Data and Modeling Needs for Assessing Numeric CHLa Criteria of the James River Estuary

prepared for the Virginia Department of Environmental Quality

by the Science Advisory Panel

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Introduction

The VA DEQ is undertaking a comprehensive review of the existing Site-Specific Numeric Chlorophyll-*a* (CHLa) criteria and associated modeling framework for the tidal James River. This effort will provide the scientific basis for a potential water quality standards rulemaking process, which may result in revisions to nutrient allocations contained in the Chesapeake Bay TMDL. A Science Advisory Panel was established by DEQ to provide recommendations on data and modeling needs for assessing the existing CHLa standard. The Panel reviewed existing data resources and modeling capacity to identify knowledge gaps in characterizing the occurrence of algal blooms in the tidal James River and associated impairments to designated uses. The Panel's recommendations provide an overall framework for addressing these needs as well as specific tasks for data collection and model development.

General Recommendations

Based on their review of data describing the incidence and impacts of algal blooms, and associated modeling efforts, the Panel recommends that additional data are needed, and that further model evaluation is warranted, to assess existing CHLa standards for the tidal James River. Additional data are needed to characterize the occurrence of blooms (e.g., intensity, duration, spatial extent) and to establish quantitative linkages between algal blooms and designated uses. There is also a need to review and enhance modeling capabilities to allow accurate assessment of designated use attainment under various nutrient loading scenarios.

The panel considered data needs inclusive of supplemental monitoring (i.e., in addition to on-going programs) as well as research activities addressing specific questions and supporting model development. The data needs were organized under two broad objectives: (1) characterizing the spatial and temporal extent of algal blooms, and (2) identifying and quantifying impairments to designated uses associated with algal blooms. The first objective entails data collection to characterize the blooms themselves (frequency, duration, intensity) as well as supplementary data and studies to understand environmental conditions that favor their occurrence. For each of these objectives, we proposed a list of tasks to address data needs.

From the outset it was recognized that data needs differed between the Upper and Lower segments of the estuary due to differences in the nature and occurrence of algal blooms in these regions. The Upper Estuary, defined here as the tidal-freshwater segment (from the Fall Line in Richmond to the Chickahominy River) is characterized by chronic algal blooms in the region near Hopewell, VA (river miles 69-75). CHLa is persistently elevated during May –October due to proximal nutrient inputs from riverine (upper James watershed) and local point sources (Bukaveckas 2011). In late summer, these blooms are dominated by cyanobacteria (blue-green algae) including harmful species capable of producing cyanotoxins (Marshall et al. 2005). Data needs for this segment of the Estuary include some additional efforts characterizing the occurrence of algal blooms but focus principally on assessing impairments to designated uses, and particularly, the effects of cyanotoxins on humans and living resources.

The Lower James River Estuary (inclusive of the oligo-, meso- and poly- haline regions) experiences algal blooms that are more ephemeral in time and place (Morse et al. 2011). Given the larger spatial area of the Lower James, and the sporadic incidence of algal blooms, a greater proportion of data collection activities must be allocated to characterizing the frequency and extent of blooms. Advanced technologies including continuous, fixed-station monitoring and continuous on-board monitoring will be needed to map their spatial extent and identify zones of bloom initiation. Assessing impairments in the Lower James is also challenging because the blooms are typically comprised of dinoflagellates which are known to cause harmful effects, though these may not be linked to the occurrence of specific toxins.

Modeling activities are needed to develop quantitative linkages between nutrient inputs and the response of algae. These relationships provide the basis for assessing changes in CHLa (and/or other potential bloom metrics) to nutrient loading, and for assessing attainment of current CHLa criteria based on various management options.. Quantitative relationships may take the form of complex, deterministic models (e.g., based on hydrodynamics, algal growth rates, etc.) or simpler, statistical relationships relating CHLa to the probability of harmful algal blooms and impairments. It is anticipated that these relationships will be derived in part from existing data resources (e.g., long-term monitoring conducted by DEQ for the CBP) and from new data collected as part of this study. Of particular importance is the need to simulate the frequency, magnitude and duration of algal blooms (as CHLa) under various nutrient loading scenarios. It is anticipated that these simulations will be performed using a deterministic model that predicts CHLa on the basis of underwater light conditions, nutrient availability, water residence time and other factors that influence algal growth and mortality. An existing model developed for Chesapeake Bay is currently used for this purpose. The model was calibrated for large-scale applicability (e.g., the Bay and its tributaries) though local optimization would improve its reliability for predicting CHLa in the James under various loading scenarios. Thus a minimum requirement in the modeling effort is to improve site-specific calibrations for the existing CHLa model. Additional effort may be warranted to develop an alternative CHLa model for the James, and/or to enhance model capabilities by improving spatial resolution, or by including additional modeling parameters that are linked to impairment of designated uses (e.g., prediction of cyanobacterial and dinoflagellate blooms). The Panel recommends therefore that a model review should be conducted to assess costs and benefits of various approaches.

