

Errata Sheet

Fulfilling Data Needs for Assessing Numeric CHLa Criteria of the Lower James River Estuary 2013 Annual Grant Data Report, Submitted to The Virginia Department of Environmental Quality Agency Award Number: 15427 by K.A. Moore, David B. Parrish and Betty B. Neikirk, The Virginia Institute of Marine Science School of Marine Science, College of William and Mary, Gloucester Point, Virginia 23062, May 2013

The use of the CFD in this report differs from the Bay Program's protocol in the following ways: 1) each data point in the assessment curve should represent a season-year rather than an individual DATAFLOW cruise, 2) the reference curve should have the same number of points as each "assessment" curve to allow for a point-by-point comparison, and 3) while the official assessment is based on three years, the report CFD only reflects this single year. Furthermore, the CFD makes the "allowable" exceedence rate at any point in time dependent on the exceedence rates observed at the *other* instances in time. In addition, the use of an areal exceedence rate of 10% is not an absolute threshold of impairment. Therefore, the exceedence rates reported are for information purposes only and should not be compared to any DEQ Assessment results.

**Fulfilling Data Needs for Assessing Numeric CHLa Criteria
of the Lower James River Estuary**

Subtask 1.1-Expand Monitoring Network

Grant Data Report

Submitted to

The Virginia Department of Environmental Quality
Agency Award Number: 15427

by

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2012 Key Findings

- James River Oligohaline (JM SOH)
 - Low CHL *a* levels were observed in the JM SOH segment from May through October 2012 with less than 10% of the surface area exceeding 10 $\mu\text{g l}^{-1}$ during this period.
 - Cumulative Frequency Distribution (CFD) plots of summer season criteria (22 $\mu\text{g l}^{-1}$) showed that exceedences were well below an arbitrary 10% reference curve for allowable exceedences.

- James River Mesohaline (JM SMH)
 - Evidence of bloom formation of four weeks or more were evident during the spring and summer.
 - During these periods bloom concentrations exceeding 40 $\mu\text{g l}^{-1}$ covered 20% or less of the open water area in the mainstem James River.
 - Bloom concentrations of over 300 $\mu\text{g l}^{-1}$ were observed in August and September 2012 but median CHL *a* concentrations were $\sim 25 \mu\text{g l}^{-1}$.
 - Cumulative Frequency Distribution (CFD) plots of the spring and summer seasonal criteria (12 and 10 $\mu\text{g l}^{-1}$ respectively) showed that exceedences were below an arbitrary 10% reference curve for allowable exceedences.
 - When summertime blooms dominated by *Cochlodinium polykrikoides* occurred they were typically located in the downstream one third of the segment area.
 - Springtime blooms dominated by *Heterocapsa triquetra* were already evident in February at the beginning of spring assessment period and lasted until the end of March.
 - Continuous monitoring of blooms at the fixed ConMon station demonstrated the high temporal variability in bloom levels in which daily means varied 20-30 $\mu\text{g l}^{-1}$ from one day to the next and individual bloom concentrations varied up to 100 $\mu\text{g l}^{-1}$ during 24 hour periods. This highlights the varying nature of the bloom exposure that benthic organism may experience and indicates that infrequent fixed point sampling may not adequately assess bloom conditions.

- James River Polyhaline (JM SPH)
 - Spring blooms of *Heterocapsa triquetra* did not affect a large area of this segment with no measureable areas found to exceed 20 $\mu\text{g l}^{-1}$.
 - CFD exceedence for the spring showed exceedences of the 12 $\mu\text{g l}^{-1}$ criteria were well below the 10% reference curve for allowable exceedences.
 - Late summer *Cochlodinium polykrikoides* dominated bloom intensities in the JM SPH segment were markedly greater than in the JM SOH and JM SMH segments of the mainstem during the period extending from mid-July to mid-August 2012.

