numerous water quality model simulations, the Chesapeake Bay Program partners determined implementation of the new Chesapeake Bay specific dissolved oxygen and water clarity criteria will necessitate nutrient reductions in these other Bay waters that will subsequently address the algal-related impairments in these other tidal waters (USEPA 2003c).

However, this was determined not to be the case in the tidal James River because the nutrients loads from the surrounding watershed do not significantly influence impact dissolved oxygen concentrations or water clarity conditions in other Bay waters (USEPA 2003c). Unlike the other major tributary systems, the tidal James River itself is relatively shallow and very well mixed (Kuo and Neilson 1987; Hagy and Boynton 2000). These physical characteristics allow enhanced diffusion of atmospheric oxygen into the water column. The proximity of the James to the Atlantic Ocean and its input of relatively well oxygenated waters also keeps the dissolved oxygen in the James comparatively good compared to the other systems in the face of the observed excessive nutrients and high chlorophyll a concentrations (Kuo and Neilson 1987).

The EPA *Regional Criteria Guidance* document encourages states to adopt numerical chlorophyll *a* criteria in waters where algal-related designated use impairments are likely to persist even after attainment of the applicable dissolved oxygen and water clarity criteria (USEPA 2003a). Of all the major tidal rivers, this situation is only observed in the tidal James River. Therefore, to provide the quantitative basis for making and enacting pollution reduction decisions necessary to address existing regulatory responsibilities to protect the designated use of a "balanced, indigenous population of aquatic life" and "control undesirable growths of aquatic plant life", Virginia has proposed the adoption of river segment and season specific numerical chlorophyll *a* criteria for the tidal James River into Virginia's Water Quality Standards Regulation.

DEFINING IMPAIRMENTS TO "BALANCED INDIGENOUS POPULATIONS"

Unlike 'traditional' water quality criteria which are derived on the basis of protecting against lethal (death) or sublethal (e.g., growth, reproduction) endpoints, the chlorophyll *a* criteria are derived to protect for balanced aquatic plant life populations and against the overgrowth of nuisance, potentially harmful algal species. The chlorophyll *a* criteria derived here are actually water quality surrogates for what could be extremely complex biological criteria protective of the existing Virginia "balanced, indigenous populations" water quality standard.

Impairments to microscopic aquatic plant life–scientifically referred to as phytoplankton and commonly described as algae–are defined here in two principal ways: imbalances in aquatic plant life and undesirable/nuisance aquatic plant life. In the sections which follow, past and present conditions within the tidal James River are characterized with respect to these two main categories of impairments.

Imbalanced Populations in Aquatic Plant Life

There are a number of indices or metrics that can be used to assess the balance or imbalance of aquatic plant life. In general, a more favorable estuarine habitat status is associated with waters composed of a diverse mix of phytoplankton groups with large celled diatoms strongly represented in contrast to high, or increasing, concentrations of blue-green and smaller autotrophic plankton (Dauer *et al*. 1998). Imbalances can be quantified and described in terms of: excessive populations/concentrations; species composition; bloom frequency; biological integrity; species diversity and excessive production.

Cell concentrations of one or more species or groups is a useful indicator. Significant increases (statistical and/or ecological) in the number of algal cells of one or more plant species per volume of water can be used to characterize excessive concentrations. The metrics most frequently used are cells per milliliter (milliliter^{-1}) or liter (liter^{-1}). The mix of different algal groups (taxa) represents the species composition. Related to species composition is the classic and widely used measure of community health and stability called species diversity. Healthy communities are characterized by diverse groups as opposed to a single group dominating. More diverse is better than less diverse. Another index is population stability or risk of algal blooms usually displayed as a frequency of occurrence. A balanced community is relatively stable with lower risk of potential blooms. By combining several related indices, one phytoplankton community can be compared to a reference, or least-impaired, habitat condition through an index of biological integrity (IBI). There is also a measure of how fast algae grow. Higher growth rates equate to more production and higher biomass, all indicators of eutrophication.

Undesirable/Nuisance Aquatic Plant Life

Undesirable/nuisance aquatic plant life can be characterized through enumeration of undesirable species, domination of small sized cells and increasing dominance of select taxa. There are many undesirable aquatic plants like weeds in the yard, just waiting for the opportunity to grow. As mentioned above, the most desirable are large algae such as diatoms known for their nutritious value. Less desirable or nuisance aquatic plants tend to be opportunistic and provide little nutritional value. They are usually smaller algae (picoplankton) such as blue-greens (cyanobacteria) and some dinoflagellates. Often associated with undesirable or nuisance aquatic life are those aquatic plants responsible for what are terms “harmful algal blooms.” It’s a generic term to describe an overabundance of certain algae that can produce natural poisons known as biotoxins. These blooms can kill fish and other marine organisms, poison people who eat contaminated shellfish, and cause respiratory distress in humans.

Characterization of Balanced, Indigenous Aquatic Life

While each of Virginia’s tidal rivers are characterized by distinct watershed, historically they contain similar estuarine phytoplankton flora (Marshall and Alden 1990). There are also common fluctuating events associated with phytoplankton dynamics in the estuary. Each season may contain separate phytoplankton assemblages or mix of different algal groups. Within the phytoplankton community, a balanced system is assumed to be one where there is a diverse group of plants and no single form or type dominates. Imbalances appear when unusual or significant changes occur to these seasonal phytoplankton assemblages. One widely accepted approach is the use of reference communities (Buchanan *et al*. 2005). Based on such an approach, York River maintains a population of flora considered “least-impaired” or desirable with a balanced phytoplankton community for comparison. For example within the tidal fresh, abundance as measured by cell concentration is not dominated by any single group yet maintains a diverse assemble of algal groups.

IMPAIRMENTS TO THE BASE OF THE JAMES RIVER FOOD WEB

Imbalances in Microscopic Aquatic Plant Life Observed in the Tidal James River

The following sections clearly document, based on current conditions of the river’s algal communities, that the tidal James River has:

1) an imbalanced population of aquatic plant life, and
2) high levels of undesirable, nuisance aquatic plant life.

Direct observed measures of an imbalanced population of aquatic plant life are excessive concentrations of algae, increasing frequency of algae blooms, phytoplankton community dominated by select undesirable groups, poor biological integrity index scores, reduced species diversity and elevated primary productivity. The increasing dominance of undesirable, nuisance aquatic plant life are measured through the dominance of smaller cell sizes and enumeration of two key recognized undesirable, nuisance algae taxa dominating tidal fresh/low and high salinity habitats within the tidal James River. These situations are in direct violation of the existing Virginia Water Quality Standards Regulation 9 VAC 25-260-10.A and 20.A, and should not be allowed to continue.

Excessive Concentrations of Algae

Excessive Algae Observed Compared To
Worldwide/Nationwide/Bay-Wide Measurements

High chlorophyll *a* concentrations are an indication of an imbalance between the primary producers (i.e., plants) and primary consumers (i.e., animals that eat plants). The tidal James River has very high chlorophyll *a* levels in comparison to 40 other estuaries worldwide (Monbet 1992). More recently, a survey and comparison among estuaries within the United States determined that "in the James River, chlorophyll *a* concentrations range from high to hypereutrophic" (NOAA 1997).

A more detailed spatial comparison among Virginia's three principal tidal rivers shows that the summer chlorophyll *a* concentrations are especially high in the tidal James River just below Hopewell at monitoring stations TF5.5 and TF5.5a (**Figure 1**). The tidal James River has higher overall mean and maximum chlorophyll *a* concentrations compared with the tidal York (**Figure 2**) and Rappahannock (**Figure 3**) rivers.

Widespread Increases in Algae Levels

When examined in comparison to other areas of Chesapeake Bay utilizing the extensive Chesapeake Bay monitoring program data, chlorophyll *a* concentrations in the tidal fresh portion of the James are rated as "Poor" (**Figure 4**). There was a degrading (i.e., increasing concentration) trend over the period of 1986 through 2002 in the tidal fresh segment of the James River (Dauer *et. al*., 2003.). Chlorophyll trends on 1986 through 2003 (**Figure 4**) indicate that the overall segment-wide trends in the James are not statistically significant due ameliorating effects of very high riverflow experienced in 2003 as well as the broad range in chlorophyll levels among different stations. However, there are still many increasing chlorophyll *a* concentration trends found when individual water quality monitoring stations are examined on an annual basis as well as on seasonal basis important for other aquatic life (e.g., SAV seasons are those months critical to the growth of submerged aquatic vegetation (**Table 1**). **Figure 5** shows the increasing chlorophyll *a* concentrations observed in the tidal fresh segment as a whole (**Figure 5a**) as well as at the individual stations within this segment (**Figures 5b-5f**). As a reference, **Figure 6** shows the monitoring station locations.

Algae Levels Higher than Reference Community Levels

Phytoplankton reference communities for Chesapeake Bay have been determined from least-impaired habitat conditions using commonly measured water quality and phytoplankton parameters (Buchanan *et al*. 2005). The measured characteristics of reference communities provide the basis of assessing plankton community health at other sites. In general, reference communities in all seasons and salinity zones were characterized by consistently low chlorophyll *a* values coupled with relatively stable proportions of the desired phytoplankton taxonomic groups and low abundance of key bloom-forming species.

This published scientific work identified the following median chlorophyll *a* concentrations as representative of a summer period (July-September) phytoplankton reference community: tidal fresh = 8.6 *u*g liter^{-1}, oligohaline = 6.0 *u*g liter^{-1}, mesohaline = 7.3 *u*g liter^{-1}, and polyhaline = 4.5 *u*g liter^{-1} . As shown in **Figure 7**, the observed median summer concentration in the lower James River tidal fresh segment (JMSTF1) (32.1 ug liter^{-1}) was more that 3.5 times higher than the tidal fresh reference community concentration of 8.6 ug liter^{-1} . Also, the observed summer median chlorophyll *a* concentrations in the oligohaline (JMSOH) and polyhaline (JMSPH) segments were above their respective reference community concentrations. Only the observed summer median chlorophyll *a* concentration in the mesohaline (JMSMH) segment was below its reference community concentration. To maintain consistency with the majority of metrics used in determining concentrations in this and the criteria document (USEPA 2003a) mean chlorophyll *a* concentrations were calculated. For spring and summer periods for phytoplankton reference communities the means were calculated directly from the Index of Biotic Integrity Database **(Table 8)**. Means for spring are: tidal fresh = < 14 ug liter^{-1}, oligohaline = < 21 ug liter^{-1}, mesohaline = < 6 ug liter^{-1} and polyhaline = < 3 ug liter^{-1}. Means for summer are tidal fresh = < 12 ug liter^{-1}, oligohaline = < 9.5 ug liter^{-1}, mesohaline = < 7.5 ug liter^{-1}, and polyhaline = < 4.5 ug liter^{-1}.

Algae Levels Higher than Trophic Based Concentrations Reflective of Desired Ecosystem Status

Several influential scientific papers, synthesizing data from many different aquatic systems, describe conditions that were judged to reflect the trophic status of different water bodies (e.g., Wetzel 2001; Ryding and Rast 1989; Smith 1998). Chlorophyll *a* is the principal parameter quantified in these literature reviews. The information is drawn from a diversity of systems across the spectrum of healthy (oligotrophic) to severely stressed (eutrophic) water bodies. Trophic classifications are useful yet general ecological concepts. The use of these trophic classifications are a general guide since the majority of the scientific literature-based values were developed for lake, coastal or marine systems, not temperate, partially mixed estuaries such as the James River. However, they can provide some relative insight into the trophic status of the James River.

Several papers in the literature synthesize data from many aquatic systems and focus on conditions that reflect different trophic states of water bodies. R. G. Wetzel's *Limnology* presents a table of phytoplankton-related trophic status based on hundreds of studies in freshwater systems (Wetzel 2001). A system is defined as eutrophic when it has: 1) very high productivity but mostly occurring in the lower trophic levels (e.g., algae, bacteria); 2) a simplified structure of biological components; and 3) reduced ability to withstand severe stresses and return to pre-stress conditions. In a eutrophic condition, "excessive inputs commonly seem to exceed the capacity of the ecosystem to be balanced, but in reality the systems are out of equilibrium only with respect to the freshwater chemical and biotic characteristics desired by man for specific purposes" (Wetzel 2001).

Mesotrophic, a desirable condition, in freshwater systems are defined by Wetzel (2001) as having chlorophyll *a* concentrations in the range of 2-15 ug liter^{-1} and eutrophic systems chlorophyll *a* concentrations greater than 10 ug liter^{-1}. (see Table V-8 and support text and references in USEPA 2003a). Current median conditions in the James segment JMSTF1 are well above this concentration at 32.1 ug liter^{-1} (**Figure 7**).

Ryding and Rast (1989) also deal with characteristics of eutrophication in lakes, based on surveys of hundreds of temperate lakes globally. They reported the peak ranges, for occasional blooms, were 2.6-7.6 *u*g liter^{-1} for oligotrophic, 8.9-29 *u*g liter^{-1} for mesotrophic and 16.9-107 *u*g liter^{-1} for eutrophic aquatic systems (see Table V-8 and support text and references in USEPA 2003a). The ranges overlap slightly, and in fact the authors recommended using multiple parameters, including total phosphorus, total nitrogen, chlorophyll *a* and Secchi depth to classify the lakes. Using their criteria, summer concentrations at stations TF5.5 and TF5.5a are in the "eutrophic" range (**Figure 1**).

In a review of lake and marine systems, Smith *et al*. (1999) equated mesotrophic status in lake systems to chlorophyll *a* concentrations ranging from 3.5 to 9 *u*g liter^{-1}. A chlorophyll *a* concentration range of 1 to 3 *u*g liter^{-1} was equated with mesotrophic status in marine systems (assumed here to be principally polyhaline in terms of salinity). Smith *et al*. (1999) published values characteristic of hypereutrophic lake as >25 *u*g liter^{-1} which the James JMSTF1 segment is well above (**Figure 7**). Marine systems are eutrophic at >5 *u*g liter^{-1} according to Smith *et al*. (1999), and the higher salinity portion of the James (i.e. segment JMSPH) is above this level at 8.1 *u*g liter^{-1} (**Figure 7**).

The Norwegian Environmental Protection Agency has constructed a system for classifying estuaries and coastal waters with respect to water quality and eutrophication using five classes of water quality (Molvaer et al. 1997). For salinities above 20 ppt, chlorophyll *a* concentrations below 2 *u*g liter^{-1} are considered Class I or "very good," whereas concentrations above 20 *u*g liter^{-1}are classified as "very bad" or Class V waters. Sweden has adopted similar chlorophyll *a* water quality standards for its estuarine (1.3 to 2.0 *u*g liter^{-1}) and marine (1.0 to 1.5 *u*g liter^{-1}) waters that reflect the lower end of these concentration ranges (Sweden Environmental Protection Agency 2002). The high salinity portions of the James (i.e. segment JMSPH) is above these standards at a median of 8.1 *u*g liter^{-1} (**Figure 7**), and individual stations have experienced concentrations above 60 *u*g liter^{-1} (see stations LE5.2, LE5.3, and LE5.4 in **Figure 1**).

Increasing Frequency of Algae Blooms

Another measure of imbalanced phytoplankton communities is found by examining phytoplankton population stability. Though most aquatic systems naturally have blooms (i.e., occasional occurrences of much higher than average conditions), an overabundance of blooms is considered an indicator of an imbalanced aquatic life community. For purposes of comparison, an algal bloom can be defined as a chlorophyll *a* concentration greater than the 95th percentile of the values in the reference condition (Buchanan *et al*. 2005). With this metric, the monitoring station in the area of chlorophyll maximum (i.e., TF5.5A) had 65 percent of all chlorophyll *a* observations above this bloom criterion (**Figure 8)** and the frequency of blooms among the 3 phytoplankton community monitoring stations in the James (i.e. TF5.5, RET5.2, LE5.5) is 30 percent. The frequency of blooms also has been increasing since 1986 in the James River (HG Marshall, personal communication).

Phytoplankton Community Dominated By Select, Undesirable Groups

An imbalance in the algae community is further demonstrated in the relative abundances of individual taxonomic groups in tidal James River. **Table 2** and **Figure 9** show the percentages of phytoplankton groups present at each station over a long-term average (1986 through 2003, July – September summer months only). Average taxonomic group abundances in tidal fresh York River are about equally represented by cyanophytes, or blue-green algae (41.8

percent), and diatoms (41.5 percent). In contrast, average abundances indicate the tidal fresh James River is dominated by the less desirable cyanophytes (60.1 percent), with lower percentages of the more desirable diatom (23.7 percent).

Poor Biotic Integrity Indices Evidence a Degraded Aquatic Plant Community

The phytoplankton index of biotic integrity provides another clear indication of imbalance in aquatic life of the tidal James River. The index is composed of several phytoplankton and phytoplankton-related metrics and indicates the status of the phytoplankton community relative to a reference, or least-impaired, habitat condition (Lacouture *et. al*. in Prep). The long-term average index of biotic integrity (IBI) scores for Virginia's tidal fresh plankton monitoring stations three tributaries are provided in **Table 3**. Based on this index, the tidal fresh York River summer communities are best (above 3) with tidal fresh James River summer communities considerably more degraded (1.35). The average summer IBI scores for all individual phytoplankton monitoring stations in Virginia tributaries are shown in **Figure 10**. Further detail on IBI scores for Virginia's phytoplankton monitoring stations can be seen by examining the IBI scores for all spring and summer monitoring events at each biomonitoring station. IBI scores of 1 - 2 are considered "Poor", 2 - 2.67 are "Fair-Poor", 2.67 - 3.33 are "Fair", 3.3 - 4 are "Fair-Good" and 4 - 5 are "Good". The James River upper and middle biomonitoring stations have a very high frequency of events when the IBI score was "Poor" or "Fair-Poor" compared to the other Virginia tidal tributaries and especially Virginia's Chesapeake Bay mainstem (**Figure 11**).

Reduced Species Diversity in Low Salinity Reach of the Tidal James

Another indication of an imbalance in the aquatic life of the tidal James River is shown by examining the diversity in the phytoplankton community. Species diversity is a classic and widely used way to measure health and stability of biological communities (Odum 1971). Diversity scores for all the Virginia Chesapeake Bay Phytoplankton Monitoring Program stations in the tidal James River are shown in **Figure 12**. The diversity of the phytoplankton community characterized by the phytoplankton monitoring station near the Chickahominy River (RET5.2) in the oligohaline segment of the James River (JMSOH) is designated as "Poor" in relation to other low salinity Chesapeake Bay and tidal tributary waters and also has a degrading trend (**Figure 13**).