Data Needs for the Upper James River Estuary

Objective 1. Characterizing Algal Blooms

Subtask 1.1—Characterizing spatial & temporal patterns

Current monitoring in the tidal-freshwater James River includes monthly sampling at 7 stations conducted by DEQ for the CBP (Figure 1). Six stations are located along the mainstem at river miles (rm) 56, 69, 75, 99, 104 and 100; with one station located in the Appomattox (ca. 1.5 miles from its confluence with the James). Additional monitoring is carried out by VCU for the City of Richmond which provides weekly data from 4 CBP stations (rm 75, 99, 104 and 110) plus 4 additional (non-CBP) sites located between rm 75 and 110. CHLa and nutrient concentrations (total and dissolved) are measured weekly at all locations; phytoplankton samples are collected monthly and only at JMS75. Continuous monitoring data (CHLa, water quality) are available from a single location (VCU Rice Center; located near JMS75) where bi-weekly samples are also collected for CHLa and nutrients.

The Work Group supports the following recommendations for modifying the current monitoring program:

1. Expanding the network of weekly sampling locations to include three CBP sites that are currently sampled only monthly (JMS56, JMS69 and APP1.53) and adding two new sites between rm 75 and 56.
2. Expanding the number of continuous monitoring locations from one to four through seasonal deployment of water quality sondes at stations JMS75, JMS69 and JMS56.

Expanding the network of weekly sampling locations from 8 to 13 stations would provide sufficient spatial resolution to characterize the size and intensity of algal blooms. Currently, the segment of the river where blooms are most prevalent is represented by a single station (JMS75) that is sampled weekly; the proposed scheme would add 4 stations in the region between rm 75 and 56 (2 new stations plus 2 upgraded from monthly monitoring). Results from the expanded sampling effort would be used to characterize the occurrence of algal blooms and determine whether data from the long-term, monthly monitoring sites is representative of CHLa in this segment of the James. Water samples collected from all sites would be analyzed for CHLa and nutrients. Samples for phytoplankton enumeration would be obtained weekly from three sites (JMS75, JMS69, JMS56; current monitoring is monthly at JMS75).

Data from continuous monitoring locations will be used to characterize the occurrence of transient algal blooms that are unlikely to be detected by weekly-monthly sampling. Currently, continuous monitoring of CHLa is restricted to a single, near-shore site which may not be representative of main channel conditions. We propose that water quality sondes should be deployed seasonally (e.g., June-October) at three of the weekly-monthly monitoring locations to characterize the occurrence of short-term excursions in CHLa in the region where algal blooms are most prevalent. These data will also contribute to assessment of impairments by detecting transient (night-time) oxygen depletion during periods of high algal abundance.

Subtask 1.2— Environmental factors favoring algal blooms

Three areas of data needs were identified by the group as necessary for understanding bloom formation and supporting modeling efforts to assess CHLa attainability. The first of these concerns

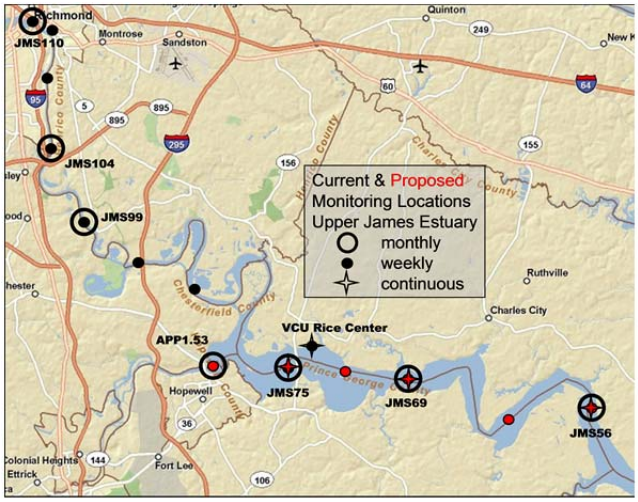

Figure 1. Map of the upper James River Estuary showing current and proposed monitoring locations for CHLa.

factors that regulate phytoplankton growth, and specifically, the forms of nutrients that sustain algal blooms (Koch et al. 2004; Filippino et al. 2011). At present there is little information for the tidal freshwater segment of the James as to the occurrence of N vs. P limitation, the importance of N fixation and the utilization of dissolved organic N. Resolution of these issues has implications for modeling bloom development, which is needed to link nutrient loads to CHLa, and may also be important to guiding nutrient mitigation strategies. Preliminary data collected by ODU (Margie Mulholland) and VCU (Paul Bukaveckas) during Summer 2011 demonstrated the prevalence of N limitation and the importance of both organic and inorganic forms of N based on experiments conducted at the Rice Research Pier. These results should be used to guide further experiments that link bloom development with nutrient availability. It is important that these experiments also explore relationships between light availability and nutrient utilization as these could be used to establish limitation thresholds.