- Median concentrations measured over the entire segment area reached $\sim 25 \mu\text{g l}^{-1}$ during August with individual patches exceeding $300 \mu\text{g l}^{-1}$.
 - During the period of maximum bloom intensity in late July, $\sim 60\%$ of the segment area exceeded $40 \mu\text{g l}^{-1}$ with nearly 80% of the surface area exceeding the $10 \mu\text{g l}^{-1}$ CHLa standard.
 - Cumulative Frequency Distribution (CFD) plots summer seasonal criteria ($10 \mu\text{g l}^{-1}$) showed that exceedences were above an arbitrary 10% reference curve for allowable exceedences in this segment.
- Elizabeth River Polyhaline (ELIPH)
 - Increased bloom intensity in the lower ELIPH segment was observed beginning in mid-June and continuing until mid-August 2012.
 - Segment median concentrations typically exceeded $30 \mu\text{g l}^{-1}$.
 - During July-August $60\text{-}80\%$ of the segment had concentrations exceeding the $10 \mu\text{g l}^{-1}$ standard with over 40% of the segment area having concentrations exceeding $40 \mu\text{g l}^{-1}$ during maximum bloom occurrence in August.
- Lafayette River Mesohaline (LAFMH)
 - Summertime CHLa concentrations in the LAFMH segment were highest and of longest duration of all the segments sampled, and the summer bloom occurrence was first observed there in June and continued until mid-September 2012.
 - During the period of mid-July to Mid-August median concentrations of $40 \mu\text{g l}^{-1}$ or more were recorded with individual measurement exceeding $300 \mu\text{g l}^{-1}$.
 - For much of the entire March to October sampling period CHLa concentrations exceeding $10 \mu\text{g l}^{-1}$ covered at least 20% of the segment, with $\sim 60\%$ of the segment exceeding this concentration from mid-July to mid-August.
 - Forty percent of the segment area had widespread blooms exceeding $40 \mu\text{g l}^{-1}$ throughout July and August 2012.

Introduction

The Virginia Department of Environmental Quality (DEQ) has been undertaking a comprehensive review of the existing Site-Specific Numeric Chlorophyll-*a* (CHL_a) 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 CHL_a 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 provided an overall framework for addressing these needs as well as specific tasks for data collection and model development. This project addresses: "Data Needs for the Lower James River Estuary, Objective 1, Subtask 1.1, Characterizing spatial and temporal pattern of algal blooms", of the Science Advisory Panel Workplan.

The Lower James River Estuary and associated lower system tributaries¹ experience algal blooms that are ephemeral in time and place. Given the large spatial area of the Lower James, and the sporadic but increasing incidence of algal blooms, a greater proportion of data collection activities must be allocated to characterize the frequency and extent of blooms. Advanced technologies including continuous, fixed-station monitoring and continuous on-board monitoring are therefore 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 such as *Cochlodinium polykrikoides* which are known to cause harmful effects, though these may not be linked to the occurrence of specific toxins.

Algal blooms occurring in the Lower James River Estuary are ephemeral in nature and as of yet 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

¹ For management purposes the lower James River region is divided into segments using three defined salinity regimes based on average salinities: the oligohaline (0.5-5), mesohaline (>5-18) and polyhaline (>18).

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 Chesapeake Bay Program (CBP), is not designed to 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 and underway monitoring (DATAFLOW) of CHL_a can be used in conjunction with GPS navigation to provide real-time mapping of algal blooms (Fig. 1a). Presently this technology is employed by both VIMS (see www.VECOS.org for details) and the Hampton Roads Sanitation District (HRSD) in a program managed by William Hunley, to map spatial variation in CHL_a for the meso- and poly-haline segments of the James, Elizabeth and Lafayette Rivers and elsewhere. This method provides the most effective means for determining the size, intensity and location of algal blooms. The Panel recommended that these efforts should be expanded to include the oligohaline segment of the James River.

There is also a need to complement CHL_a mapping efforts with fixed-station, continuous monitoring (ConMon) to enhance temporal coverage and bloom detection capabilities (Fig. 1b). Specifically, It was proposed that CHL_a sensors be deployed in potential areas for bloom development. One site in the James River Mesohaline (JMSMH) segment was proposed using this protocol (Fig. 2).

The JMSMH location represents a region where algal blooms are often first observed either by initiation and/or hydrodynamic transport. At this site the impacts of bloom events on market-sized oysters have been evaluated by Dr. Kim Reese and her associates at VIMS (Subtask 2.1) for pathological damage due to digestive exposure to dinoflagellate cells. One Chesapeake Bay Program (CBP) segment, the James River Oligohaline (JMSOH), was proposed for sampling in 2012 using water quality mapping (DATAFLOW) sampling to complement other DATAFLOW sampling conducted by HRSD during that period.