Elevated Primary Production in the Tidal Fresh James

The high level of productivity in the phytoplankton community is another clear indication of an imbalance of aquatic life in the tidal James and is indicative of undesirable anthropogenic eutrophication. The tidal fresh segment of the James River has very high levels of primary productivity as measured by C^{14} productivity studies; this condition is considered undesirable as noted by its classification as "Poor" in **Figure 13**.

Undesirable, Nuisance Aquatic Plant Life Increasing Over the Past Decade

Small Cell Sizes Dominate throughout the Tidal James

The first overall metric of an undesirable phytoplankton community can be found by examining the average cell size. The ratio of total biomass to total abundance of the community gives an indication of overall average cell size. A high biomass-to-abundance ratio indicates larger cells which are more desirable food sources for animals such as zooplankton, larval fish, oysters, and menhaden. The ratio tends to be larger in least-impaired waters (Buchanan *et al*. 2005). The phytoplankton monitoring stations in the tidal James River all have smaller average cell sizes indicating a "poor" current status in relation to other Chesapeake Bay and tidal tributary waters of similar salinity (**Figure 13)**.

Increasing Dominance of Blue-Green Algae in the Tidal James

Undesirable phytoplankton species are those that are less favorable as a food source in the Chesapeake Bay ecosystem. Several of the more than 700 phytoplankton species in the Chesapeake Bay are known to be harmful to other aquatic organisms. Approximately 2 percent of all these observed species have shown evidence of producing toxins (Marshall 1996). Some of these undesirable species form blooms and can dominate the community at particular locations during specific times of the year.

In tidal-fresh regions, a colonial cyanophyte, *Microcystis aeruginosa*, forms surface blooms that cover the upper reaches of certain Bay tributaries for miles during the summer. This species has been documented to adversely affect zooplankton communities under bloom conditions (Lampert 1981; Fulton and Paerl 1988). A substantial body of literature deals with the negative effects of toxic cyanobacteria on the feeding, growth, behavior and survival of micro- and mesozooplankton. Numerous studies have documented the avoidance of toxic and nontoxic strains of *Microcystis aeruginosa* by specific taxa of zooplankton (Clarke 1978; Lampert 1981; Gilbert and Bogdan 1984; Fulton and Paerl 1987, 1988; DeMott and Moxter 1991). Both physiological and behavioral problems have also been associated with its ingestion (Lampert 1981, 1982; Nizan *et al*. 1986; Fulton and Paerl 1987; DeMott *et a*l. 1991; Henning *et al*. 1991).

There has been a significant trend over the past decade of increased abundance and biomass of cyanophytes or blue green algae in two of the three reaches of the James River, including *Microcystis aeruginosa* and several filamentous taxa (**Figure 13**). *Microcystis* has been associated with toxin production (microcystin) in freshwater and estuarine systems. The microcystin toxin has been found in the Chesapeake Bay system. Though there has been no known toxic impact yet, the increasing levels of cyanophytes could lead to such problems in the future.

There has been a dramatic and troublesome increase in cyanobacteria abundance observed at phytoplankton monitoring station TF5.5 in the tidal fresh James River **(Figure 14)**. In addition, there is clear evidence of increasing number of varieties of cyanobacteria present. For example, Old Dominion University scientists running Virginia's Chesapeake Bay phytoplankton monitoring program found 25 cyanobacteria taxa in the tidal fresh James River in 1994. That number increased to 110 taxa in the 2004 survey (**Figure 15**). Included among these taxa are the more common presence of *Microcystis* and several filamentous species.

Microcystis sp. is the group of blue green algae species that is most abundant in the tidal fresh James River, about 9 to 10 times higher than in the Rappahannock and York rivers' tidal fresh reaches, respectively (**Table 4**). As discussed previously above, undesirable blue green algae dominate summer surface waters at this James tidal fresh station. These algae (cyanophytes) represent about 60 percent of the total abundance whereas diatom abundance, more desirable algae, is only 24 percent (**Table 2**). The total biomass at that station for these undesirable species is high (10.9 percent). The lowest abundance and biomass of these blue green algae is reported in the York River (29 percent of the total abundance comprising just 3.4 percent of the total biomass), followed by the Rappahannock River (blue green algae making up 42 percent of total abundance and 9.3 percent of the total biomass).

From a summary of laboratory studies, 10,000,000 cells liter^{-1} of *Microcystis aeruginosa* was determined to be an appropriate threshold above which zooplankton communities can be adversely altered by large particle size of the colonies, increased density of particles in the water column, or directly by the toxin result in poor food quality to these primary consumers (USEPA 2003; Lampert 1981; Fulton and Paerl 1987; Smith and Gilbert 1995). **Figure 16** shows that this threshold was exceeded in 11 of the 17 years of the Chesapeake Bay phytoplankton monitoring program data record (65 percent) in the tidal fresh James River. In addition, **Figure 17** shows that the average summer *Microcystis aeruginosa* cell density in the upper James (station TF5.5) is above this threshold and at a level much higher than observed at any other Chesapeake Bay phytoplankton monitoring program station.

In 1983, a large bloom of blue-green algae developed in the James River near Richmond and created taste and odor problems for the Richmond drinking water system. It is also notable that a very large boom of *Microcystis* sp. occurred in the Potomac River in 2004, causing extensive beach closures and recreational use impairments. The increasing cyanobacterial trends and dominance by these forms indicates that the tidal James River has increasing potential to develop these same adverse conditions.

Undesirable Dinoflagellates in the Upper and Lower James River

In addition to the cyanobacteria, high biomasses of certain dinoflagellates appear to adversely affect zooplankton. As shown in **Figure 13**, the status in the tidal James for these undesirable forms of algae is “poor” in the tidal fresh and oligohaline segments and only fair in the polyhaline segment. Their representation in the Bay and tidal tributaries has also increased over the past decade. In 1994 only 125 dinoflagellate taxa were recorded and in 2004, 191 taxa were identified (HG Marshall, personal communication).

Among these dinoflagellate taxa are numerous bloom producers (and potentially toxic species) that are most common in the lower reaches of Virginia’s tidal rivers. During bloom periods the cells are introduced into other estuaries by way of tidal flow. Over the past several years many of these blooms have increased in their range and bloom duration. The result has been a broader establishment of these taxa throughout the Bay. Many of the summer/fall blooms of dinoflagellates are becoming longer in duration and areal coverage and what previously took 1-2 tidal cycles to dissipate a bloom may now involve 2-4 tidal cycles (HG Marshall personal communication). A large mahogany tide bloom assumed to be a dinoflagellate was noted in 2004 in the lower James River and reported by the Chesapeake Bay Foundation (Portlock personal communication and photographic evidence).

Many of these dinoflagellates form resting stages that settle in the sediment, allowing their development to continue the following year if favorable conditions are present. A special study was performed in 1996 to determine the spatial distribution of dinoflagellate cysts (Marshall, undated report). Data from this report by Old Dominion University scientists shows that the tidal James River had much higher average numbers of dinoflagellate cysts (1,424 cysts gram^{-1} sediment) than the tidal Rappahannock, York or Virginia Chesapeake Bay mainstem (554, 355, and 798 cysts gram^{-1} sediment respectively). Cysts of three potentially toxic forms were identified and the James also had much higher average numbers of these (412 cysts gram^{-1} sediment) than the Rappahannock, York or Virginia Chesapeake Bay mainstem (83, 146, and 33 cysts gram^{-1} sediment respectively) (**Figure 18**).

One undesirable dinoflagellate, *Prorocentrum minimum*, commonly blooms in spring and summer. *Prorocentrum minimum* effects may be a function of bloom density or toxicity and the species has been shown to harm various life stages of the Eastern oyster, *Crassostrea virginica* (Ho and Zubkoff, 1979; Luckenbach *et al*. 1993; Wickfors and Smolowitz 1995). Blooms of *Prorocentrum minimum* in the source intake waters to Virginia and Maryland oyster hatcheries were suspected to have caused oyster larvae mortality at the two hatcheries in 1998 (Luckenbach and Merritt personal communication). While there has been no documented case of shellfish toxicity or mortality associated with *Prorocentrum minimum* blooms in the Chesapeake Bay, the potential exists for toxic repercussions to shellfish and other organisms as a result of this species. A concentration of 3,000 cells liter^{-1} of *Prorocentrum minimum* was chosen as an impairment threshold (USEPA 2003). This level was exceeded in May 2003 at the Virginia Chesapeake Bay phytoplankton monitoring program station in the lower James River (LE5.2) when 4,091 cells liter^{-1} was observed.

Another undesirable dinoflagellate found in higher salinity waters is *Cochlodinium heterolobatum*, which has been linked to deaths in fish culturing grounds (Yuki and Yoshimida, 1989) and is listed as a toxin producer (Steidinger 1993). This algae species was generally localized to the York River prior to 1992 but since that time has apparently expanded its range to become an annual bloom producer in the James River system (Marshall 1996).

DERIVATION OF JAMES RIVER SPECIFIC NUMERICAL CHLOROPHYLL *A* CRITERIA

The chlorophyll *a* criteria derived for the tidal James River were based on determining seasonal and salinity specific concentrations that would best support a balanced, indigenous phytoplankton community, providing the best available food for the rest of the river's aquatic food web. Based on the best available scientific information, achievement of the established chlorophyll *a* concentrations should protect against conditions that promote an overabundance of undesirable, nuisance forms of algae. These numerical chlorophyll *a* criteria provide for a quantification of the water quality conditions necessary to achieve the existing Virginia Water Quality Standards Regulation's narrative for protection of aquatic life.

Imbalances in aquatic plant life were addressed in derivation of the chlorophyll *a* criteria through consideration of available scientific information on historical concentrations, species composition and biological integrity. Preventing dominance of undesirable/nuisance aquatic plant life was addressed through the derived criteria based on data enumerating abundances of undesirable species above thresholds protective of aquatic life. Chlorophyll *a* concentrations characteristics of abundance of dominant select taxa above those protective thresholds were then determined and factored into the criteria.

As described in detail below, numerical chlorophyll *a* criteria were derived for spring and summer seasons. Each respective chlorophyll *a* criterion was tailored to address specific impairments and protection of aquatic life in each individual salinity-based reach or segment of the tidal James River.

Tidal James River Segmentation

Of Virginia's three major tributaries to the Chesapeake Bay, James River is by far the largest with its basin covering approximately 25 percent of the Commonwealth. The James River watershed is also the most varied basin in terms of geology and hydrology. Because of its unique drainage, it provides a very efficient delivery of both nutrients and sediments to tidal waters.

Within the tidal length of the river, there are a variety of freshwater and estuarine phytoplankton species. The river divisions between the tidal fresh/low salinity and high salinity sections (mesohaline and polyhaline) of the river are not constant, but move longitudinally within the river basin. This movement is in response to changes in the amount of river flow and tidal influence. The abundance of algae in any section of the river is directly associated with hydrodynamic events in the river with algae (as measured directly by chlorophyll *a*) concentrations inversely related to freshwater input and directly related to the water's residence time in the river. Other factors influence algae abundance in the river including nutrients, tidal cycles, turbidity and light availability (Fisher and Butt 1994; Marshall and Burchardt 1998).

Tidal Fresh James

The tidal fresh section of the James River has some unique features. The upper tidal reach, extending from Richmond to Hopewell, is narrow, creating fast advective transport without exposed shoals. This combination of bathymetry and hydrodynamics translates to a lower water residence time for algal biomass to develop, leading to naturally lower chlorophyll *a* concentrations.

At Hopewell, the river widens from approximately 0.4 miles across to as much as 1.6 miles shortly down river. Here wider shoals flank the riverbanks creating a greater photic zone area due to the increased width-depth ratio of the river. Because of the increased cross-sectional area, river flows decrease significantly creating longer water residence times and conditions more favorable to phytoplankton growth and abundance. For this reason, the original Chesapeake Bay Program tidal fresh segment of James River (JMSTF) was sub-divided into an upper segment (JMSTF2) and a lower segment (JMSTF1) for derivation and application of chlorophyll *a* criteria (USEPA 2004).

Low Salinity James

A transitional zone characterized by naturally turbid water, called the turbidity maximum, is found below the tidal fresh reach of James River (JMSOH). This is a zone where fresh water mixes with higher salinity bay/ocean waters. Within the turbidity maximum, algal biomass may decline because of increased shading and salinity changes. This natural occurrence in JMSOH is not stationary and may move downstream with increasing river flows. Below the turbidity maximum but still in this segment, is a second estuarine feature where waters clear. This natural event creates a zone known as the chlorophyll maximum. As the name implies, algae accumulate by taking advantage of the increase light leading to naturally high chlorophyll *a* concentrations.

Higher Salinity James

Below the transitional zone of the river, bay and ocean waters further dilute riverine conditions. Nutrient concentrations usually decline because of algal uptake in the chlorophyll maximum. Because this lower region of the river (JMSMH and JMSPH) is dominated by lower nutrients and bay/ ocean waters, the system once again has naturally lower chlorophyll *a* concentrations with rapid transport to the lower Bay and coastal shelf waters.

Protecting a balanced, indigenous aquatic plant community

Concentrations Characteristic of Less Nutrient Enriched Conditions

The historical records of chlorophyll *a* concentrations, while sporadic, reflected a more balanced, mesotrophic Chesapeake Bay (USEPA 2003). The database was assembled through quantified reviews and assessments by decade since the 1950s (Harding 1994; Harding and Perry 1997; Olson 2002). Based on the analysis of Chesapeake Bay water-quality data, benchmark levels of chlorophyll *a* were developed for the mainstem. A tabular summary of annual means for chlorophyll *a* from 1950 to 1994 are presented in **Table 5**.

Recognizing the limitations in spatial and temporal coverage of the available data during for this early period (1950s and 1960s), the lowest concentrations were reported in the lower Bay. Region 1, extending from the Mobjack Bay to the mouth of the Bay, had an annual mean of 0.46 *u*g liter^{-1} (1950 and 1951 only). Region 2, including the mainstem from Mobjack Bay to the mouth of Rappahannock River, had an annual concentration of 1.2 *u*g liter^{-1} for the same period. Concentrations tended to increase further up bay reaching a maximum of 4.3 *u*g liter^{-1} just above where the Potomac River enters the mainstem Bay and just below the turbidity maximum.

The spring, summer and annual mean and median chlorophyll *a* associated with relatively unimpaired water quality conditions in the historical data (1950 - 2000) are summarized in **Table 6**. Historically, the highest chlorophyll *a* concentrations occurred during the summer in the lower saline waters (tidal fresh, oligohaline and mesohaline waters) with averages often above 7.0 *u*g liter^{-1}. The polyhaline zone showed highest chlorophyll levels during the spring reported around 4.0 *u*g liter^{-1}. A summary of the results of these reviews and evaluations of the historical and recent chlorophyll *a* concentration data records are presented in **Table 7**. These concentrations are also reflected in **column 2 of Table 11 (Summary Table)**.

Concentrations Supporting Reference Phytoplankton Communities

Biological communities found in pristine or minimally affected habitats provide essential information on how restoration efforts might improve ecosystem structures and functions.

Chesapeake Bay water quality and phytoplankton data collected at Chesapeake Bay Program biomonitoring stations between 1984 and 2001 were analyzed to identify reference phytoplankton communities for Chesapeake tidal waters (Buchanan *et al*. 2005). The seasonal and salinity-specific reference communities were used to quantify chlorophyll *a* concentrations in the least-impaired water quality conditions currently found in the Chesapeake Bay and its tidal tributaries (**Table 8**). These concentrations are also reflected in **column 5 of Table 11 (Summary Table)**.

For the purposes of deriving the reference communities, least-impaired water quality conditions were defined as the co-occurrence of high light penetration, low dissolved inorganic nitrogen and low dissolved inorganic phosphorus concentrations. Low dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (PO_4) concentrations are the threshold concentrations shown to limit phytoplankton growth in Chesapeake Bay waters (Fisher *et al*. 1999), whereas high light penetrations are the Secchi depth values identified by the Relative Status, or benchmark, method as "good" (Olson 2002b). The high light penetration levels are approximately the same as those necessary for restoring underwater bay grasses (USEPA 2000; Kemp *et al*. 2004). Thresholds for DIN, PO_4 and Secchi depth for spring and summer across four salinity zones (tidal-fresh, oligohaline, mesohaline and polyhaline) were applied to the 1984 through 2001 CBP monitoring database to bin the data records into six water quality categories. Reference communities were derived from the least impaired water quality categories found in each season-salinity regime (USEPA 2003a).

It is important to realize that the chlorophyll *a* concentrations in **Table 8 and 11** reflect phytoplankton reference communities in the absence of robust grazer populations. There are no undisturbed sites in the Chesapeake Bay with a full complement of natural grazers. Harvesting and disease have significantly decreased Chesapeake oyster abundances (Newell 1988). Menhaden populations have declined to approximately 5 percent of 1970s levels (unpublished data from Maryland Department of Natural Resources). Comparisons of historic and contemporary populations of mesozooplankton and benthos indicate that declines may also have occurred in these grazers. Median chlorophyll *a* concentrations in the reference communities are significantly lower than those in impaired waters, and algal blooms are absent. Reference community chlorophyll *a* concentrations are slightly higher than historic Chesapeake Bay concentrations and are typical of mesotrophic conditions.

These values were selected from samples subject to low nutrient loadings from a larger data set obtained under generally nutrient- and sediment-enriched conditions. Under better water quality conditions (lower annual nutrient loadings, more zooplankton grazing and better trophic coupling), these chlorophyll *a* values might be even lower than those obtained under low current nutrient loadings due to the carryover of nutrients from previous high load conditions.

The phytoplankton reference community approach does not demonstrate any direct relationship between chlorophyll *a* concentrations and designated use impairments. However, this method does provide solid insights into the chlorophyll *a* concentrations that will likely be observed in estuarine systems that are nutrient-limited and light-saturated.