A second issue to be addressed is the role of consumers in regulating algal abundance in the tidal freshwater James. It has been argued for Chesapeake Bay that loss of oyster populations may preclude attainability of lower CHLa even with reductions in nutrient loads. While oysters do not occur in the tidal freshwater James, other consumers may play an equally important role in regulating algal abundance. The food web of the James has likely undergone substantial changes, in part due to fisheries introductions, but there is little recent or historical

data on grazing rates. The most recent study reported grazing rates by zooplankton of ~5% CHLa/d, which are low even by estuarine standards (typically ~30%/d). This study did not consider other potential consumers and the Work Group recommends that some effort should be devoted to estimating grazing losses.

The grazing impacts of consumers are determined by (a) the proportion of algae in their diet, (b) their consumption (grazing) rate, and (c) their numerical abundance. A key first step would be to identify the main consumers of algal biomass in the James food web. This work could be conducted in conjunction with the food web toxin accumulation study (see below) by measuring CHLa and toxins in stomach contents. Target species (based on known feeding habits and numerical abundance) would include benthic and pelagic grazers such as Corbicula, juvenile Atlantic menhaden, gizzard shad and juvenile blue catfish. Results of gut contents or stable isotope analyses could be used to assess algal contributions to diet and would also aid in the interpretation of toxin accumulation data. Subsequent studies would entail measurement of feeding rates (e.g., using mesocosms) for consumers with high algal contributions to their diet. Data on feeding rates of individual species would need to be weighted according to their relative abundance in the James to quantify consumer controls on algal abundance. Empirical data could be collected as part of this study to quantify the abundance of dominant consumers. Alternatively it may be possible to use literature values, or results of bioenergetics models, to incorporate grazing estimates in CHLa models (see Modeling Sub-task 1.2).

Lastly, the panel recognized the importance of understanding not only the general causes of algal blooms but specifically those factors that favor the occurrence of harmful algal blooms, in this case, cyanobacteria. Some insight may be gained by exploring empirical-statistical relationships between cyanobacteria abundance (or Microcystin concentration) and environmental factors (temperature, nutrients, etc.). It is also useful to consider experimental studies in which these factors could be manipulated to assess their effects on cyanobacterial dominance. If successful, empirical relationships derived from field or experimental data could be incorporated in the modeling component to improve simulation of harmful algal blooms (see Modeling Sub-task 2.2).

Objective 2. Characterizing Impairments Associated with Algal Blooms

Subtask 2.1—Algal contributions to water clarity

Water clarity, along with depth, determines the underwater light conditions experienced by phytoplankton and therefore is important to understanding when and where algal blooms occur. Phytoplankton suspended within the water column absorb and scatter light, thereby diminishing light availability and inhibiting the growth of submersed aquatic vegetation. Thus the relationships between phytoplankton abundance and light conditions is central to both modeling algal blooms and assessing impairments. A recently completed study (not yet published) has shown that phytoplankton contribute a large proportion of the particulate organic matter in the Upper James, but that organic matter itself accounts for a small proportion (~25%) of total suspended solids. These findings indicate that mineral particulates derived from the watershed account for the bulk of turbidity though it should be noted that particulates of varying composition may differ in their mass-specific contribution to light attenuation. The Work Group recommends that some consideration should be given to the issue of water clarity impairment associated with chronic algal blooms in the Upper James. Specifically, existing data could be used to model relationships between water clarity and algal/non-algal contributions to suspended particulate matter. If needed, these data may be supplemented with measurements of light attenuation obtained during weekly CHLa monitoring and/or with turbidity measurements obtained from the continuous monitoring stations. These data would be used to derive empirical relationships for forecasting changes in water clarity associated with anticipated declines in CHLa following nutrient reductions. Improvements in water clarity, coupled with bathymetry data for the Upper James, could then be used to assess potential benefits for SAV habitat.

Subtask 2.2—Cyanotoxins in water, sediments and living resources

The Panel's consideration of impairments arising from algal blooms in the upper James focuses largely on occurrence of harmful algae and particularly those that produce toxins. The Panel felt that a key issue in assessing impairments was to identify and quantify the loss of resources, inclusive of water quality (e.g., as a drinking water source) as well as living resources (fisheries, wildlife). The focus on algal toxins provides a direct basis for linking algal blooms with

diminishment of resources and therefore supports efforts to define numeric CHLa criteria. The World Health Organization has established a safety threshold for Microcystin in drinking water of 1 µg/L and the Virginia Department of Health has established a provisional Microcystin action level of 6 µg/L for recreational water. Thus, quantifying Microcystin concentrations in water provides a basis for linking impairment to CHLa. Microcystin concentrations could be used in conjunction data on the abundance of Microcystis (algal counts) to derive empirical models. Completion of this task requires enhancing current monitoring efforts to include detection of likely algal toxins (e.g., Microcystin), not only in sources (phytoplankton, sediments), but also in food webs. Microcystin concentrations are currently monitored weekly by VCU at four sites (JMS69, JMS75, JMS99 and Rice Pier). The Work Group recommends that weekly monitoring of Microcystin be expanded to include JMS56, APP1.53 and the two new proposed sites between rm 75 and 56. Analyses of sediment samples obtained from these sites would provide a basis for assessing exposure to benthic organisms.