An overall three-tiered framework was proposed for assessing the probability of impairment due to harmful algae in the Lower James River. In it CHL_a is routinely monitored

using fixed station and mapping approaches describe above. Additional samples were collected by VIMS and HRSD for toxicity bioassays when CHL_a levels exceeded 50 µg/L until July 18, 2012 when this level was adjusted to 100 µg/L for VIMS samples and 150 µg/L for samples from HRSD.. These samples were then to be analyzed by the Reece laboratory at VIMS to determine phytoplankton community composition and cell density (via microscopy and/or molecular-genetic approaches) and the presence of diagnostic pigments (via HPLC). The composition and density of the phytoplankton community were then to be used to assess system impairment based on field and laboratory research linking these levels to system impairment.

This Year 1 data report summarizes 2012 CHL_a monitoring data measured by VIMS and also monitoring data provided to VIMS by HRSD for the JMSOH, JMSMH, JMSPH, LAFMH and ELIPH segments (Figs. 2-5). These data are needed to help characterize the occurrence of blooms (e.g., timing, intensity, duration, spatial extent) in the Lower James River region using the latest and most state-of-the-art methods of monitoring and analysis. The overall goal is to provide information that is vital to undertaking a comprehensive review of the existing Site-Specific Numeric CHL_a) criteria for the tidal James River system. This effort provides measurements of Lower James River conditions that will provide the scientific basis for the potential water quality standards rulemaking process, which may result in revisions to nutrient allocations contained in the Chesapeake Bay TMDL.

Objectives and Scope of Project (Fulfilling Data Needs for Assessing Numeric CHL_a Criteria for the Lower James River Estuary, 2012. Subtask 1.1 – Expand Monitoring Network)

- 1) Collect data to be used in assessing numeric water quality standards for CHL_a, and to better quantify algal variability for assessment.
- 2) Collect data for diagnosing reasons for any non-attainment of these water quality criteria.
- 3) Collect data to improve overall understanding and modeling of processes influencing these water quality criteria.
- 4) Provide calibration data for refined James River Model simulations of water clarity and phytoplankton that will be completed over the next three years.

- 5) Provide continuous water quality data from a site in the JMSMH in conjunction with in situ plantings of oysters to assess biological impairments as they relate to the duration and intensity of exposure to bloom events.

Methods

DATAFLOW sampling in 2012 was conducted by VIMS in one Chesapeake Bay Program segment, the JMSOH. Collection of data from 0.25-0.5m below the surface was performed twice a month from May through June during one spring and one neap tidal period. During the most intensive bloom period of July-September the cruises were conducted weekly and twice monthly again in October. The DATAFLOW system (Fig. 1a) allowed for the continuous measurement of dissolved oxygen (DO), CHL_a, turbidity, salinity, specific conductivity, temperature, and pH while underway in a small boat. The data collected in any one day were then interpolated to provide a complete surface “map” of water quality conditions throughout the segment and then were compared against water quality criteria. Cruises took place during the mid day, over an approximate four to five hour interval beginning at approximately 0900 or 1000.



A.



B.

Figure 1. DATAFLOW (A.) and James River Mesohaline Continuous Monitoring (ConMon) (B.) Sampling Systems.

These JMSOH DATAFLOW cruises were conducted in coordination with similar mapping cruises conducted in meso- and poly-haline regions of the James, as well as the Elizabeth and Lafayette Rivers by HRSD. Both VIMS and HRSD have worked closely over the past number of years establishing identical methodologies, and the latest QA/QC procedures (Quality Assurance Project Plan for the Project: Fulfilling Data Needs for Assessing Numeric CHLa Criteria of the Lower James River Estuary, 2012) were submitted to and approved by DEQ.

The DATAFLOW system currently used by HRSD is modeled after the VIMS system, and companion mapping runs were initially conducted to assure comparability of measurements. All HRSD and VIMS DATAFLOW data and visualizations of the data are served on the Virginia Estuarine and Coastal Observing System (VECOS; www3.vims.edu/vecos) website and database for convenient use. All Lower James River quality assured mapping data collected by both VIMS and HRSD for 2012 will be similarly served on the VECOS site after approval by DEQ.