Concentrations based on EPA recommendations

Because of the regional and site-specific nature of algal-related water quality impairments, baywide numerical criteria have not been published. Along with the documented methodologies described within the current work, tabulated chlorophyll *a* concentrations were provided as a synthesis of the best available technical information for the Commonwealth and its potential use in our development and adoption of more regional and site-specific numerical chlorophyll a standards. These thresholds were based on information related to blooms, water clarity perception, trophic status or historical concentrations (**Table 10**) (Presented By EPA CBP to Chesapeake Bay Water Quality Standards Ad Hoc Committee, March 24, 2004). These concentrations are also reflected in **column 4 of Table 11 (Summary Table).**

Protecting against undesirable/nuisance aquatic plant life

Chesapeake Bay Harmful Algal Species

The scientific literature indicates that certain phytoplankton community taxonomic groups produce poor quality food and even toxins that impair the animals that feed on them (Roelke *et al*. 1999; Roelke 2000). Phytoplankton assemblages can become dominated by poor quality food taxonomic groups to an extent that the overall food quality of that phytoplankton assemblage becomes significantly reduced. Chlorophyll *a* concentrations were identified that corresponded to an increased probability that potentially harmful algal taxa would exceed specific impairment thresholds.

Several of the more than 700 phytoplankton species in Chesapeake Bay are known to be harmful to consumers. Approximately 2 percent of these species have shown evidence of producing toxins (Marshall 1996). Some species, however, form blooms and can dominate the community at particular locations during specific times of the year. Some of these species are even capable of producing toxins.

The dinoflagellates, *Prorocentrum minimum* and *Cochlodinium heterolobatum*, which commonly bloom in spring and summer, respectively, in certain mesohaline areas of the estuary, have been shown to harm various life stages of the Eastern oyster, *Crassostrea virginica* (Ho and Zubkoff, 1979; Luckenbach *et al*. 1993; Wickfors and Smolowitz 1995). The dinoflagellate *Karlodinium micrum* has been associated with numerous fish kills in the Chesapeake Bay (Goshorn *et al.* 2003). In tidal-fresh regions, a colonial cyanophyte, *Microcystis aeruginosa*, forms surface blooms that cover the upper reaches of certain Bay tributaries for miles during the summer. This species has been documented to affect zooplankton communities under bloom conditions (Lampert 1981; Fulton and Paerl 1987).

The occurrence of harmful algal blooms is a complex, incompletely-understood phenomenon. Many harmful blooms cannot effectively be predicted or modeled at this time, and the physical, chemical and biological controls on many such blooms are not known. Nutrient concentrations or loads are only one of many environmental parameters that can potentially affect harmful algal blooms. For example, some harmful blooms may respond more to nutrient ratios than absolute concentrations, or may be regulated by top-down controls (e.g., grazer dynamics) more than by nutrient availability. Despite this, the likelihood of bloom conditions being produced by some harmful or nuisance algal species can be directly associated with elevated chlorophyll *a* levels. And increases in the number of harmful algal species in the Bay have been implicated with elevated nutrient levels favorable to growth of opportunistic species (Marshall 1996; Mulholland 2004a,b).

Concentrations Characteristic of Harmful Algal Blooms

Microcystis aeruginosa

A substantial body of literature deals with the negative effects of toxic cyanobacteria on the feeding, growth, behavior and survival of microzooplankton and mesozooplankton. Numerous studies have documented the avoidance of ingestion of toxic and nontoxic strains of *Microcystis aeruginosa* by specific taxa of zooplankton (Clarke 1978; Lampert 1981; Gilbert and Bogdan 1984; Fulton and Paerl 1987, 1988; DeMott and Moxter 1991) while others indicate physiological and behavioral problems associated with its ingestion (Lampert 1981, 1982; Nizan *et al*. 1986; Fulton and Paerl 1987; DeMott *et al*. 1991; Henning *et al*. 1991).

From laboratory studies, 10,000 cells milliliter^{-1} was determined to be the threshold above which zooplankton communities can be adversely altered by the poor food quality, large particle size of the colonies, increased density of particles in the water column or directly by the toxin (Lampert 1981; Fulton and Paerl 1987; Smith and Gilbert 1995). USEPA 2003a provides more detailed descriptions of the determination of the effects threshold.

Upon matching the chlorophyll *a* concentrations to samples containing *M. aeruginosa*, normalized frequency distribution plots were constructed for *M. aeruginosa* bloom frequency and the frequency of both bloom and non-bloom abundances versus chlorophyll *a* concentrations **.**Chlorophyll *a* concentrations < 15 *u*g liter^{-1} characterize *M. aeruginosa* concentrations less < 10,000 cells milliliter^{-1} (**Figure 19)**. Increasing concentrations of chlorophyll *a* above 15 *u*g liter^{-1} leads to increasing frequencies of bloom samples > 10,000 cells milliliter^{-1} (**Figure 20)**. These concentrations are also reflected in **column 7 of Table 11 (Summary Table)**.

Colonies of *M. aeruginosa* vary in their cell counts but colony counts provide an additional measure of bloom conditions. The ratio of cells per colony is approximately 17:1, providing an estimate of 588 colonies containing 10,000 cells as a translation to threshold levels for zooplankton community impacts.

M. aeruginosa counts were made from water samples collected by the Maryland Department of Natural Resources (unpublished data) through a separate water quality monitoring program from the tidal-fresh and oligohaline waters of Maryland's Chesapeake Bay. Between 1985 and 2000, *M. aeruginosa* colony counts showed low concentrations (< 588 colonies milliliter^{-1}) and low variance between 0-33 *u*g liter^{-1} chlorophyll *a*. Beyond 33 *u*g liter^{-1} chlorophyll *a*, the variance of colony counts increases significantly and counts exceeding the 588 colonies milliliter^{-1} threshold increase to 42 percent providing a threshold and probability for potentially harmful blooms of this cyanobacteria with respect to chlorophyll *a* measures. The chlorophyll *a* range of 15-33 *u*g liter^{-1} provides a threshold region between levels that protect against *M. aeruginosa* blooms versus conditions with a high likelihood for blooms (USEPA 2003a).

An site specific analysis of data in the plankton IBI database indicates that the tidal freshwater James River is the only region in Virginia's tidal waters with biomass of Cyanophytes above a threshold for zooplankton impacts estimated during workgroup discussions during development of EPA 2003a (139 ug C liter^{-1}). At the phytoplankton monitoring station in this segment (TF5.5), these begin to occur in the 35-40 ug liter^{-1} chlorophyll *a* range (**Figure 21**).

The strength of this scientific evidence for establishing chlorophyll *a* criteria values for the tidal-fresh and oligohaline regions of the James River lies in the evidence provided in the many laboratory and field studies that indicate adverse affects on zooplankton populations caused by cyanobacteria in general and, more specifically, by *M. aeruginosa*.

Numerous field studies have documented changes in zooplankton community structure associated with blooms of cyanobacteria in general (Infante and Riehl 1984; Orcutt and Pace 1984; Threlkeld 1986; Burns *et al*. 1989; Gilbert 1990; Fulton and Jones 1991). These studies most frequently cite the inability of many zooplankton taxa in using cyanobacteria as a nutritive food source. Therefore, it can reasonably be stated that high chlorophyll *a* concentrations in tidal-fresh and oligohaline regions of the James River estuary in summer often are associated with high densities of cyanobacteria, which can adversely alter the zooplankton community structure in these areas.

Colony counts have a lower variance than, and a positive relationship to, *M. aeruginosa* cell counts, providing a robust indicator to describe bloom conditions. Both data sets in these analyses independently define a relatively narrow range of conditions that separate the bloom from non-bloom regions of the chlorophyll *a* gradient.

There are recognized limitations given the threshold value for the cell density that affects zooplankton populations was derived from two laboratory studies citing impairment thresholds at very different cell densities (see Appendix G in USEPA 2003a). A third study has been identified that documented negative effects on zooplankton at *M. aeruginosa* cell densities of 50,000 cells milliliter^{-1}, which is an intermediate value compared to the two previously cited studies (Smith and Gilbert 1995).

Some of the detrimental effect of *M. aeruginosa* on zooplankton assemblages is related to the toxin content of a particular strain of this cyanobacterium (one reason that the threshold density of the two laboratory studies is so different). The toxin content of the strains of *M. aeruginosa* found in Chesapeake Bay has not been determined, which forced the extrapolation of the threshold to be chosen as a midpoint between the thresholds of the two laboratory studies (USEPA 2003a).

Prorocentrum minimum

P. minimum effects may be a function of bloom density or toxicity. In Japan in 1942, *P. minimum* was attributed as the cause of a shellfish poisoning in Japan in which 114 people died (Nagazima 1965, 1968). *P. minimum* isolated from a 1998 bloom in Choptank River and subsequently grown in the laboratory was found to be toxic to scallops (Wickfors, personal communication). Blooms of *P. minimum* in the source intake waters to Virginia and Maryland oyster hatcheries were suspected to have caused oyster larvae mortality at the two hatcheries in

1998 (Luckenbach and Merritt, personal communication). There has been no documented case of shellfish toxicity or mortality as a result of the 1998 *P. minimum* bloom in the Chesapeake Bay, but clearly the potential exists for toxic repercussions to shellfish and other organisms as a result of this bloom.

The *P. minimum* density of 3,000 cells milliliter^{-1} was chosen as a threshold for the chlorophyll *a* criteria analysis based on laboratory analyses (Wickfors and Smolowitz 1995; Luckenbach *et al.* 1993; USEPA 2003a). When the threshold is applied to Chesapeake Bay plankton monitoring program data, the normalized frequency distribution of chlorophyll *a* concentrations associated with bloom densities (> 3000 cells milliliter^{-1}) illustrates that concentrations > 5 *u*g liter^{-1} can generate densities that may impair the survival of various life stages of oysters (**Figure 22**). The likelihood of bloom level events tends to increase with increasing chlorophyll *a* concentrations (**Figure 23**).

When the threshold is applied to Chesapeake Bay plankton monitoring program data, the normalized frequency distribution of chlorophyll *a* concentrations associated with the *P. minimum* bloom densities (greater than 3,000 cells milliliter^{-1}) indicates a large increase at chlorophyll *a* concentrations of 25 to 30 *u*g liter^{-1} (USEPA 2003a). More than 19 percent of samples containing *P. minimum* in mesohaline waters in spring are characterized by densities that exceed the threshold whereby oyster life stages are impaired and fall within the chlorophyll *a* range of 25 to 30 *u*g liter^{-1}. In addition, more than 70 percent of the above-threshold data for *P. minimum* occur at chlorophyll *a* concentrations greater than 25 *u*g liter^{-1} (USEPA 2003a). These normalized frequency distributions thus indicate that chlorophyll *a* concentrations of greater than 25 *u*g liter^{-1} in spring in mesohaline waters often are associated with densities of *P. minimum* that may impair the survival of various life stages of oysters.

In an analysis of a separate Maryland Department of Natural Resources database from 1985-2000, a probability analysis illustrated that no blooms of *P. minimum* occurred at or below 4 *u*g liter^{-1} (USEPA 2003a). This analysis of an independent data set complements the previously described Chesapeake Bay Plankton Monitoring Program database analysis indicating the low threshold needed to eliminate conditions for blooms of *P. minimum* in the mesohaline Chesapeake Bay. Maximum bloom probability was 11 percent in the spring, or 1 in every 9 samples when conditions are optimal. Protecting against the conditions for 50 percent of maximum bloom potential occurred at approximately 25-30 *u*g liter^{-1} (USEPA 2003a). These concentrations are also reflected in **column 8 of Table 11 (Summary Table)**.

Currently, the impairment thresholds are usually reached in spring in mesohaline waters, but *P. minimum* commonly occurs in both spring and summer in oligohaline, mesohaline and polyhaline habitats.

P. minimum blooms occur in the higher salinity portions of the James River estuary. The appearance of the major bloom events in these areas occur on regular seasonal basis. Therefore this would be a useful indicator species to monitor. This taxon's effects are fairly well-documented, although the toxin content of different strains seems to be variable. The consumer organism that has been tested, *Crassostrea virginica*, the Eastern oyster, is important economically in the lower tidal James River and ecologically as a filter-feeder. The associated chlorophyll *a* threshold is well-defined based upon the historic data from the Chesapeake Bay phytoplankton and water quality monitoring programs. Both data sets used in these analyses independently defined a relatively narrow range of conditions that separate the bloom from non-bloom regions of the chlorophyll *a* gradient.

There are recognized limitations in the existing scientific record. Toxin content of different strains of *P. minimum* varies. Although widespread anecdotal evidence suggests that oyster larvae are negatively affected by blooms of *P. minimum* in the Chesapeake Bay, no direct evidence supports this hypothesis. The value chosen as a threshold for impairment is extrapolated from several laboratory studies and does not pertain directly to the strains of *P. minimum* found in the Chesapeake Bay. Effects on oysters associated with *P. minimum* appear to be limited to a uni-algal diet of *P. minimum*.

Model Simulation of Attainable Chlorophyll a Criteria

Attainability information was considered in the development these site-specific numerical chlorophyll *a* standards using the Chesapeake Bay water quality model "Tributary Strategies Cap Load allocations Confirmation Scenario" (USEPA 2003a,c). Chlorophyll *a* concentrations outputs were from 10 years of model simulation. Both monthly and seasonal mean concentrations for the two seasons of interests were compiled. In this case, both spring (March - May) and summer (July - September) means were calculated by year, and then averaged by individual season across 10 years (**Table 9).** Attainable concentrations are also reflected in **column 3 of Table 11 (Summary Table)**.

While not definitive, model simulations demonstrate that chlorophyll *a* concentrations should be less than 10 ug liter^{-1} during the spring throughout the entire tidal tributaries. Simulations indicated chlorophyll *a* levels should be higher during the summer in the tidal fresh James particularly the region below Hopewell. In this region, chlorophyll *a* values required for attaining the dissolved oxygen levels were any value less than 17 ug liter^{-1} based on the cap load allocations. Lowest required levels (< 6 ug liter^{-1}) were in the higher salinity regimes (meso- and polyhaline) while the oligohaline section of the river required less than 12 ug liter^{-1}. This attainability information is considered preliminary. Additional analysis of attainability under Virginia's Tributary Strategy loadings is forthcoming and will be used to verify these levels.

Regional Numerical Chlorophyll *a* Criteria for the Tidal James River

Tidal Fresh and Low Salinity James River Criteria

Based on the scientific literature summary of chlorophyll *a* concentrations reflecting trophic-based water quality, phytoplankton community and ecological conditions, seasonal average chlorophyll *a* concentrations in freshwater mesotrophic systems should fall in the range of 2 to 15 ug liter^{-1} with a mean around 7 ug liter^{-1}. Achievement of chlorophyll *a* concentrations and other water quality conditions characteristic of mesotrophic systems will lead to more balanced aquatic life (see Table V-2 and supporting text and references in USEPA 2003a).

The spring and summer chlorophyll *a* concentrations characterizing each of the respective salinity-based phytoplankton reference communities provide the most direct water quality measures of a more balanced phytoplankton assemblage (Buchanan *et al*. 2005) (see **Table 8 and 11**). Chlorophyll *a* concentrations characteristic of the phytoplankton reference communities, which straddle the boundary between mesotrophic and eutrophic conditions, are higher than those observed in the 1950s (see **Table 6**) which reflect oligotrophic conditions.

For tidal fresh habitats, spring and summer median chlorophyll *a* concentrations of 4.3 and 8.6 *u*g liter^{-1}, respectively, are supportive of the defined phytoplankton reference communities. In oligohaline habitats, those same seasonal median concentrations are 9.7 and 6.0 *u*g liter^{-1}, respectively. Maximum concentrations (95th percentile) supportive of the phytoplankton reference communities for tidal fresh spring and summer seasons were 13.5 and 15.9 *u*g liter^{-1}, respectively, and 24.6 and 24.4 *u*g liter^{-1}, respectively, for oligohaline habitats.

To protect against the principal undesirable, nuisance species in tidal fresh habitats, chlorophyll *a* concentrations <15 *u*g liter^{-1} characterize *M. aeruginosa* concentrations less that the10,000 cells milliliter^{-1} aquatic life protection threshold (**Figure 19**). Increasing concentrations of chlorophyll *a* above 15 *u*g liter^{-1} leads to increasing frequencies of bloom samples greater than the 10,000 cells milliliter^{-1} threshold (**Figure 20**). Based on the available scientific information, spring and summer seasonal mean chlorophyll a concentrations of between 10-15 *u*g liter^{-1} would support return of balanced phytoplankton community and protect against dominance by undesirable, nuisance algal species.

As described above, given different natural river bathymetric and hydrodynamic characteristics, the James River tidal fresh segment was subdivided into two separate segments (USEPA 2004). Recognizing the natural conditions results in different algal growth patterns and chlorophyll a concentration, different criteria concentrations were derived for the two new segments.

Spring is a period of high river discharge often dominated by favorable, large celled diatoms with lower chlorophyll *a* concentrations often diluting cell concentrations. Therefore, a chlorophyll *a* criterion concentration of 10 *u*g liter^{-1} is recommended for the upper James tidal fresh segment (JMSTF2) with a 15 *u*g liter^{-1} criterion concentration recommended for the lower James tidal fresh segment (JMSTF1). The naturally lower chlorophyll *a* concentrations observed in segment JMSTF2 are seen in the 18 year record previously illustrated in **Figure 1**.[3] Because chlorophyll *a* concentrations naturally increase downstream of the tidal fresh reach of this estuarine river and below the turbidity maximum zone, a chlorophyll *a* criterion concentration of 15 *u*g liter^{-1} was derived for protection of the oligohaline middle James River segment (JMSOH).

Summer conditions change dramatically in the river with warmer temperatures, lower flows, and greater light. In the tidal fresh and low salinity habitats, the period of highest productivity occurs between mid-spring and continues into mid-fall (October) (Marshall and Burchardt 1998). Therefore, chlorophyll *a* criterion concentrations of 15 *ug* liter^{-1} and 20 *u*g liter^{-1} for segments JMSTF2 and JMSTF1, respectively, are based on the river's hydrodynamics

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[3] Segment JMSTF2 contains monitoring stations TF5.2 and TF5.3 whereas segment JMSTF1 contains stations TF5.5, TF5.5a and TF5.6.

described above. A chlorophyll *a* criterion concentration of 15 ug liter^{-1} is recommended for segment JMSOH.

The 20 ug liter^{-1} chlorophyll *a* criterion concentration cited above for the lower tidal fresh segment (JMSTF1) runs counter to the 10-15 ug liter^{-1} range drawn from the available scientific literature and monitoring findings. This higher criterion concentration is justified based on naturally higher chlorophyll *a* concentrations observed in this section of the tidal fresh reach of the James River.