While a comprehensive characterization of the James River food web is outside the scope of this study, an assessment of the occurrence of algal toxins in sentinel and "high value" species is warranted. Target species should include benthic and pelagic macro-organisms that are important components of the food web either due to their numeric abundance or their contribution to designated uses (e.g., anadromous fish and apex predators). The selected suite of species should also span a range of trophic (feeding) groups that include benthic omnivores (blue crabs, gizzard shad, juvenile blue catfish), filter-feeders (Corbicula, blue-back herring, Atlantic menhaden, threadfin shad) and predators (adult blue and flathead catfish). The Work Group proposes that monitoring of Microcystin accumulation in tissues of target species should be undertaken before, during and after bloom periods to assess cyanotoxin accumulation and persistence within the food web. Cyanotoxins are known to biomagnify in food webs but are also subject to depuration (i.e., metabolic loss). Analyses of tissues obtained from target species would be used to track changes in toxin accumulation during and after the period when cyanobacterial blooms occur. Collection of feather samples from juvenile (nestling) osprey during June-August would quantify Microcystin exposure in an apex predator. It is anticipated that sampling intervals of 2-4 weeks would be required depending on the persistence of toxin-producing algae and the turnover rates of the toxin in tissues of the target species.

Subtask 2.3—Application of genetic tools to assess risk of impairment

Monitoring of Microcystin should be augmented by the use of genetic techniques to quantify the presence of toxin-forming strains. qPCR methods have been developed to quantify specific marker genes for cyanobacteria, Microcystis and microcystin-producing genotypes (inclusive of Microcystis and other taxa). The abundance of cyanobacterial 16S rDNA copies, Microcystis-specific 16S rDNA copies and mcyD (Microcystin) gene copies can be determined using available primers and probes. Their respective abundances would be used to estimate the proportional contributions of Microcystis to the cyanobactaerial community and the proportion of cyanobacteria that are capable of producing the toxin. This information would be useful for understanding the environmental conditions that favor the occurrence of toxin-producing strains and toxin production. These data could be used to derive empirical relationships for inclusion in models that predict HAB occurrence

Subtask 2.4—Cyanotoxins and living resources

In addition to monitoring of toxins in water, sediment and tissues, the Work Group recommends that an assessment of impairment should include experimental data to directly link toxin exposure to deleterious effects on species that are important components of the James food web. These data would provide an empirical basis for justifying standards, either for toxin concentrations directly, or for proxy indicators (e.g., CHLa, cyanobacterial abundance). Toxicity tests would involve exposure of representative taxa from various trophic groups to Microcystin. Candidates may include benthic omnivores (e.g., blue crabs, gizzard shad and juvenile blue cats) and filter feeders (Corbicula, blueback herring, Atlantic Menhaden and threadfin shad).

Data Needs for the Lower James River Estuary

Objective 1. Characterizing Algal Blooms

Subtask 1.1—characterizing spatial & temporal patterns

Algal blooms occurring in the Lower James River Estuary are ephemeral in nature and unpredictable in their timing, location and duration. Algae have the capacity to bloom quickly and to be transported by currents. As a result, sites of bloom initiation may be geographically distinct from areas where blooms develop and cause detrimental effects on water quality and living resources. The distinction between sites of initiation and impact is important because mitigation actions designed to prevent blooms would need to be focused at sites of bloom initiation whereas actions aimed at mitigating bloom impacts would need to focus on sites where blooms accumulate. Fixed station monitoring, such as the program carried out by DEQ for the CBP, is not designed lo locate, map and track these events. Thus, alternative monitoring strategies are needed to characterize the occurrence of algal blooms in the Lower James. A method of on-board monitoring of CHLa can be used in conjunction with GPS navigation to provide real-time mapping of algal blooms. Presently this technology is employed by HRSD to map spatial variation in CHLa for the meso- and poly- haline segments of the James, Elizabeth and Lafayette Rivers on a weekly basis (Figure 2). This method provides the most effective means for determining the size, intensity and location of algal blooms. The Panel recommends that these efforts should be expanded to include the oligohaline segment of the James (Figure 3).

There is also a need to complement CHLa mapping efforts with fixed-station, continuous monitoring to enhance temporal coverage and bloom detection capabilities. Specifically, CHLa sensors should be deployed in potential "hot spots" for bloom initiation that are identified from previous mapping efforts and/or their proximity to nutrient inputs. Two potential sites are suggested, one in the JMSMH segment and another in the LAFMH segment (Figure 4). The proposed LAFMH station location corresponds to a region where algal blooms are often initiated. The proposed JMSMH location represents a region where algal blooms are often first observed either by initiation and/or hydrodynamic transport from the LAFMH segment. Inclusion of these continuous monitoring stations will provide greater temporal coverage and resolution of algal

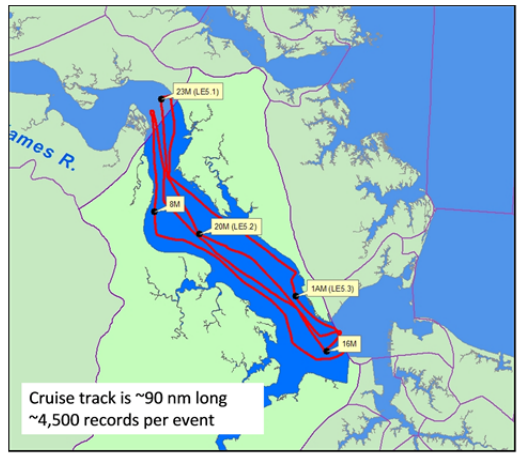

Figure 2. Map of the Lower James River Estuary illustrating cruise tracks employed to map spatial variation in CHLa within the mesohaline segment in relation to fixed station monitoring locations.