A total of five verification stations (Fig. 2, Table 1) were sampled from just below the surface, at the same depth as the sample intake, during each DATAFLOW cruise for CHLa, phaeophytin, total suspended solids (TSS) and volatile suspended solids (VSS). Vertical profiles DO, temperature, salinity, specific conductivity, and pH were measured by VIMS using a YSI 600 XLM sonde. HRSD measurements were taken at sub-surface only. Secchi depths and vertical profiles of photosynthetically available radiation (PAR) were measured using a LI-COR datalogger and associated quantum sensors by both teams. In addition, bloom samples were collected for phytoplankton enumeration by researchers at VIMS in the Reece laboratory and a subset of additional samples were collected for analysis at Old Dominion University. All sample collection cruises were coordinated between HRSD and VIMS sampling efforts.

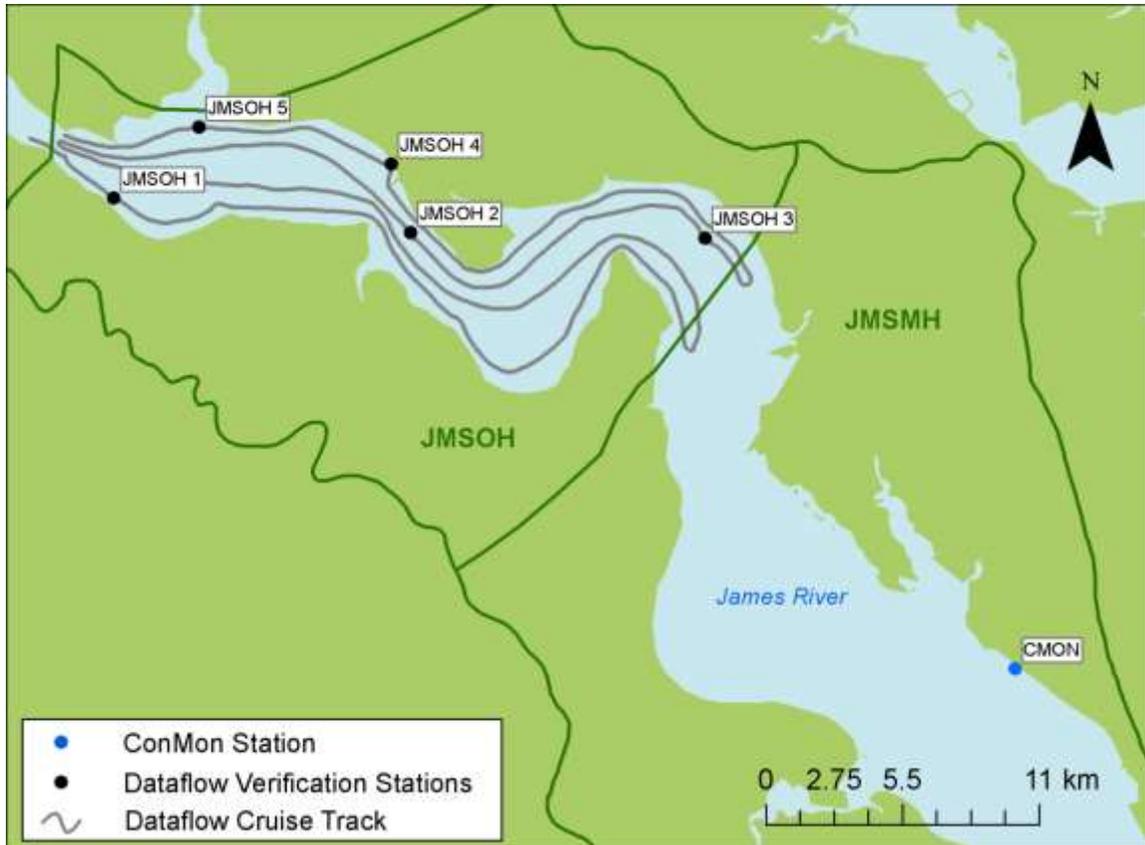


Figure 2. James River Oligohaline DATAFLOW Cruise track, verification sampling stations and Fixed Continuous Monitoring in James River Mesohaline segment.