High Salinity James River Criteria

In high salinity (polyhaline) marine ecosystems, mesotrophic status is characterized by seasonal averaged chlorophyll *a* concentrations from 1 to 7 ug liter^{-1} with a mean around 3 ug liter^{-1}. Achievement of chlorophyll *a* concentrations and other water quality conditions characteristic of mesotrophic systems will lead to more balanced aquatic life (see Table V-2 and support text and references in USEPA 2003a).

For mesohaline habitats, spring and summer median chlorophyll *a* concentrations of 5.6 and 7.3 ug liter^{-1}, respectively, are supportive of the defined phytoplankton reference communities. Mean chlorophyll *a* concentrations representative of spring and summer periods for phytoplankton reference communities in mesohaline habitats are < 6 ug liter^{-1} and < 7.5 ug liter^{-1} respectively **(Table 8).** In polyhaline habitats, those same seasonal median concentrations are 2.8 and 4.5 ug liter^{-1}, respectively. Mean chlorophyll *a* concentrations representative of spring and summer periods for phytoplankton reference communities for polyhaline habitats are < 3 ug liter^{l} and < 4.5 ug liter^{-1}, respectively.

When the *Prorocentrum minimum* threshold is applied to Chesapeake Bay phytoplankton monitoring program data, the normalized frequency distribution of chlorophyll *a* concentrations associated with bloom densities (> 3,000 cells milliliter^{-1}) illustrates that concentrations > 5 ug liter^{-1} can generate densities that may impair the survival of various life stages of oysters (**Figure 21**). The likelihood of bloom level events tends to increase with increasing chlorophyll *a* concentrations (**Figure 22**). When the threshold is applied to Chesapeake Bay phytoplankton monitoring program data, the normalized frequency distribution of chlorophyll a concentrations associated with the *P. minimum* bloom densities (greater than 3,000 milliliter^{-1}) indicates a large increase at chlorophyll *a* concentrations of 25 to 30 ug liter^{-1}.

Based on the available scientific information, spring and summer seasonal mean chlorophyll *a* concentrations of between 3 and 8 ug liter^{-1} would support return of balanced phytoplankton community and protect against dominance by undesirable, nuisance algal species. This concentration was adjusted upwards to result in a chlorophyll *a* criterion concentration of 10 ug liter^{-1} for both the lower James River (JMSMH) and mouth of the James River (JMSPH) segments to reflect attainability of these criteria **(Table 9).**

Given the limitations of some of the scientific evidence (particularly the paucity of spring and summer data in the historical data set) the derived criteria give primary consideration to the reference community approach, protection from harmful algal blooms, and reduction from current conditions to levels which would provide a more balanced aquatic life community. This, along with attainability information, supports the derived numerical chlorophyll *a* criteria concentrations as attainable at the adopted tributary strategy cap loads and also assures these criteria are necessary, protective and reasonable. All proposed criteria concentrations are reflected in **column 6 of Table 11 (Summary Table)**.

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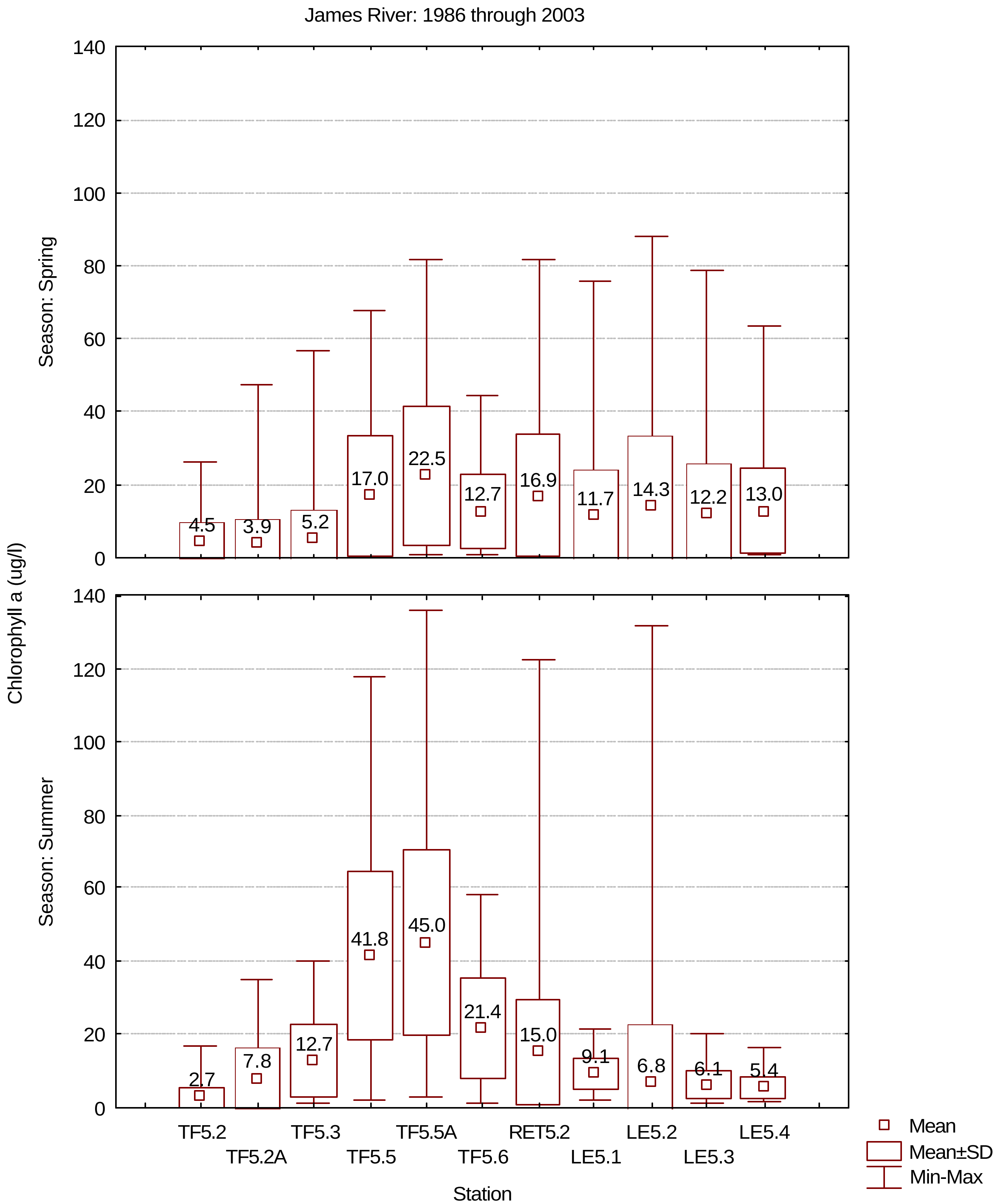
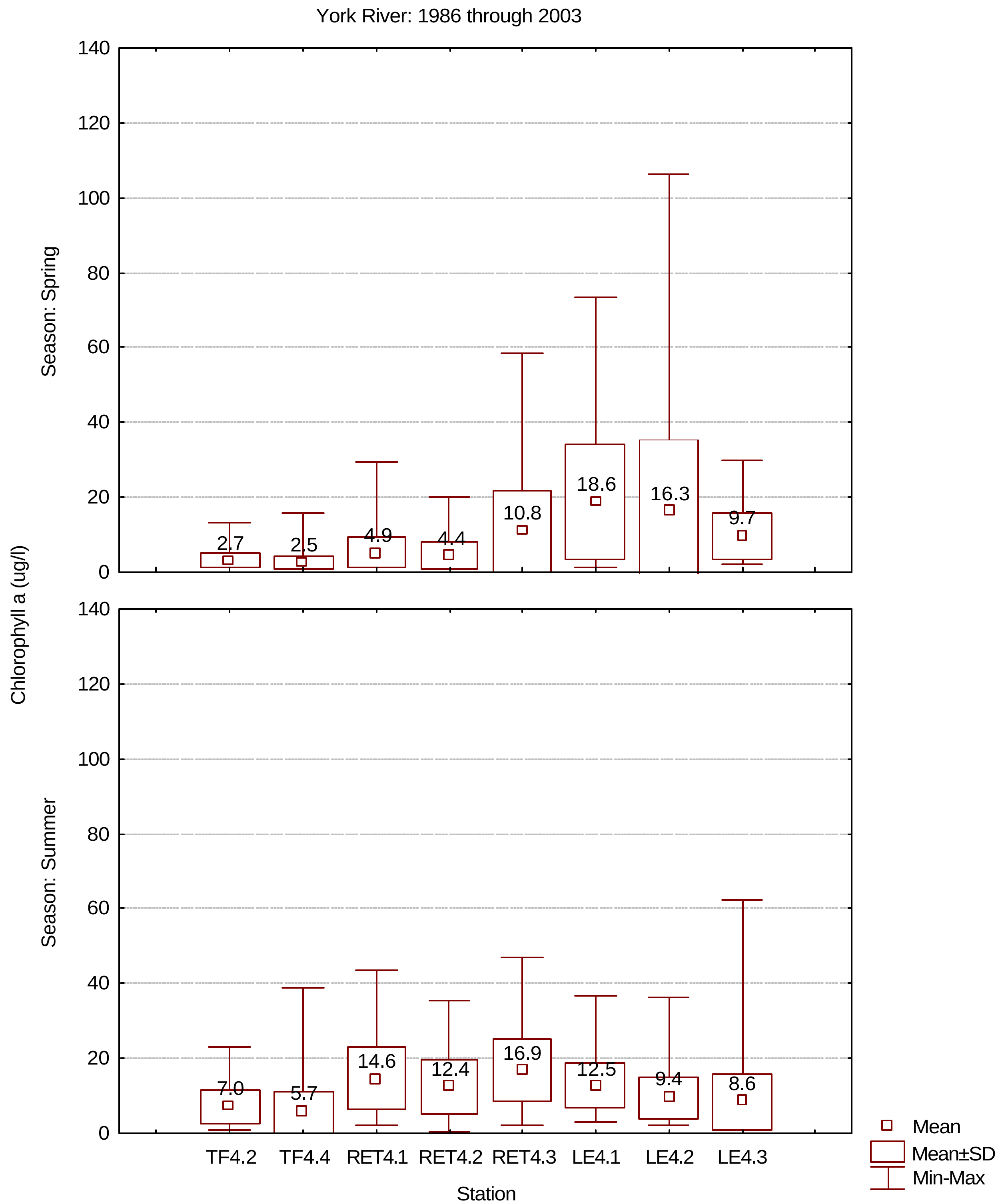
Figures

Figure 1. Tidal James River Chlorophyll *a* Concentrations by Monitoring Station: 1986-2003.



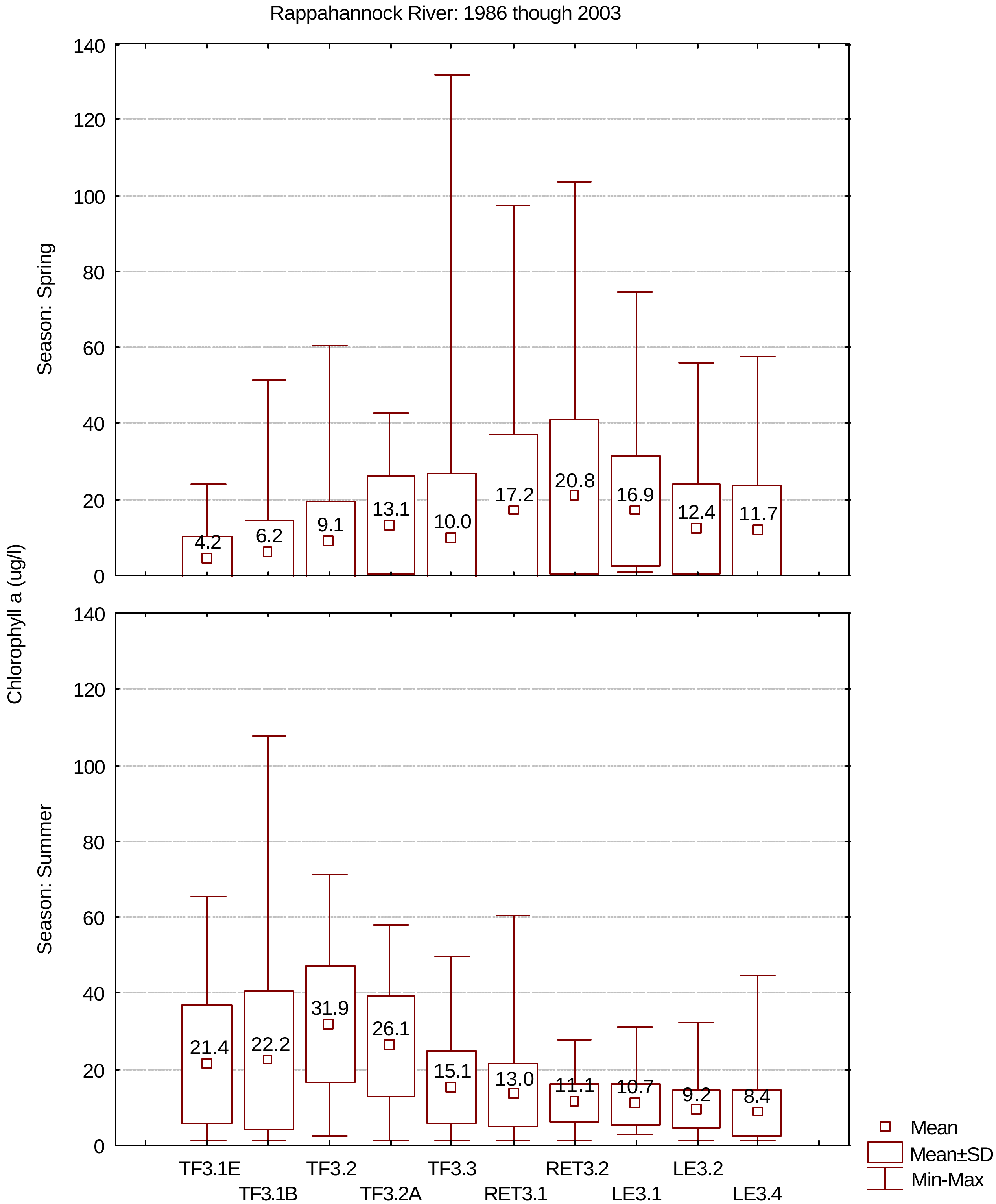
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 2. Tidal York River Chlorophyll *a* Concentrations by Monitoring Station: 1986-2003



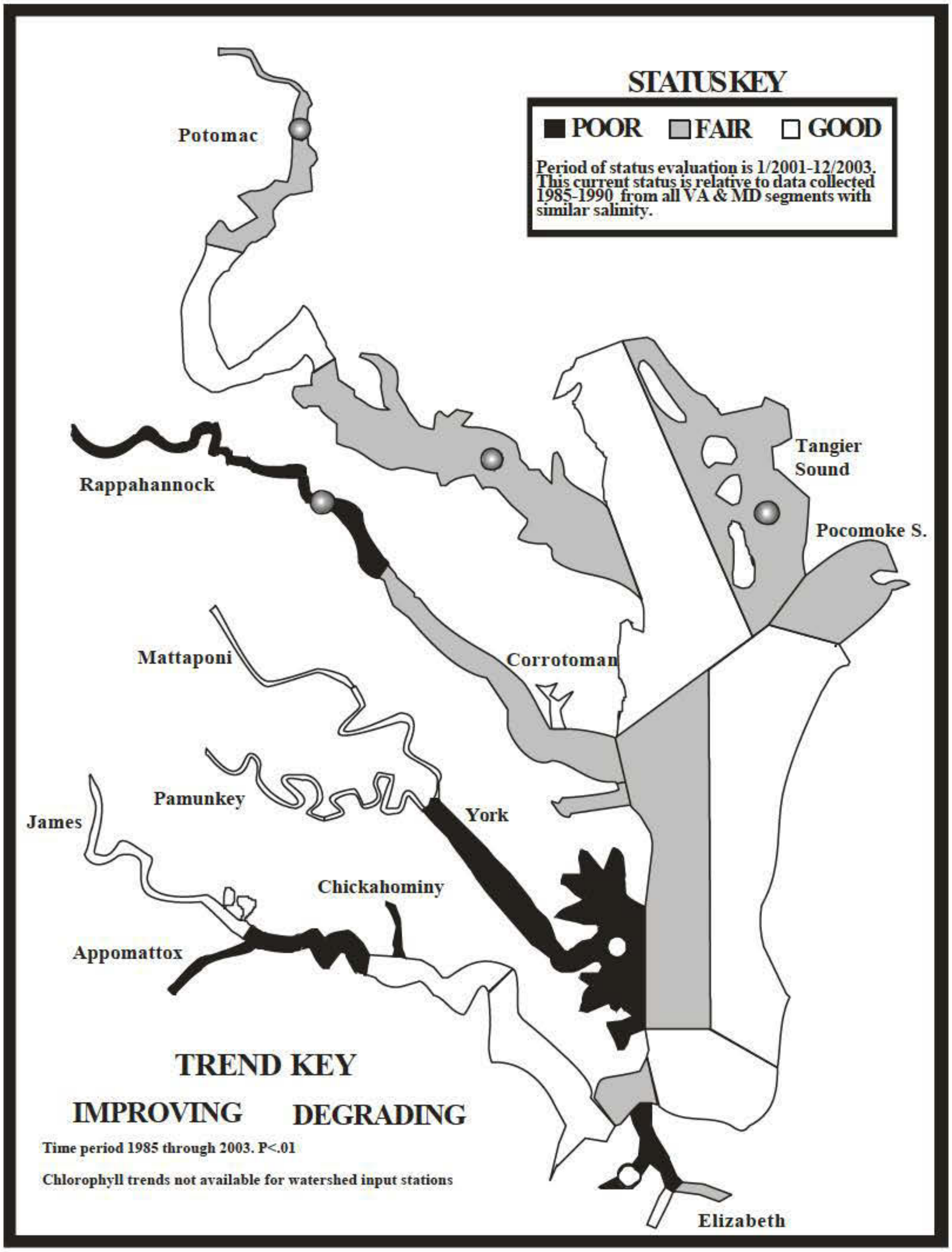
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 3. Tidal Rappahannock River Chlorophyll *a* Concentrations by Monitoring Station: 1986-2003.



Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

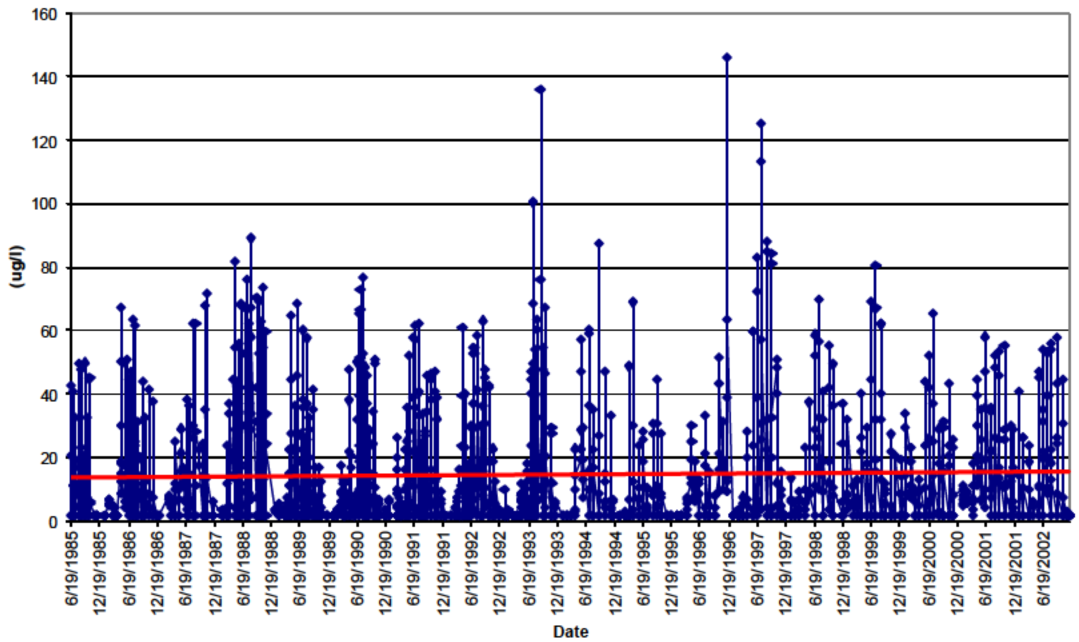
Figure 4. Status and Trends in Chlorophyll a Concentrations Across Virginias Chesapeake Bay and Tidal Waters.



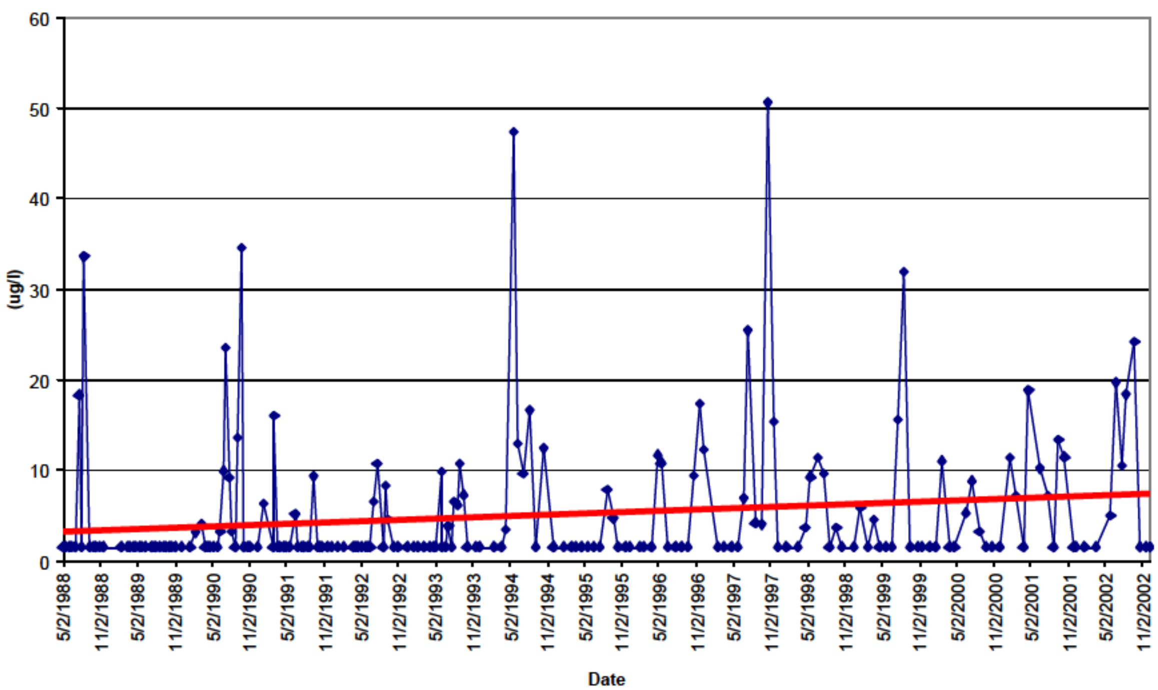
Source: "2004 Annual Report from the Secretary of Natural Resources on Virginia's Chesapeake Bay Program: Section on Environmental Conditions and Water Quality Status and Trends, November 2004)

Figure 5. Chlorophyll *a* Concentration Trends at James River Tidal Fresh Monitoring Stations (1986-2002).

a. All Tidal Fresh James River Monitoring Stations



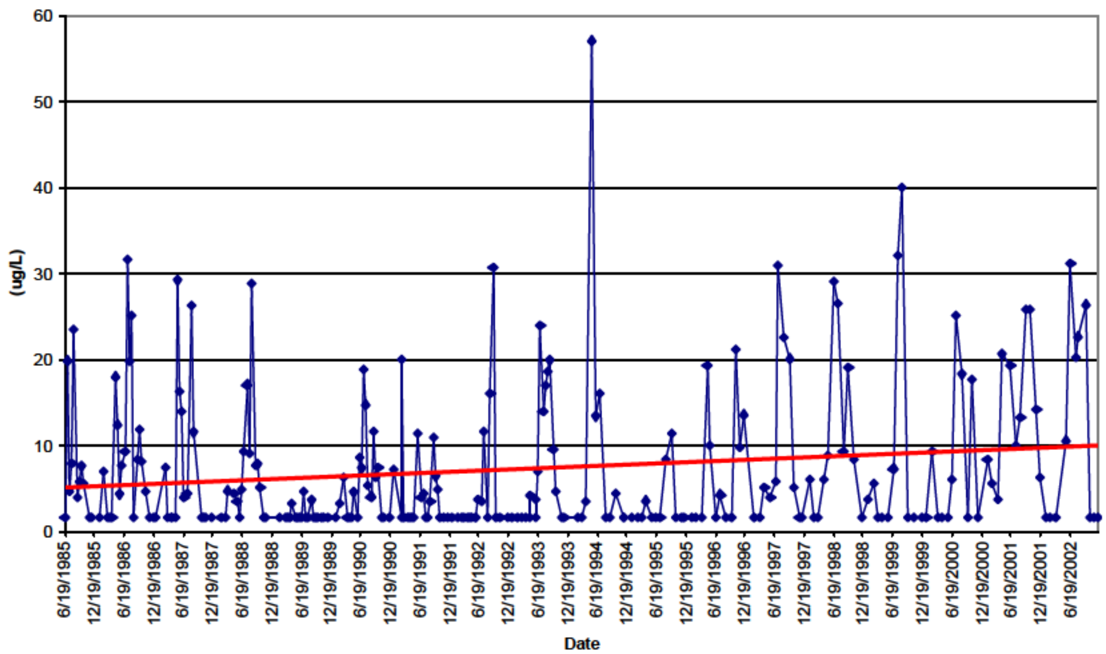
b. Station TF5.2A



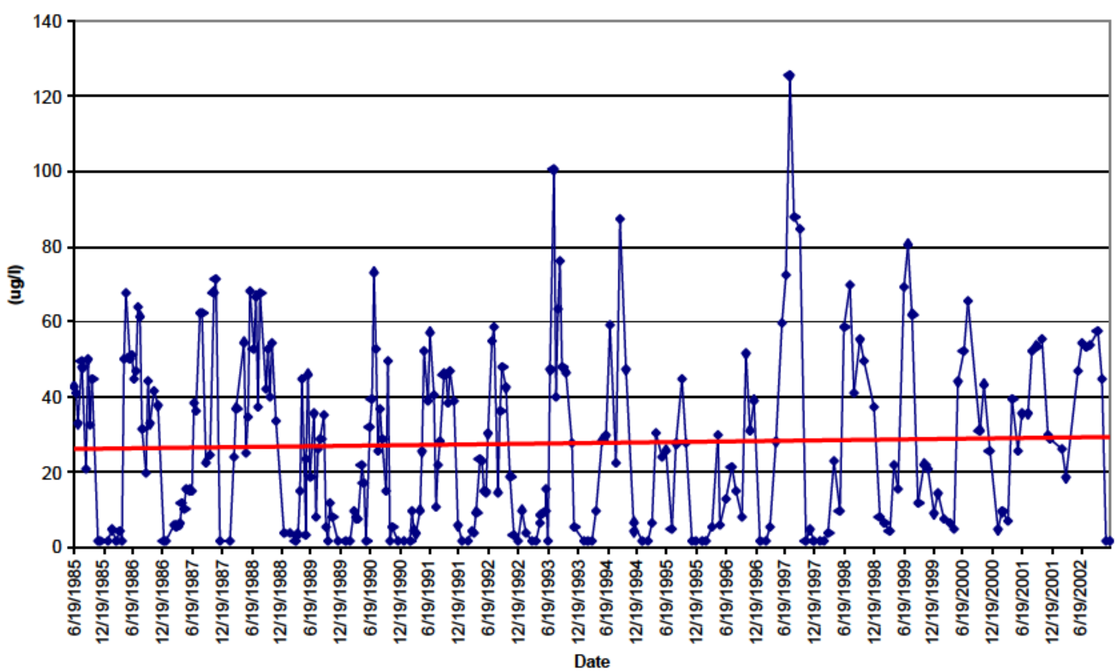
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 5 cont. Chlorophyll *a* Concentration Trends at James River Tidal Fresh Monitoring Stations.

c. Station TF5.3



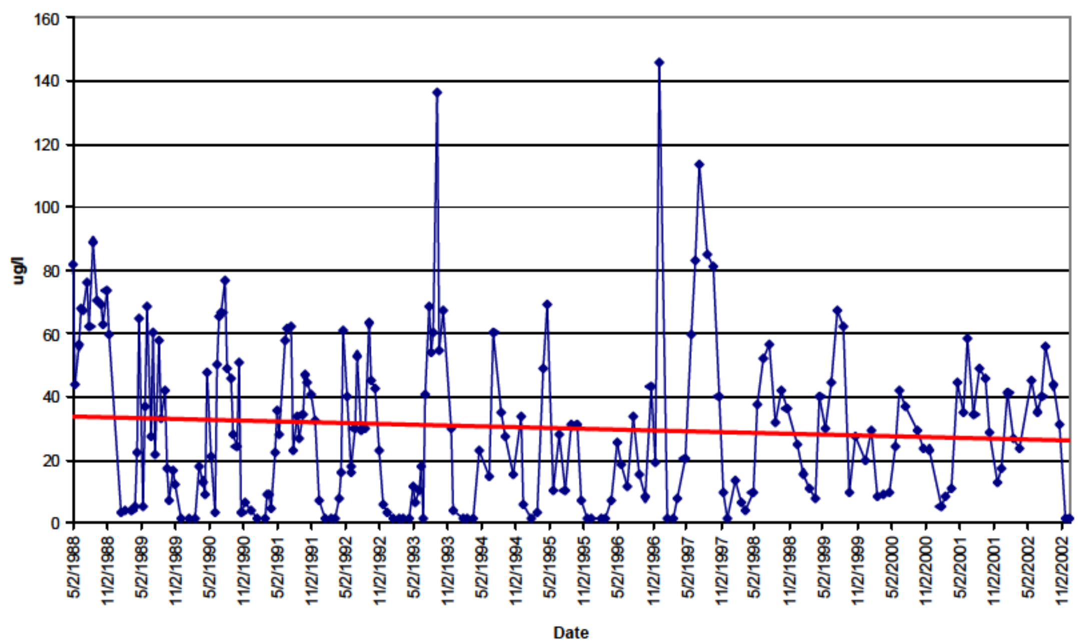
d. Station TF5.5



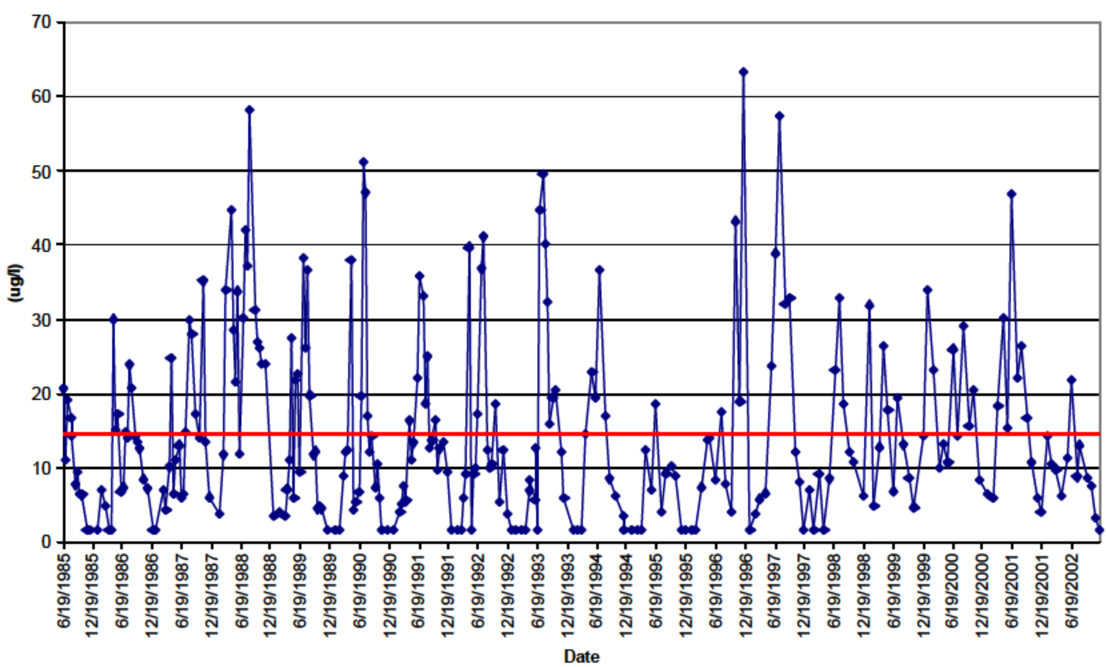
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 5 cont. Chlorophyll *a* Concentration Trends at James River Tidal Fresh Monitoring Stations

e. Station TF5.5A



f. Station TF5.6



Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 6. Locations of Chesapeake Bay Monitoring Program stations in Virginia.