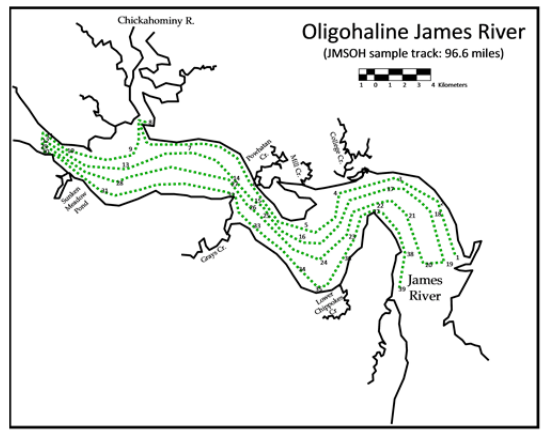

Figure 3. Map of the oligohaline segment of the James River Estuary illustrating the proposed location of additional cruise tracks to map spatial variation in CHLa.

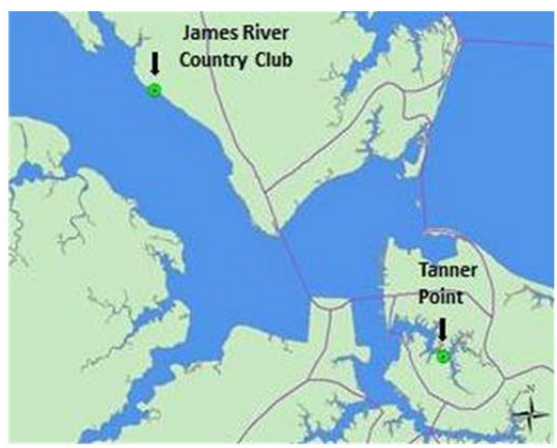

Figure 4. Map of the Lower James River showing candidate sites for continuous CHLa monitoring to detect bloom initiation.

dynamics These monitoring locations (positioned at piers) have been utilized in previous years by VIMS and ODU.

Lastly, the present CHLa monitoring season runs from March 1st-May 31st and July 1st to September 30th. Monitoring to date indicates that some early and late algal blooms could be missed, as well as those occurring in June. It is recommended that the monitoring season be extended to run continuously from February 15th to October 15th to capture these events.

Subtask 1.2—CHLa, diagnostic pigments and the occurrence of harmful algae

Characterizing spatial and temporal variation in CHLa is a central focus of James River monitoring and modeling efforts as this pigment occurs in diverse algal groups (e.g., cyanobacteria, dinoflagellates, etc.) and is therefore a useful indicator of algal abundance. However, harmful algae often comprise only a small proportion of the total algal community and therefore measurements of CHLa alone may be insufficient for assessing the occurrence of algae that are directly linked to impairments of designated uses. Therefore the Panel recommends that some additional effort is needed to evaluate other metrics specific to harmful algal blooms and to assess their relationship with CHLa. These include data from microscopic examination of algal communities and the use of diagnostic pigments that are specific to groups associated with harmful effects (e.g., dinoflagellates).

A three-tier framework is proposed (Figure 5) whereby CHLa is monitored routinely (using the fixed-station and mapping approaches described in sub-task 1.1) and additional sample collection is triggered when CHLa concentrations exceed screening criteria (currently, 15 µg/L). These samples will be analyzed to determine phytoplankton community composition and cell density (via microscopy and/or molecular-genetic approaches) and the presence of diagnostic pigments (via HPLC). Major phylogentic groups (e.g., dinoflagellates) contain unique pigment signatures and specific pigments which may be detected with great sensitivity. If specific pigments can be linked to harmful taxa, pigment analysis may allow early detection of harmful algal blooms and associated impairments of designated uses. Empirical relationships should be quantified by assessing cell density and phytoplankton pigment signature (via HPLC) over a range of seasons and cell densities. These data are needed to establish whether laboratory phytoplankton pigment signatures can be used as a surrogate for determining the abundance of harmful taxa. The proposed three-tiered framework may also be useful for regulatory assessment whereby results from each sampling event would be used to determine the proportion of area that passes each of the proposed criteria.