Table 1. James River Oligohaline Verification station and James River Mesohaline ConMon station descriptions and locations.

Station Name 1	Station Name 2	Latitude	Longitude	Description
JMSOH 1	JMS050.74	37.21335	-76.9173	South shore at channel range marker
JMSOH 2	JMS042.92	37.20294	-76.78219	DEQ long term station at Swann's Point
JMSOH 3	JMS032.59	37.20297	-76.64833	DEQ long term station at near buoy 36
JMSOH 4	JMS043.78	37.22775	-76.79147	Jamestown 4H center (this use to be a CMON station for us)
JMSOH 5	JMS048.03	37.2398	-76.87915	North shore mouth of the Chickahominy
CMON	JMS017.96	37.04883	-76.5045	JMSMH CMON

One ConMon fixed station was established by VIMS in the JMSMH near the James River Country Club as described in the document (Fig. 1b). This station consisted of a YSI extended deployment datasonde (YSI 6600EDS V2), which sampled DO, CHL_a, turbidity, salinity, specific conductivity, temperature, and pH. Sondes were switched out at approximately two-

week intervals or as needed to minimize fouling. The station required two dedicated sondes for continuous measurements which were provided by VIMS. The ConMon sampling station was in place from May through October 2012. The station collected and telemetered its measurements at 15-minute intervals in real time and the real time information and graphs of data were available for viewing via the www.VECOS.org web site. Concomitant data and water samples were collected at these single point ConMon sites during the HRSD DATAFLOW mapping cruises and when the fixed station sonde was exchanged for maintenance by VIMS. Data collected for DATAFLOW verification stations and ConMon sonde exchanges included CHL_a, phaeophytin, TSS, VSS, and secchi depth. Vertical profiles of photosynthetically available radiation (PAR) were measured using a LI-COR datalogger and associated quantum sensors. In addition, vertical profiles of DO, temperature, salinity, specific conductivity, and pH using a YSI 600 XLM sonde were measured during the ConMon instrument exchange.

All data received QA/QC as described in the above QAPP document and ConMon data and visualizations will be provided on the VECOS web site and to DEQ after approval by DEQ. Additional bloom samples were taken during instrument exchanges or at other times as necessary for phytoplankton enumeration by the Reece laboratory. Samples of oysters deployed as sentinels near the ConMon station were also collected during bloom events.

The main objective of this program was to collect data of sufficient quantity and quality to assess James River standards for CHL_a. These data needed to be representative and comparable across all of the monitored tributaries. The greater spatial and temporal density of data which could be used to assess surface water quality criteria and standards was an important component and strength of this monitoring program. Another strength of this study was the comparability of data with that collected by HRSD for lower segments in the James River, as well as ongoing data collections by other Chesapeake Bay Monitoring Programs. Through the use of the same Chesapeake Bay Program and DEQ approved protocols, instrumentation, quality control checks, and communication, an integrated net of data was generated for this system.

DATAFLOW Mapping System

The DATAFLOW system, which was developed by VIMS, consisted of a flow-through design that measures water quality using a YSI 6600 datasonde, a Garmin GPS/depth unit, and

integrating software. This system has been used to measure surface water quality by taking water quality point measurements during monthly cruises typically representing a single Chesapeake Bay Segment. DATAFLOW is a compact, self-contained surface water quality mapping system, suitable for use in a small boat operating at speeds of about 25 KT (Fig. 1a). The system collected water through a pipe ("ram") deployed on the transom of the vessel, pumps it through an array of water quality sensors, and then discharges the water overboard. The entire system from intake ram tube to the return hose was shielded from light to negate any effect high intensity surface light might have on phytoplankton in the flow-through water that is being sampled. A blackened sample chamber was also used to minimize any effect of light on measurements by the fluorescence probe.

Area of Operations, Cruise Tracking, and Sample Frequency

The area of DATAFLOW operations by VIMS personnel (Fig. 2) included the JMSOH. This area is included in the EPA Chesapeake Bay Program Office's designated Chesapeake Bay segments (see www.chesapeakebay.net/pubs/segmentscheme.pdf for description of CBP segments). Operations followed different cruise tracks depending on the morphology of the segment being monitored and the amount of navigable shallow water. In the lower segment of the river, where the width of the river is normally wide, a series of tracks running parallel to the shoreline along fixed depth contours was followed. For example, the track followed the shoreline down river along the ≤ 2 meter depth contour, then up river along a mid depth contour (approximately 5 meters), then down river along the channel (>10 meters depth), then finished up along the other shoreline in the shallows.