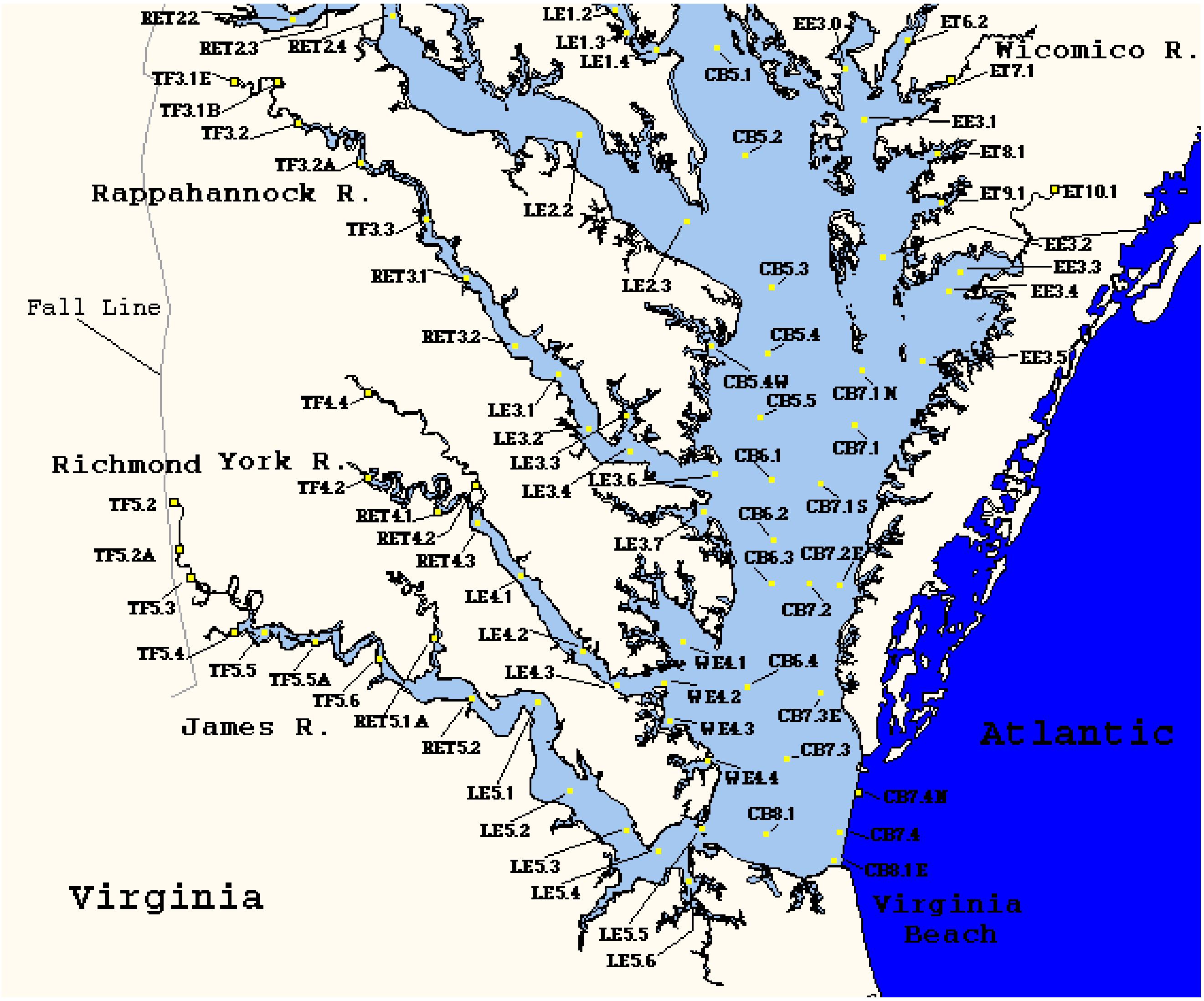
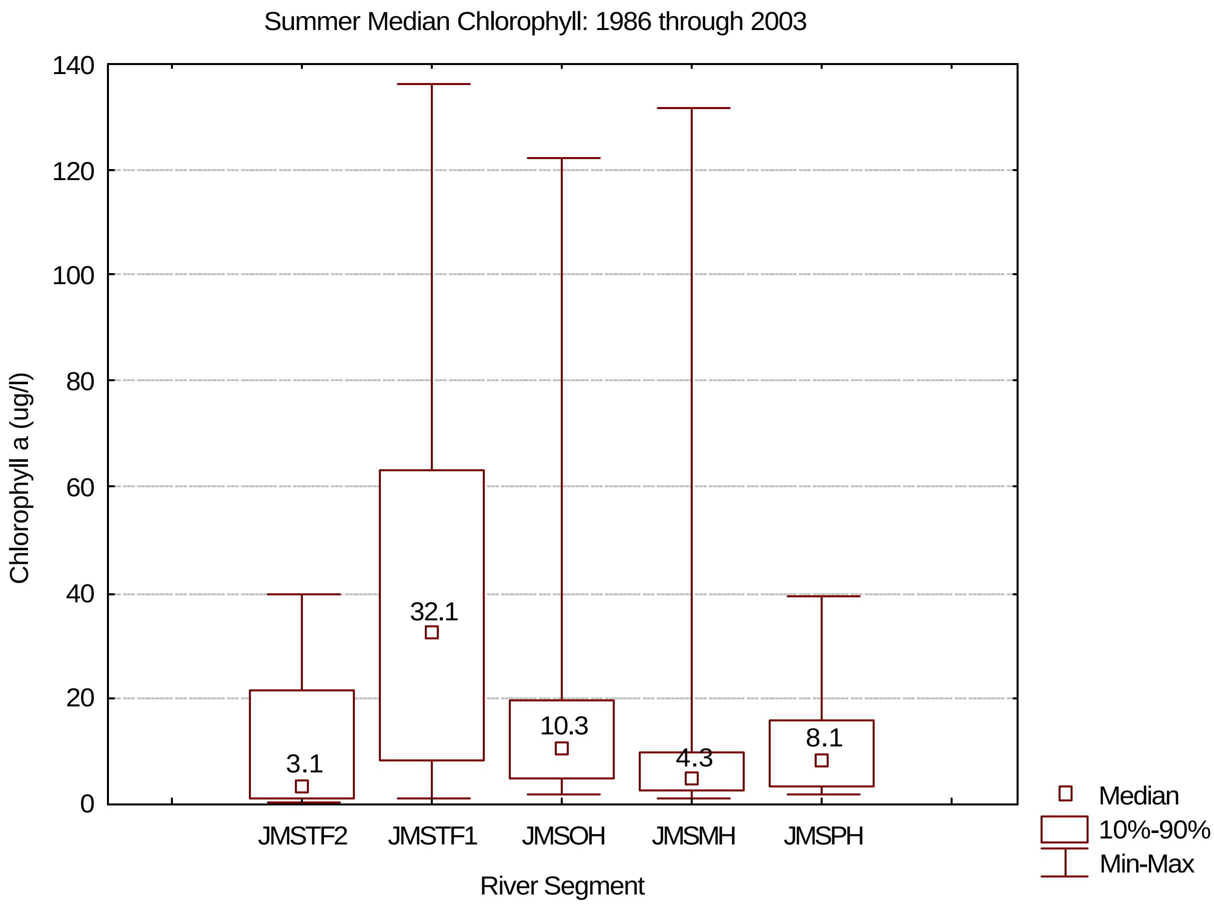
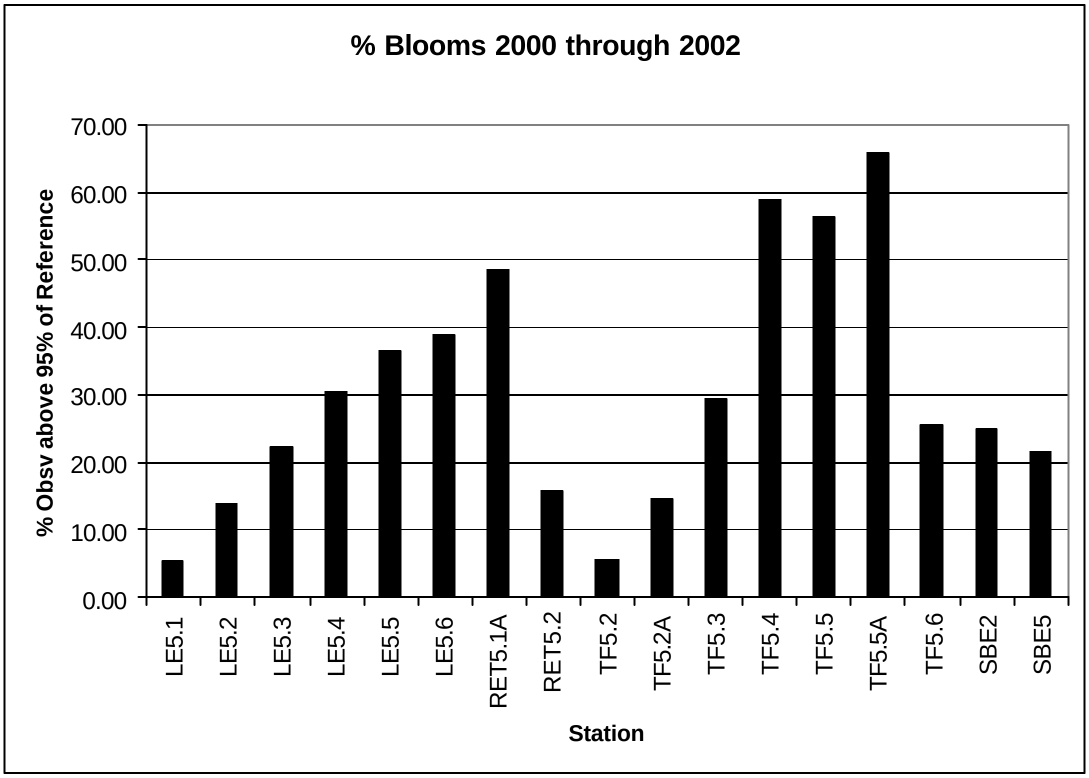


Figure 7. 1986-2003 Summer Median Chlorophyll *a* Concentrations by James River Segment.



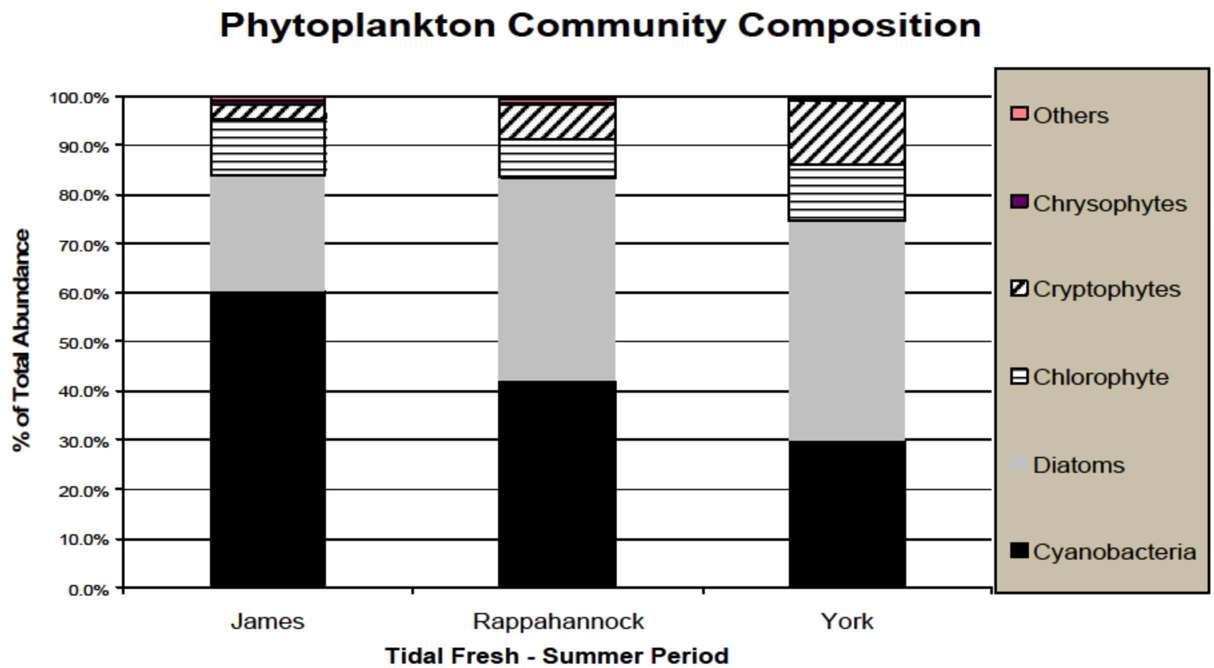
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 8. Percentage of chlorophyll *a* observations above 95^{th} percentile of reference community denoting bloom conditions.



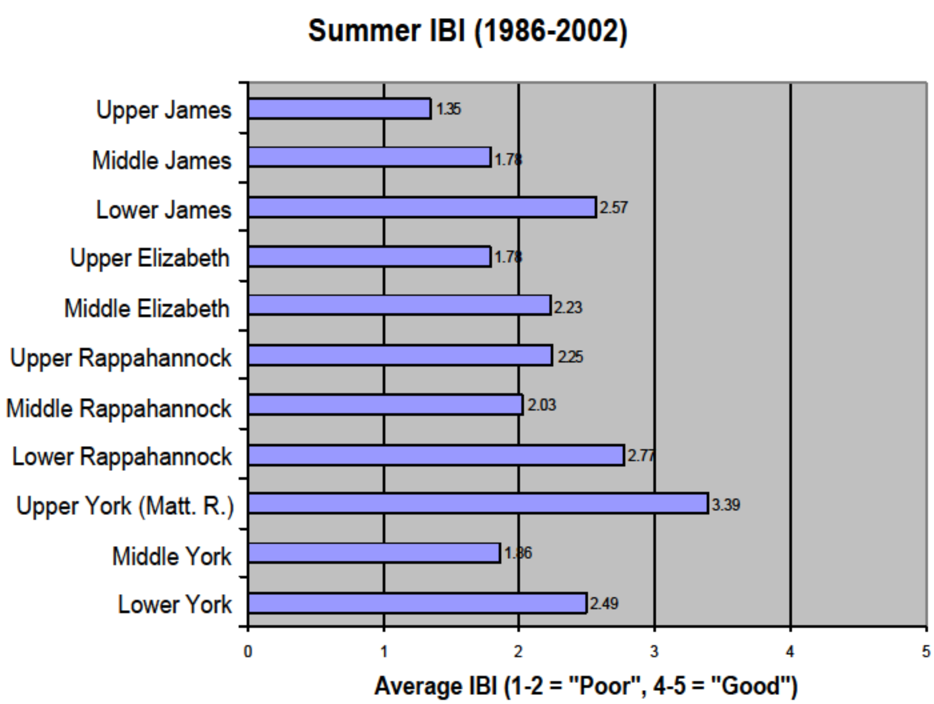
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 9. Summer Phytoplankton community composition at tidal fresh monitoring stations in the James (TF5.5), York (TF4.2), and Rappahannock (TF3.3) Rivers: 1986 – 2003.



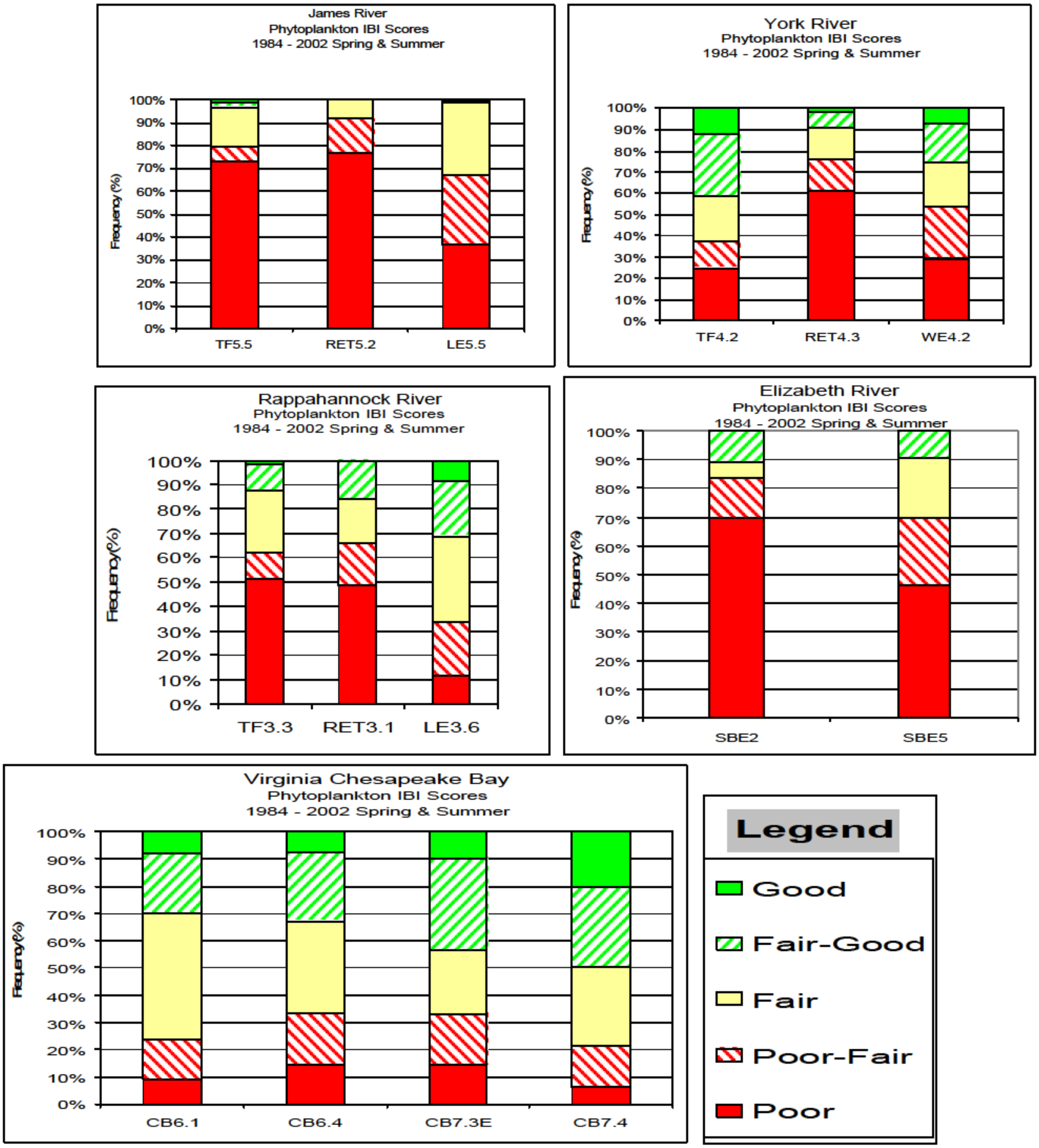
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 10. Summer Phytoplankton IBI scores by Virginia Tidal Tributaries Segment: 1986-2002.



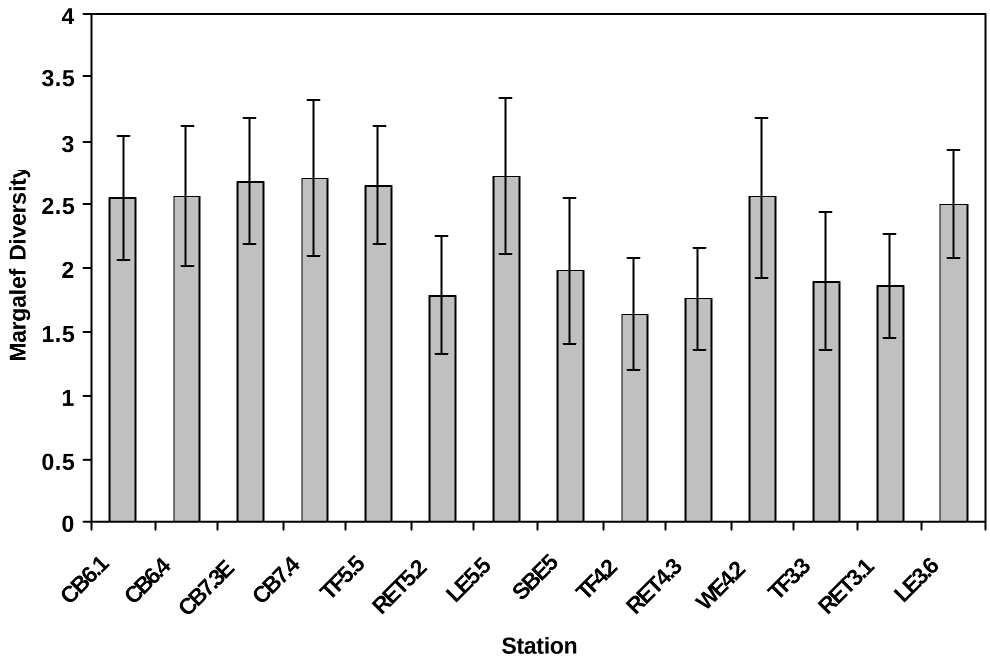
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 11) Spring and Summer Phytoplankton IBI Scores by Station at Phytoplankton monitoring stations.