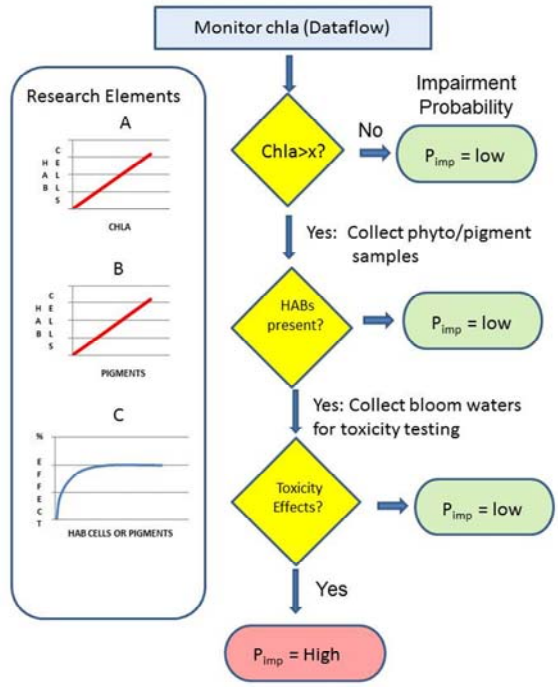

Figure 5. Proposed data collection activities in the Lower James River Estuary to assess the probability of impairment due to harmful algal blooms.

Subtask 1.3—Environmental factors favoring harmful algal blooms

Research to date indicates that runoff associated with localized storm events delivers nutrient pulses to the Lower James River Estuary. These events may be important to triggering bloom initiation. Additional studies are needed to measure nutrient pulses in the James associated with storm events and to link their occurrence with results from CHLa mapping efforts. Recent advances in technology for continuous monitoring of nitrogen concentrations may aid in this effort (e.g., in conjunction with continuous monitoring of CHLa). Data arising from this work will directly support model development efforts for

simulating CHLa in the Lower James. Recent studies also suggest that nutrient storage and release from sediments may play an important role in algal bloom dynamics. Tidal- and wind- driven mixing can bring about the re-suspension of sediments and the introduction of sediment-derived nutrients into the water column. These events may trigger algal blooms even in the absence of new, external nutrient inputs via runoff. The accumulation of nutrients in sediments has been documented in other systems and therefore the Panel recommends that further studies should be undertaken in the James River to assess the importance of sediment-derived nutrients. Lastly, the importance of top-down controls by Atlantic menhaden, oysters and other grazers occurring in the Lower James is poorly understood (see also Upper James sub-task 1.3). The Panel recommends that additional studies are required to assess their potential importance in controlling algal blooms. Incorporation of these data into the model development effort may enhance model accuracy (see Modeling sub-task 1.2).

Objective 2. Characterizing Impairments Associated with Algal Blooms

Subtask 2.1—Determining linkages between algal blooms and impairments

Non-toxic species can cause adverse biological (impacts on grazers), chemical (grazing deterrents, allelopathic agents, or low DO), or aesthetic effects (discoloration of water, foul odor). Additional information is needed to identify species of concern, their spatial and temporal distribution and their impacts on human and ecosystem health in the Lower James. The Panel recommends an approach similar to toxicity testing whereby laboratory experiments with sentinel species and natural bloom waters are used to establish algal abundance thresholds at which adverse biological effects occur. Some bioassay testing results are available from the literature for a few of the harmful algae that occur in the Lower James. However, new research will be needed to assess those species not previously tested which are commeon to the lower James (e.g., *Heterocapsa triquetra, Prorocentrum minimum, Scrippsiella trochoidea, Akashiwo sanguinea, Cochodinium polykrikoides;* Marshall 2005)..

Response metrics may include survivorship, growth rates and reproduction of target organisms. Ideal target species for these studies would be those that are indigenous to the Lower James or close analogues that are available for laboratory testing (e.g., larval *Cyprinodon variegatus*, larval *Crassostrea virginica* and *Artemia salina)*. As bloom events are sporadic in the Lower James, routine (e.g., fixed-interval) toxicity testing is not practical or efficient. Results from the CHLa and harmful algal bloom monitoring (sub-tasks 1.1 and 1.2) would be used to determine the timing of the toxicity studies (Figure 5). It is anticipated that 5 bioassay suites per year could be performed and that these would include dilution series, whole cell and lysate, filtered estuarine water, and artificial sea water controls (e.g., Lovko et al. 2003; Mulholland 2009). Repeating these studies over multiple years would provide a basis for identifying harmful species and the concentration at which cell densities cause impairments. Although toxicity testing will be primarily event-based, it is important to document exposure effects during non-bloom conditions to document that low levels of CHLa (or related metrics) are not associated with measurable impacts and to elucidate where along the gradient deleterious effects are detected.

Modeling Needs for the James River

Objective: Application of a water quality-phytoplankton model to predict attainability of the current CHLa criteria for the tidal James River under various nutrient loading scenarios.

Task 1 – Model Review & Selection

Various models, including those currently used by USEPA, are potentially suitable for this application. Therefore model development should begin with a review phase that considers the capabilities, strengths and weaknesses of these models. The review process may also identify modifications and enhancements to existing models that would improve their performance or capabilities. The results of this review should include a consideration of their potential benefits as well as costs for undertaking these revisions. The review will include an evaluation of the data/information requirements of the preferred modeling approach, a comparison of these requirements to data/information availability and recommendations for filling data/information needs, such as by the modification of existing monitoring programs or the performance of special studies. It is anticipated that the model review will be completed in the first year of the project. The results of this review will be used by the Science Advisory Panel to guide further decisions on data needs and model development. Specific components of the model review are described in greater detail below.