HRSD personnel conducted similar cruises in the James River Mesohaline (Fig. 3) and Polyhaline (Fig. 4) (JMSMH and JMSPH) segments, Elizabeth River Polyhaline and Lafayette Mesohaline segments (Fig. 5) (ELIPH and LAFMH). VIMS personnel associated with this project previously assisted HRSD personnel in the construction and operation of their DATAFLOW system and simultaneous operation of both systems has been conducted to assure that they are operating similarly. Results of some of their monitoring efforts are reported here.



Figure 3. James River Mesohaline DATAFLOW Cruise track and verification sampling stations.

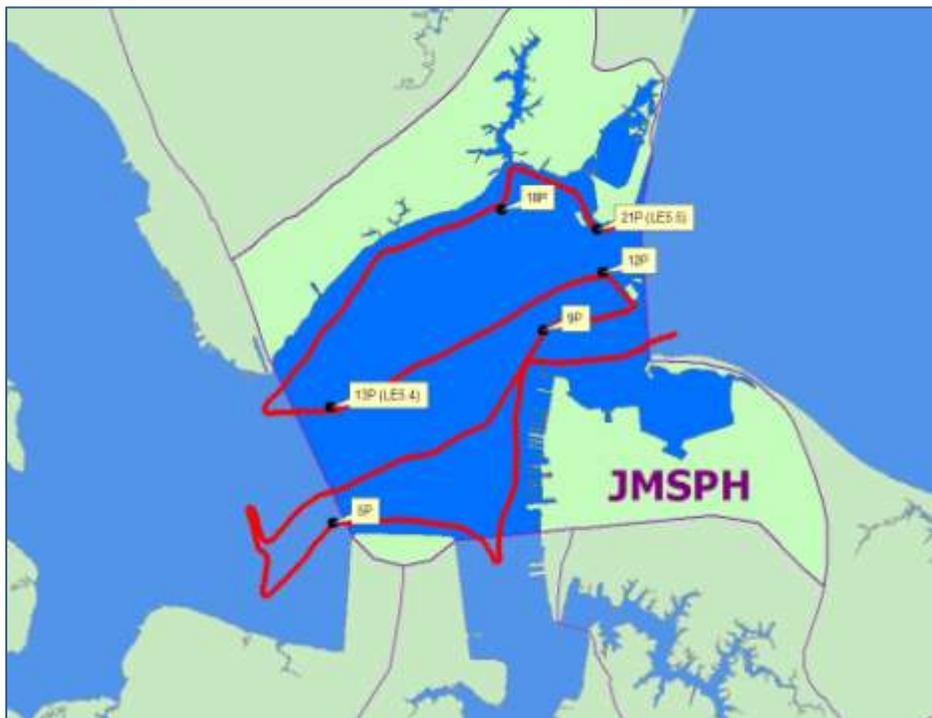


Figure 4. James River Polyhaline DATAFLOW Cruise track and verification sampling stations.