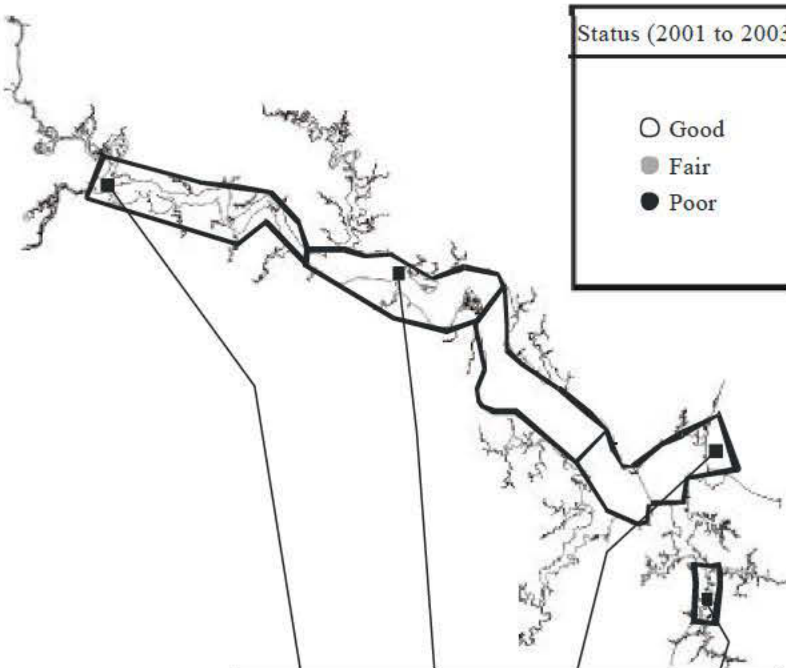
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 12) Margalef diversity index scores for phytoplankton monitoring program stations in Virginia Chesapeake Bay mainstem and major tidal tributaries: 2000 - 2002



Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 13. Summary of tidal James River phytoplankton community status (2001 through 2003) and trends (1985 through 2003).

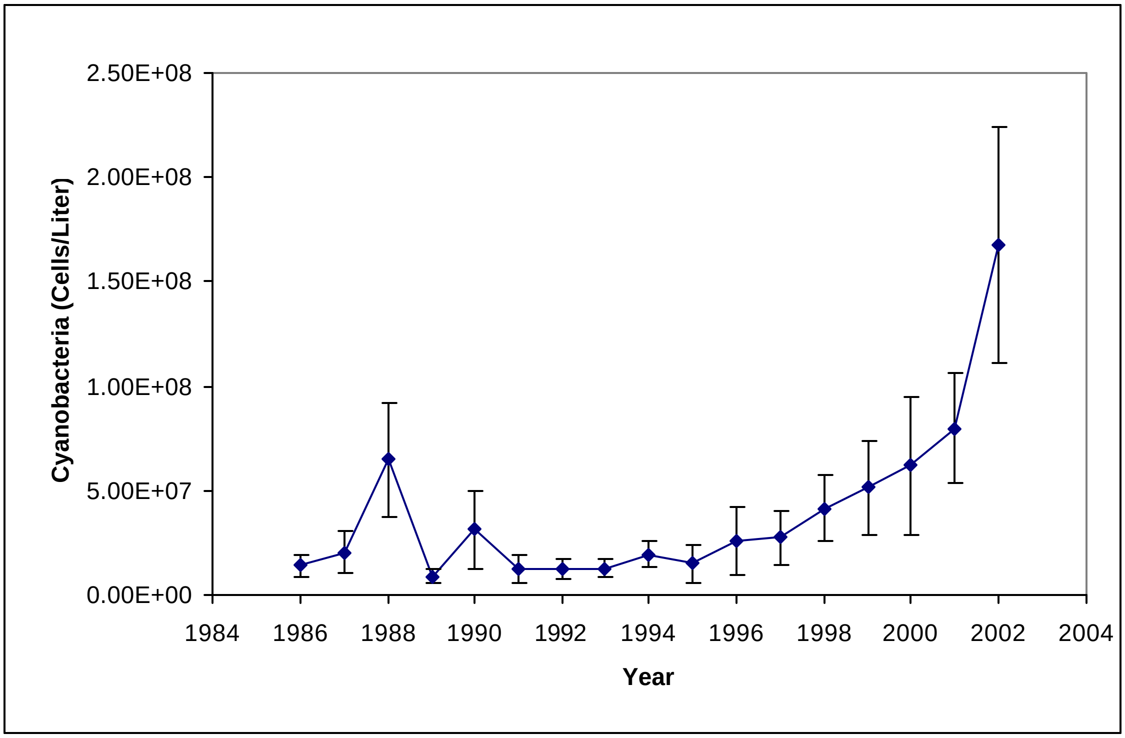


Status (2001 to 2003)	Trends (1985 to 2003)
○ Good ● Fair ● Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend ↓ Decreasing ↑ Increasing

	TF5.5		RET5.2		LE5.5		SBE5	
Total Abundance		↑		NS		↑		↑
Total Biomass	Good	↑	Fair	↑	Poor	↑	Poor	↑
Biomass to Abundance	Poor	△	Poor	△	Poor	△	Poor	NS
Margalef Diversity Index	Good	NS	Poor	▼	Good	NS	Good	NS
Productivity	Poor	NS	Good	▽	Fair	▽	Good	▽
Diatom Biomass	Good	△	Good	△	Fair	△	Fair	△
Dinoflagellate Biomass	Poor	NS	Poor	NS	Fair	▲	Fair	NS
Cyanophyte Biomass	Poor	▲	Poor	NS	Poor	▲	Fair	▲
Chlorophyte Biomass	Good	△	Good	△		△	Good	△
Picoplankton Biomass	Poor	NS	Poor	▽	Fair	NS	Good	NS
Cryptophyte Biomass		△		△		NS		△
Cyanophyte Abundance	Poor	▲	Poor	NS	Poor	▲	Fair	▲

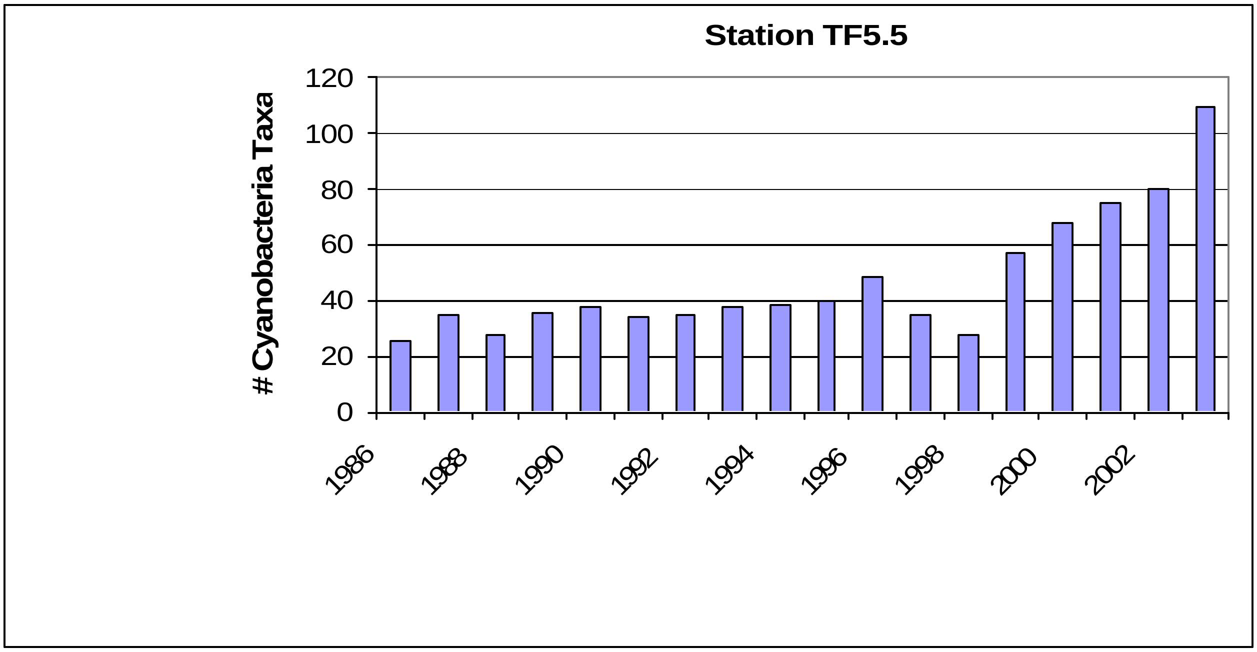
Source: Dauer et. al. 2005

Figure 14. Annual mean cyanobacteria abundance trends at tidal fresh James River monitoring station TF5.5 (1986-2003).



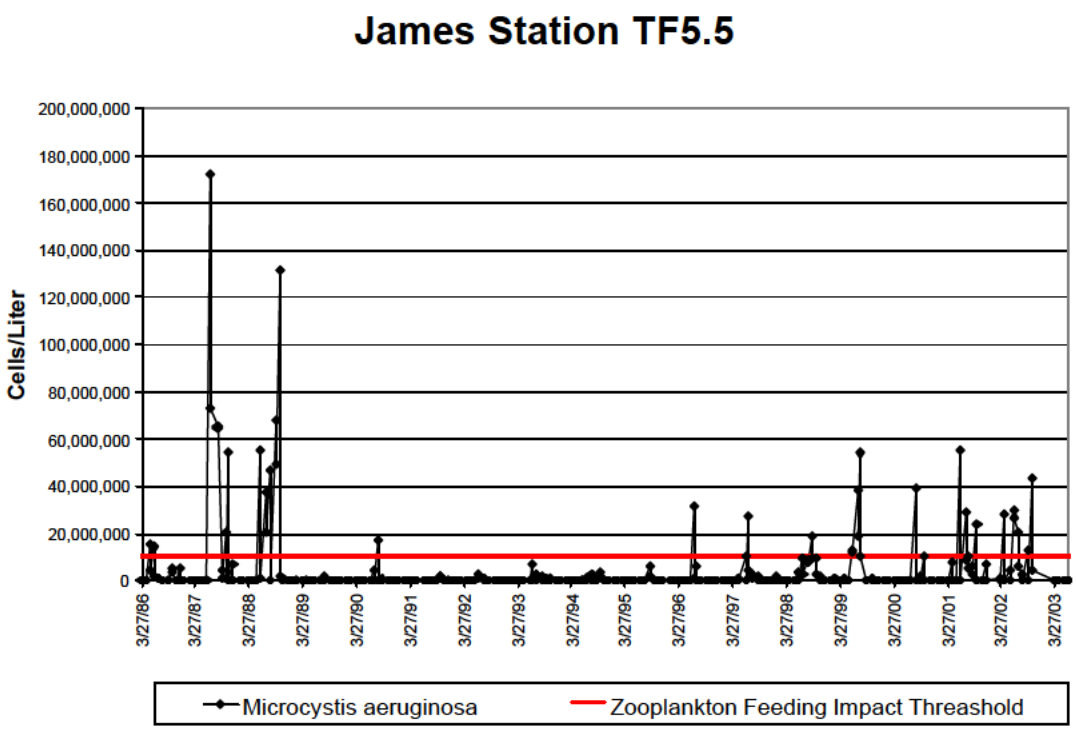
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality.

Figure 15. Number of Cyanobacteria taxa observed at tidal fresh James River monitoring station TF5.5



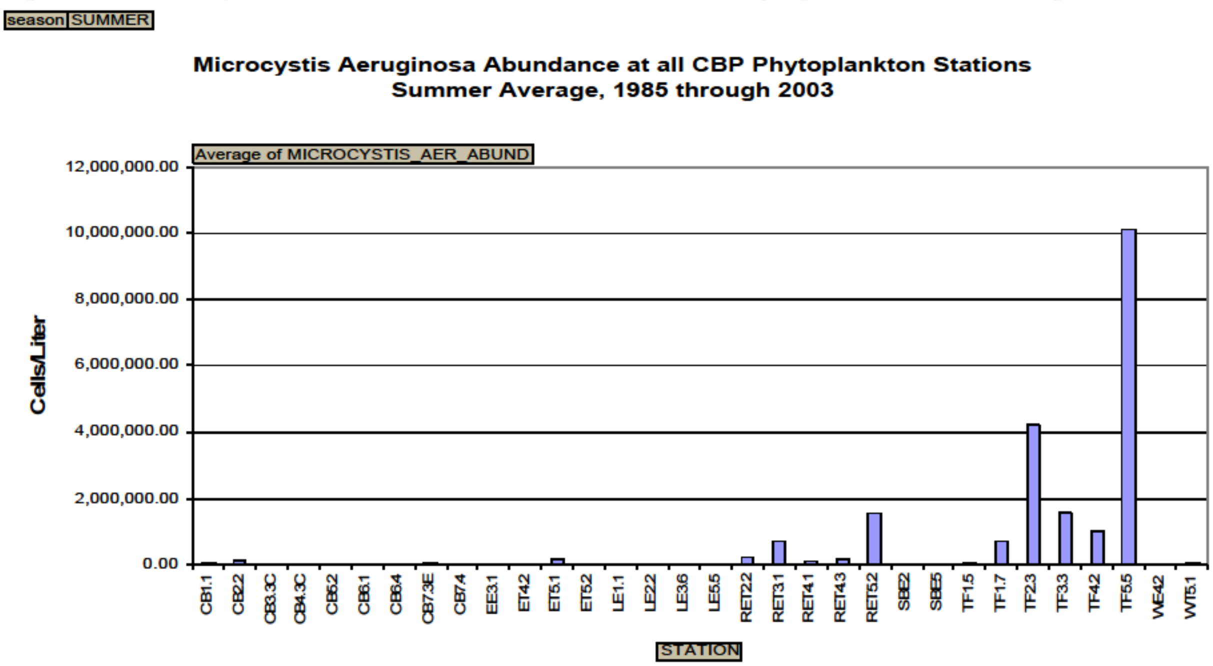
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Figure 16. *Microcystis aeruginosa* abundances at James River tidal fresh monitoring station in comparison to Zooplankton feeding impact threshold (1986 – 2003).



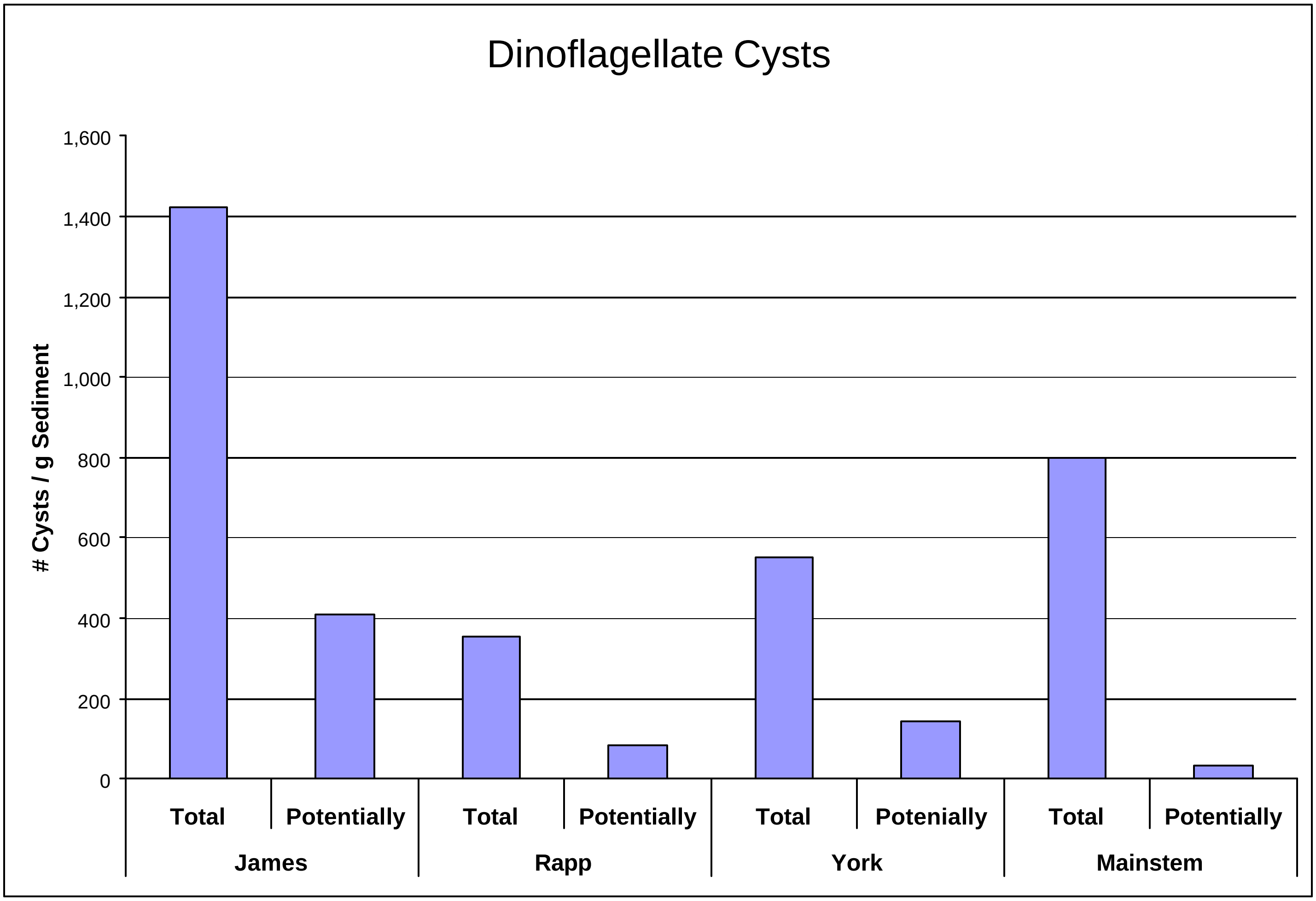
Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Figure 17. *Microcystis* concentrations at all MD and VA Phytoplankton Monitoring Stations.



Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Figure 18. Number of dinoflagellate cysts observed in sediment in the Virginia Chesapeake Bay and the James, York, and Rappahannock Rivers.



Source: Marshall, HG. Undated Report. Supplemental Sampling and Analysis to Survey for Toxin Producing Phytoplankton in the Lower James River.

Figure 19) Normalized frequency of *Microcystis* abundance above threshold (i.e., > 10,000 cells liter^{-1}) versus summer tidal fresh chlorophyll *a* levels.