Subtask 1.1—Watershed/loading sub-model

Nutrient loading models are linked to hydrodynamic and water quality models in order to simulate the effects of various nutrient loading scenarios on water quality parameters such as CHLa. Task 1 should include a review of methods for simulating nutrient loads to the tidal James River. If use of the USEPA Chesapeake Bay watershed model is recommended, it should be determined whether this model needs adjustment or recalibration to provide the level of accuracy required for the objectives of this project. A review of model capabilities should also consider whether localized events that deliver nutrient pulses to the Lower James could be captured in this modeling framework (see Lower James Workplan, sub-task 1.3).

Subtask 1.2—Hydrodynamic and water quality sub-models

The ability to correctly simulate CHLa is dependent on accurate simulation of hydrodynamics (water movement). This is especially important in estuaries because they are subject to both river and tidal forces. For example, the location of persistent algal blooms in the Upper James River Estuary has been attributed in part to local water residence time (Shen & Lin 2006; Bukaveckas et al. 2010), and recent research has shown the importance of hydrodynamics in determining the location of blooms in the Lower James Estuary (Morse et al. 2011). Model options should be reviewed with respect to their capability for making accurate predictions of hydrodynamics and key water quality parameters (esp. CHLa). The review should consider specific aspects of hydrodynamic/water quality modeling in the James River including revision of existing models, development of new models, and linkage of deterministic-empirical models. The Panel identified specific areas of concern that need to be addressed before undertaking model simulations.

1. The existing water quality/sediment transport model used by USEPA (developed by the Army Corps of Engineers) was applied to the entire Chesapeake Bay system, and thus has lower spatial resolution than might be needed to model algal blooms in the James. The model review should consider the costs and benefits of adopting a finer grid structure for simulating CHLa in the James River.

2. The existing model has limited ability to simulate shallow-water processes which may be important due to the extensive shallow areas occurring in the James. For example, sediments are a major reservoir of nutrients which fuel algal blooms through sediment re-suspension or other fluxes to the water column. Simulating the effects of nutrient load reductions on CHLa must therefore take into account legacy effects due to historical loading of nutrients. A model review should consider the manner by which existing models simulate nutrient releases from the sediment, and evaluate the costs/benefits of enhancements in this area.

3. The existing water quality model includes only three algal groups: cyanobacteria (blue-green algae), diatoms, and chlorophytes (green algae). Better CHLa calibration has been achieved on the Potomac River estuary by expanding the number of algal groups. For the James, there is specific interest in the occurrence of cyanobacteria in the tidal freshwater segment and dinoflagellates in the brackish-marine segment. Augmenting the existing model to predict the abundance of these two groups may improve CHLa simulations and allow prediction of impairments associated with harmful algal blooms. The model review should consider the costs and benefits of adding these algal groups and whether data arising from this project will be sufficient to support this model component.

4. Algae utilize diverse forms of nutrients including dissolved inorganic fractions (ammonia, nitrate, and orthophosphate) as well as dissolved organic fractions (see Upper James Workplan, sub-task 1.2). In addition, some cyanobacteria are capable of fixing dissolved nitrogen gas (N_2). Modeling algal blooms may therefore require information on the forms and availability of these nutrient fractions as well as information on which fractions limit growth. Estuarine algae are generally considered to be limited by the availability of nitrogen, though phosphorus limitation could occur in tidal freshwater zones. A model review should consider the capabilities of existing models to simulate algal uptake of various nutrient fractions, the cost/benefits of enhancing models accordingly, and the suitability of data arising from this project to support modeling efforts in this area..

5. Algal blooms arise when growth rates exceed losses by senescence, hydrologic transport, sedimentation and grazing. While much attention is paid to growth-limiting factors such as temperature, light and nutrients, the timing and location of blooms may be determined in part by conditions that favor low loss rates. In the James, filter-feeders such as oysters and menhaden might be an important top-down control on CHLa (see Upper James Workplan, sub-task 1.2). Top-down effects can be incorporated into models in various manners, from simple loss terms to more explicit simulation of specific feeders. The review should consider the capabilities of existing models for simulating top-down controls, address the cost-benefits of incorporating these effects and identify data needs to parameterize this component of the model.

Task 2 – Model Development

This task focuses on the development of a James River Water Quality/Phytoplankton model that will be used to simulate CHLa under various nutrient loading scenarios. Project elements include: creating the model input files (fall line and lateral watershed loads, bathymetry, metrological, branch inflow, Bay boundary conditions, etc.), revising the model grid scale (if necessary), and revising model algorithms as required (e.g., expanded algal groups).