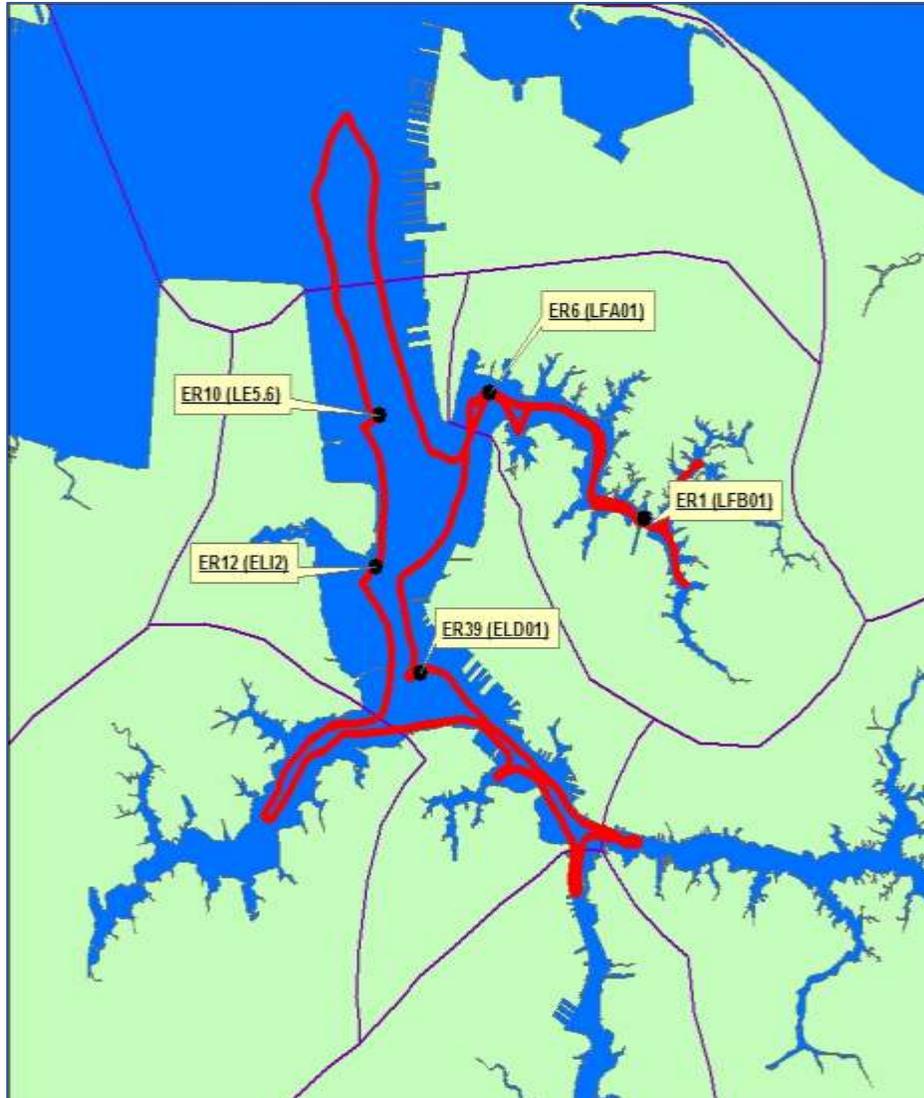


Figure 5. Lafayette Mesohaline and Elizabeth Polyhaline DATAFLOW Cruise track and verification sampling stations.

The DATAFLOW mapping system collected a sample once every 3-4 seconds. The resulting distance between samples is therefore a function of vessel speed. Vessel speeds varied throughout the cruises depending on depth of water, navigational hazards, weather conditions and the slowing of the vessel approaching or leaving verification stations. Average speed underway was typically 20 knots, which resulted in an observation collected every 30 meters. As speeds decreased samples were taken closer together, but for the most part when underway between the speeds of 10-20 knots samples occurred every 15-30 meters.

Water Quality Instrumentation

The DATAFLOW system utilized either an YSI 6600EDS (VIMS) or YSI 6600EDS V2 (HRSD) sonde equipped with a flow-through chamber. The sensors included a Clark-type 6562 DO (VIMS) probe or a ROX 6150 Optical DO (HRSD) probe, a 6561 pH probe, a 6560 conductivity/temperature probe, a 6136 turbidity probe, and a 6025 chlorophyll probe. The sonde transmitted data collected from the sensors directly to a ruggedized laptop computer (Panasonic Toughbook) using a data acquisition system created with LabView software (National Instruments, Inc.). Custom software written in the LabView environment provided for data acquisition, display, control, and storage. Real-time graphs and indicators provided feedback to the operator in the field; ensuring quality data were being collected. All calibrations and maintenance on the YSI sondes were completed in accordance with the YSI, Inc. operating manual methods (YSI 6-series Environmental Monitoring Systems Manual; YSI, Inc. Yellow Springs, OH).