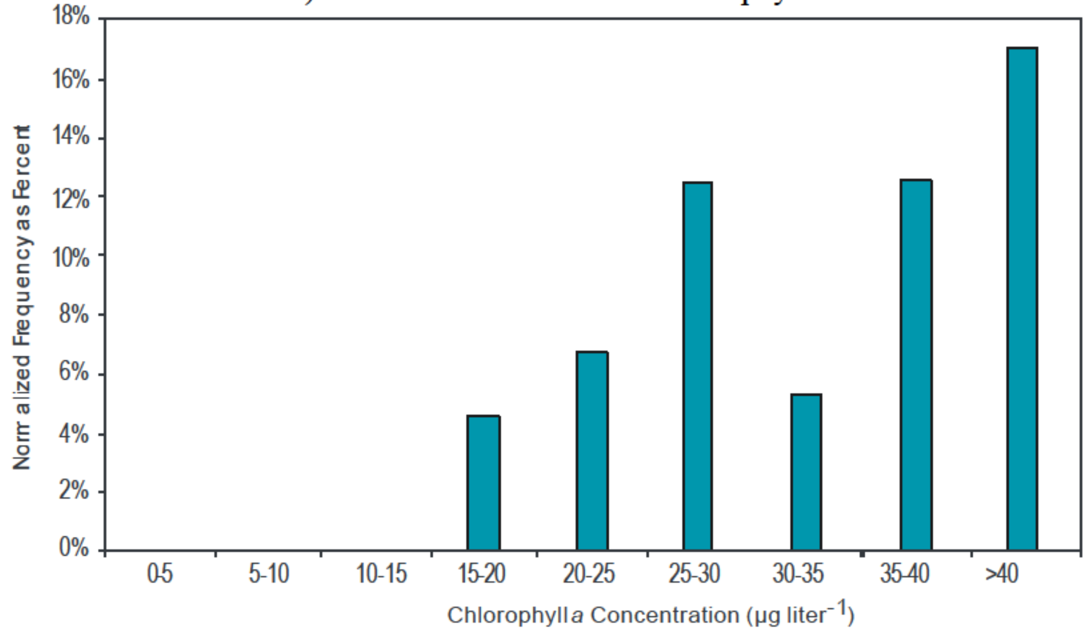


Figure 20) Normalized frequency of above- and below-thresholds of *Microcystis* abundance versus summer tidal fresh chlorophyll a levels.

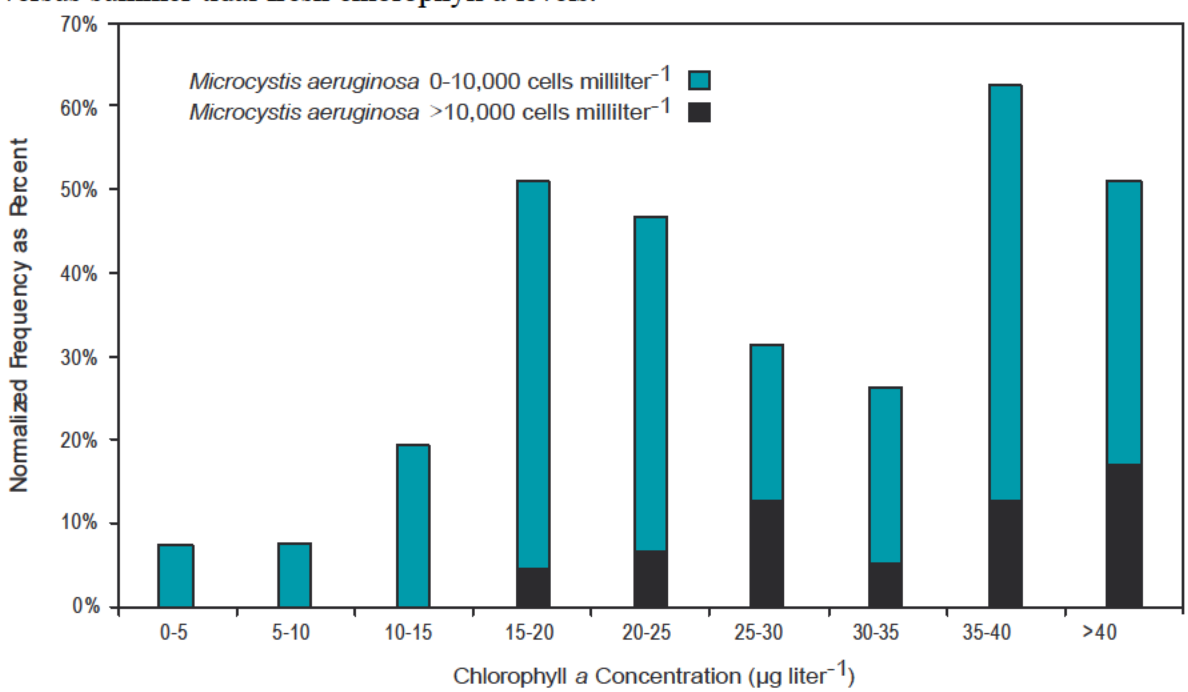


Figure 21. Threshold levels of chlorophyll *a* associated with Cyanophyte levels at James River tidal fresh station TF5.5 during the summer.

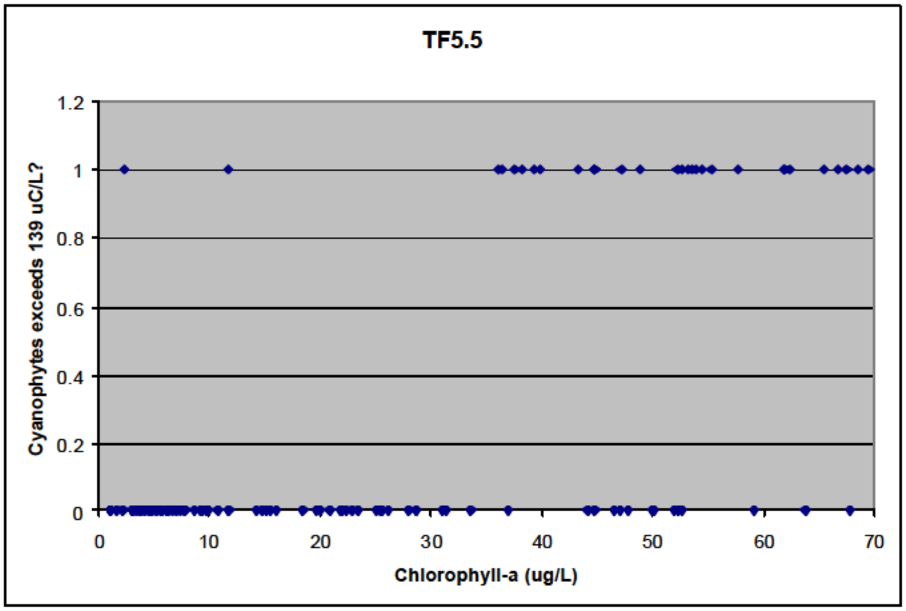


Figure 22) Normalized frequency of *Prorocentrum* abundance above threshold (i.e., > 3,000 cells/ml) versus spring mesohaline Chesapeake Bay and tidal tributary chlorophyll *a* levels.

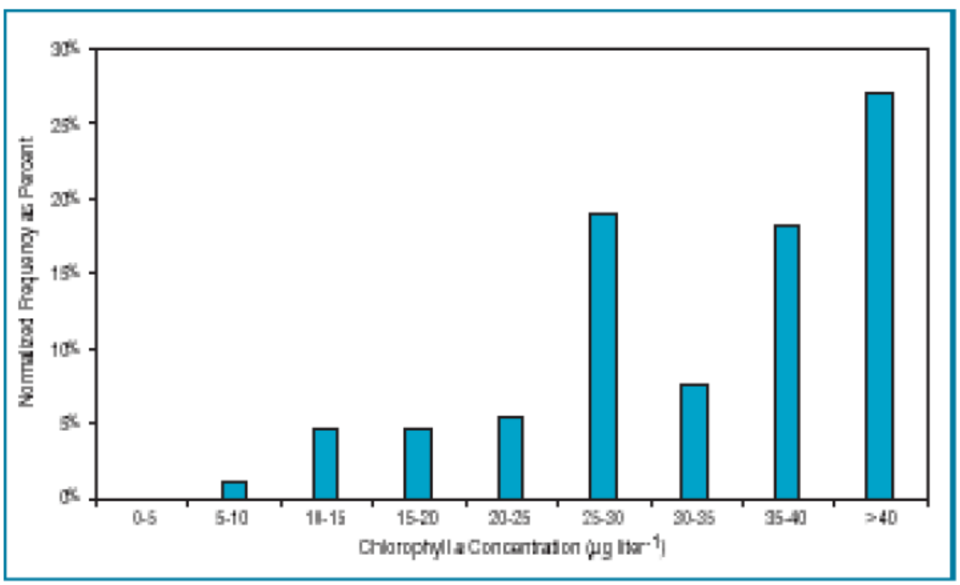
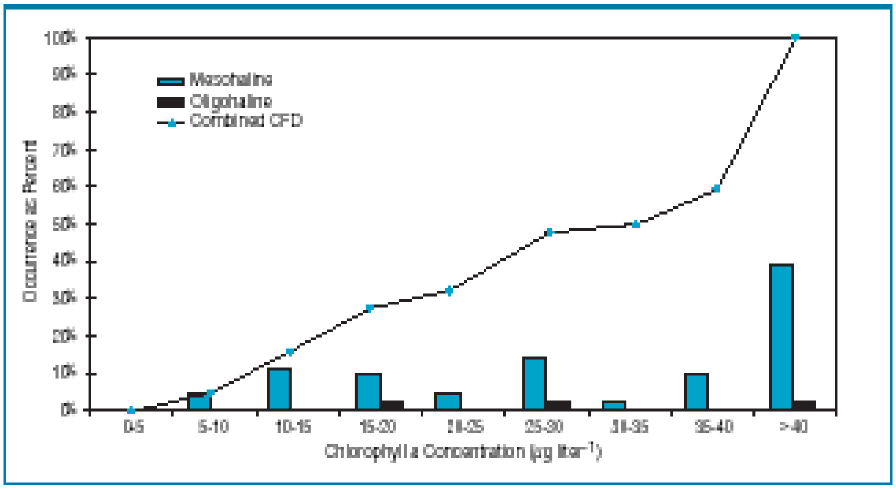


Figure 23. All occurrences of *Prorocentrum* abundance above threshold versus combined spring and summer mesohaline and oligohaline Chesapeake Bay and tidal tributary chlorophyll *a* levels.



Tables

Table 1. Chlorophyll *a* trends at individual monitoring stations in the Tidal Fresh James River:. 1985 through 2003. P<.05

SEGMENT	STATION	SEASON	DIRECTION
JMSTF	TF5.3	ANNUAL	INCREASING
JMSTF	TF5.3	SAV1	INCREASING
JMSTF	TF5.3	SUMMER1	INCREASING
JMSTF	TF5.5	ANNUAL	INCREASING
JMSTF	TF5.5	WINTER	INCREASING
JMSTF	TF5.5A	WINTER	INCREASING
JMSTF	TF5.6	SUMMER2	DECREASING
JMSTF	TF5.6	WINTER	INCREASING
JMSOH	LE5.1	SPRING2	INCREASING
JMSMH	LE5.2	SUMMER1	INCREASING
JMSMH	LE5.3	ANNUAL	INCREASING
JMSMH	LE5.3	SAV1	INCREASING
JMSMH	LE5.3	SUMMER1	INCREASING
JMSPH	LE5.5	SAV1	INCREASING
JMSPH	LE5.5	SUMMER1	INCREASING
JMSPH	LE5.5	SUMMER2	INCREASING

Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Table 2. Comparison of phytoplankton groups in VA's three tidal fresh regions during summer, presented as a % of total abundance (Summer period 1986-2003, stations TF5.5, TF4.2, TF3.3)

	Chlorophyte	Chrysophytes	Cryptophytes	Cyanophytes	Diatoms	Others
Rappahannock	7.9%	0.2%	6.9%	41.8%	41.5%	1.7%
York	11.5%	0.0%	12.8%	29.7%	44.8%	1.2%
James	11.6%	0.9%	2.8%	60.1%	23.7%	0.9%

Other forms include dinoflagellates and other less abundant forms

Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Table 3. Phytoplankton IBI for VA's summer tidal fresh tributary stations (1986-2002)

Basin	IBI Index
Rappahannock (TF3.3)	2.25
York (TF4.2)	3.39
James (TF5.5)	1.35

Scale of 1-3-5, with 1 representing most degraded condition and 5 the least-degraded condition

Source; Lacouture et al., In prep.

Table 4. Average abundance of *Microcystis* at Tidal Fresh monitoring stations (1986-2002)

	Abundance (cells/liter)	Ratio
Rappahannock (TF3.3)	1,583,345	1.5
York (TF4.2)	1,044,708	1
James (TF5.5)	10,104,846	9.7

Source: Chesapeake Bay Monitoring Program, Virginia Department of Environmental Quality

Table 5. Chesapeake Bay mainstem surface chlorophyll a concentrations ($ug\ liter^{-1}$) annual means from 1950 to 1994.

Time Period	Region	Chlorophyll *a* Annual Mean	Number of Observations	Percent Difference [1]
1950-1959	I	0.46	41	-
	II	1.21	18	-
	II	3.58	108	-
	IV	4.33	7	-
	V	3.19	15	-
	VI	2.51	18	-
1960-1969	I	1.89	8	310
	II	2.61	9	115
	III	7.09	28	98
	IV	7.48	58	73
	V	7.79	97	144
	VI	15.59	295	521
1970-1979	I	4.39	101	853
	II	6.89	31	468
	III	7.95	100	122
	IV	7.29	206	68
	V	13.12	324	311
	VI	12.90	845	414
1985-1994	I	5.49	1862	1093
	II	7.40	2350	510
	III	8.03	1261	124
	IV	8.20	1022	89
	V	10.86	1164	240
	VI	5.57	1005	122

1 - Percent difference of annual mean chlorophyll a concentration for each region is based upon a comparison with the corresponding chlorophyll a concentrations in 1950-1959.

Source: Harding and Perry 1997.

Table 8. Chlorophyll *a* ($ug\ liter^{-1}$) concentrations in the salinity and season-based on "good" Chesapeake phytoplankton reference communities.

Salinity Zone	Spring (Mar-May)	Summer (Jul-Sept)
Tidal Fresh	< 14	< 12
Oligohaline	< 21	< 9.5
Mesohaline	< 6	< 7.5
Polyhaline	< 3	< 4.5

Source: Buchanan, IBI Database

Table 7. Summary of Chesapeake Bay chlorophyll *a* concentrations (ug $liter^{-1}$).

Salinity Regime	**Harding and Perry (1997) 1950s annual mean concentrations for mainstem Chesapeake Bay**	**Olson (2002) 1950s spring/summer/annual mean concentrations**	**Olson (2002) relative status spring/summer/annual benchmark concentrations**
Tidal Fresh	2.5	1.1/1.1/ -	3.7/7.0/4.2
Oligohaline	2.5-3.2	2.3/2.0/3.1	5.9/7.6/6.0
Mesohaline	3.6-4.3	3.7/4.4/3.1	7.2/7.2/7.9
Polyhaline	0.5-1.2	3.9/ - /3.2	4.1/3.7/4.3

Table 9. Summary of chlorophyll a concentrations necessary to meet the Cap Load Allocations based on Water Quality Model results.

Season/Salinity Regime		Attainable Spring/Summer chlorophyll a mean concentration (ug liter $^{-1}$) Based on Achievement of Cap Load Allocation						
		James[1]	York[2] Mobjack	Rappahannock	CB5MH	CB6PH	CB7PH	CB8PH
Spring	Tidal Fresh	<6/<10	<3/<4	<8	-	-	-	-
	Oligohaline	<9	<4/<5	<8	-	-	-	-
	Mesohaline	<8	>11	<8	-	-	-	-
	Polyhaline	<9	<7/<6	-	-	6	7	6
Summer	Tidal Fresh	<10/<17	<10/<17	<5/<8	<13	-	-	-
	Oligohaline	<12	<9/<11	<10	-	-	-	-
	Mesohaline	<6	<11	<7	-	-	-	-
	Polyhaline	<6	<7/<6	-	-	6	5	5

1. In the tidal fresh rows within this column, the first value is for the upper tidal fresh James River and the second value is for the lower tidal fresh James River.
2. In the tidal fresh and oligohaline rows within this column, the first value is the Mattaponi River and the second value is for the Pamunkey River.

Table 10 EPA Recommended chlorophyll a (ug liter^{-1}) concentration thresholds for Virginia

Salinity Zone	Spring	Summer
Tidal Fresh	< 10	< 15
Oligohaline	< 10	< 15
Mesohaline	< 5	< 5
Polyhaline	< 5	< 5

Table 11. Summary of mean chlorophyll *a* (*u*g liter^{-1}) concentrations with site-specific numerical criteria for Chesapeake Bay segments, JMSTF2, JMSTF1, JMSOH, JMSMH, and JMSPH by season.

Salinity Regime	Historical Conc.[1]	Attainable Conc. James[2]	EPA Recommended Conc.[3]	Reference Community Conc.[4]	**VA Proposed Conc.** [5]	Harmful Algal Bloom Conc.[6]	HAB Threshold Conc.[7]
Spring (March 1 - May 31)							
JMSTF2	3.7	<6	< 10	< 14	**10**	NA	-
JMSTF1	3.7	<10	< 10	< 14	**15**	NA	-
JMSOH	5.9	<9	< 10	< 21	**15**	NA	-
JMSMH	7.2	<8	< 5	< 6	**10**	NA	-
JMSPH	4.1	<9	< 5	< 3	**10**	>25	-
Summer (July 1 - September 30)							
JMSTF2	7.0	<10	< 15	< 12	**15**	> 15	-
JMSTF1	7.0	<17	< 15	< 12	**20**	> 15	-
JMSOH	7.6	<12	< 15	< 9.5	**15**	NA	-
JMSMH	7.9	<6	< 5	< 7.5	**10**	NA	25-30
JMSPH	3.7	<6	< 5	< 4.5	**10**	> 25	25-30

Sources:

1) EPA 2003, *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries*, April 2003, Table V-5.
2) Presented by EPA Chesapeake Bay Program to the Chesapeake Bay Water Quality Standards Ad Hoc Committee, March 24 (2004), based on Chesapeake Bay Water Quality Model "Tributary Strategies Cap Load Allocation Confirmation Scenario."
3) Presented by EPA Chesapeake Bay Program to the Chesapeake Bay Water Quality Standards Ad Hoc Committee, March 24 (2004).
4) Buchanan, C., et al. 2004.
5) Based on Lines of evidence provided in columns 1-7 and best professional judgment. Still awaiting confirmation with Water Quality Model run using 2004 Tributary Strategy Allocations.
6) EPA 2003; Buchanan (pers. comm.)
7) EPA 2003 *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries*, April 2003