Subtask 2.1—Data acquisition & compilation

Identify and collect all requisite data (stationary, dataflow, special projects, etc.). Data will be analyzed and integrated under one GIS application. This format will be used to identify potential data gaps (extreme flow or climate events, etc.). The deliverable may include a geospatial data inventory spreadsheet listing the file name, source, date, and intended use. The deliverable will also include metadata files which follow the most current version of the Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata (CSDGM).

Subtask 2.2—Empirical data analysis

The purpose of this sub-task is to perform data analyses in support of model development by developing quantitative linkages between the occurrence of algal blooms and potential forcing functions in the upper and lower James estuary. The analysis will focus on the 2000-2010 period. Specific data analyses needs are as follows:

1. Quantify the major sources of flow and nutrients to the James and Elizabeth River estuaries. Construct a time series of external nutrient inputs based on available data. Supplement this information with data-based or literature-based information on internal sources of nutrient loading (e.g., sediment). Interpret this information with respect to the major sources of flow and nutrients to the system on different time scales. Determine whether load-CHLa relationships exist, and if so, whether these have been stable over time.

2. Review historic data and characterize dry, wet, and average conditions and to identify major algal blooms (type, location and extent) where possible in conjunction with physical conditions (flows, tide, season, salinity, etc). Based on these results, develop methods for empirical data analysis of bloom occurrence, which could include regression, conditional probability modeling, or other techniques. Identify critical conditions for bloom formation and describe the historical frequency/duration of these conditions. This analysis should include a consideration of water quality metrics and forcing functions which are most useful for predicting algal blooms based on CHLa or related algal metrics (e.g., cyanobacteria and dinoflagellate abundance).

Task 3 – Model Application

This task focuses on the application of the James River Water Quality/Phytoplankton model to assess current CHLa criteria using newly calibrated and enhanced modeling tools. Project elements include: identifying time series for model calibration and verification, performing preliminary calibration/validation of the model and conducting model test runs.

Subtask 3.1—Model calibration & verification

The model calibration should consider all relevant data, including the results of special nutrient pulsing studies if they are available. The deliverable for this task is a calibrated, verified model.

Subtask 3.2—Model sensitivity and uncertainty analysis

The purpose of this sub-task is to evaluate the sensitivity of model predictions to key input

parameters, and to describe the uncertainty of the model in predicting CHLa. Even in a well-studied, data-rich system, accurate prediction is still inherently uncertain (Stowe et al. 2002) and the Panel recommends that uncertainty in model predictions should be quantified. An analysis of uncertainty is complicated, particularly for models that include both deterministic and probability-based elements. For example, inclusion of a model component to simulate harmful algal blooms (HABs), may require the use of conditional probability techniques to relate their likelihood of occurrence to physical or water quality conditions. If these algorithms are incorporated into the model, the sensitivity and uncertainly analysis may include elements such as: (1) testing the sensitivity of the model to inclusion or deletion of certain processes (2) using data assimilation to constrain the model and improve prediction (3) finding optimal parameter using inverse methods under a testbed paradigm. If a linked deterministic/probability-based method is used, this analysis should address the uncertainty associated with both the deterministic and probability-based components.

Subtask 3.3—Scenario development and implementation

This task entails implementing various model scenarios necessary to assess the impact of nutrient input load reductions on CHLa and, if feasible, the occurrence of harmful algal blooms. This should include scenarios under diverse physical forcing and nutrient load conditions (e.g., wet, dry and average conditions) to assess the effects of inter-annual climatic variability. The calibrated model will be used to examine the attainability of CHLa criteria for the James River Estuary under a range of loading/management scenarios.

Concluding Points

The Panel recognizes that the Workplan entails an ambitious agenda of data collection and modeling activities. Prospects for completing the agenda within the proposed time frame are significantly enhanced by on-going data collection and modeling activities related to algal blooms in the James River Estuary. Current monitoring programs include those conducted by DEQ for the Chesapeake Bay Program, as well as those supported by the City of Richmond (Upper James) and HRSD (Lower James). These on-going efforts and related research by University-affiliated investigators will enable a rapid response to the data and modeling needs identified in this Workplan. It should be noted however that there are considerable knowledge gaps, particularly in our understanding of potential detrimental effects associated with algal blooms and model selection criteria. These uncertainties favor the use of an adaptive management approach whereby results in the early phases of the project are used to inform further decisions on data and modeling needs.

The Panel recommends that data collection efforts in Year 1 should focus on the proposed supplemental monitoring activities that are needed to characterize algal blooms (CHLa and related metrics). These data will be important to model development and calibration and therefore should be collected in the early stages of the project. Starting these activities in Year 1 will also allow an assessment of inter-annual variability in algal blooms over the anticipated 3-year time frame of data collection. The availability of multi-year data will facilitate analyses of bloom initiation and development under variable environmental conditions. Lastly, these data will be used to inform the design and execution of experimental studies (e.g., toxicity tests, grazer effects) in Years 2 and 3. It is anticipated that modeling activities will progress by the order of tasks with model review completed in Year 1. The results of this review, as well as concurrent data collection and analyses, will be used to guide model development efforts in Year 2 and model application in Year 3.

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