The fixed ConMon station utilized the YSI 6600EDS V2 equipped with the Clean Sweep Extended Deployment System (EDS) and with sensors including a ROX 6150 Optical DO probe, a YSI 6560 conductivity/temperature probe, a 6561 pH probe, a 6136 turbidity probe, and a 6025 chlorophyll probe. The EDS was comprised of a brush that at set intervals would sweep across the sensors to dislodge any fouling organisms or material that had settled on the sensors. This feature ensured better quality data over longer deployment periods in areas with high fouling rates. The YSI ROX 6150 DO probe utilized the luminescence-lifetime technique to provide DO measurements which were less likely to be affected by fouling or low DO environments.

Verification Sampling

Field verification samples for pH, salinity, DO and temperature were taken during the ConMon deployment/retrieval procedure with a YSI 6920 sonde. Water samples at the depth of the instrumentation were taken when the YSIs were switched out for TSS, VSS, CHL_a and phaeophytin. CHL_a and phaeophytin water samples were immediately filtered and filters were folded, wrapped in foil and stored in sterile Whirlpak bags. These were then packed on ice and returned to the laboratory where they were stored at -20°C. Samples for TSS and VSS were

packed on ice and returned to the laboratory where they were filtered immediately upon return and frozen. Samples were then delivered to the VIMS Analytical Service Center (ASC) for further processing. At these stations secchi depth, a vertical profile of photosynthetically available radiation (PAR), as well as a vertical profile for temperature, DO, conductivity, salinity and pH were also conducted. Details on the procedures were provided in the 2012 QAPP document previously submitted to DEQ (VIMS 2012).

The data being gathered by the original YSI 6600EDS V2 were also verified by placing the newly calibrated and cleaned YSI 6600EDS V2 into the water beside it for a 20 minute time period at the end of its deployment. The two data sets were then compared to determine that the YSI sondes were functioning correctly.

Analyses

To determine CHL_a (corrected for phaeophytin) for the individual 15-minute measurements made at the JMSMH ConMon station, the chlorophyll pre-calibration concentrations (measured as fluorescence by the YSI 6600EDS V2) were used in a linear regression model of pre-calibration chlorophyll to extracted CHL_a using verification samples taken from the combined Lower James River segments (JMSPH, JMSMH, ELIPH, LAFMH). The 2012 daily mean, minimum, and maximum CHL_a values for the JMSMH ConMon station were then calculated.

The datasets from each DATAFLOW cruise resulted in spatially dense sets of point samples, where each point represented a measured water quality value (pre-calibration chlorophyll measured by fluorescence) and the associated location (latitude and longitude). To analyze the DATAFLOW data, pre-calibration chlorophyll measurements were interpolated for each cruise across the associated segment using the kriging function in the Geostatistical Analyst (included in the ArcMap software). The default software settings were used except for those that were manipulated as included in Table 2. The results of the interpolations were stored in a grid format, where each 25 m² cell contained a value for pre-calibration chlorophyll.

Table 2. Geostatistical Analyst Settings

Method Type	Ordinary Kriging
Model Type	Spherical
Max Sample Points	25 / Sector
Min Sample Points	2
Neighborhood Sectors	4
Account for Anisotropy	Yes

Segment specific regression models of pre-calibration chlorophyll to extracted CHL_a were used To determine CHL_a (corrected for phaeophytin) from the DATAFLOW interpolation results. These regressions were applied to the interpolation results on a cell-by-cell basis to calculate a CHL_a surface for each cruise (Fig. 6 & 7). Monthly mean CHL_a surfaces were calculated and compared to seasonal CHL_a criteria (Table 3). CHL_a surfaces were also compared to CHL_a thresholds of 10, 20, and 40 $\mu\text{g l}^{-1}$ on a cell-by-cell basis for simpler visualizations. The percent of total interpolated area for each DATAFLOW cruise was then calculated where corrected CHL_a equivalent values were below each threshold or criteria. The CHL_a regression modelse were also applied to the DATAFLOW pre-calibration chlorophyll measurements prior to interpolation for boxplot visualizations

Table 3. James River Seasonal Chl_a Criteria (Spring-March 1-May 31; Summer- July1-Sept 30)

Segment	Seasonal Mean Criterion ($\mu\text{g l}^{-1}$) Spring/Summer
James River Oligohaline (JM SOH)	15/22
James River Mesohaline (JM SMH)	12/10
James River Polyhaline (JM SPH)	12/10

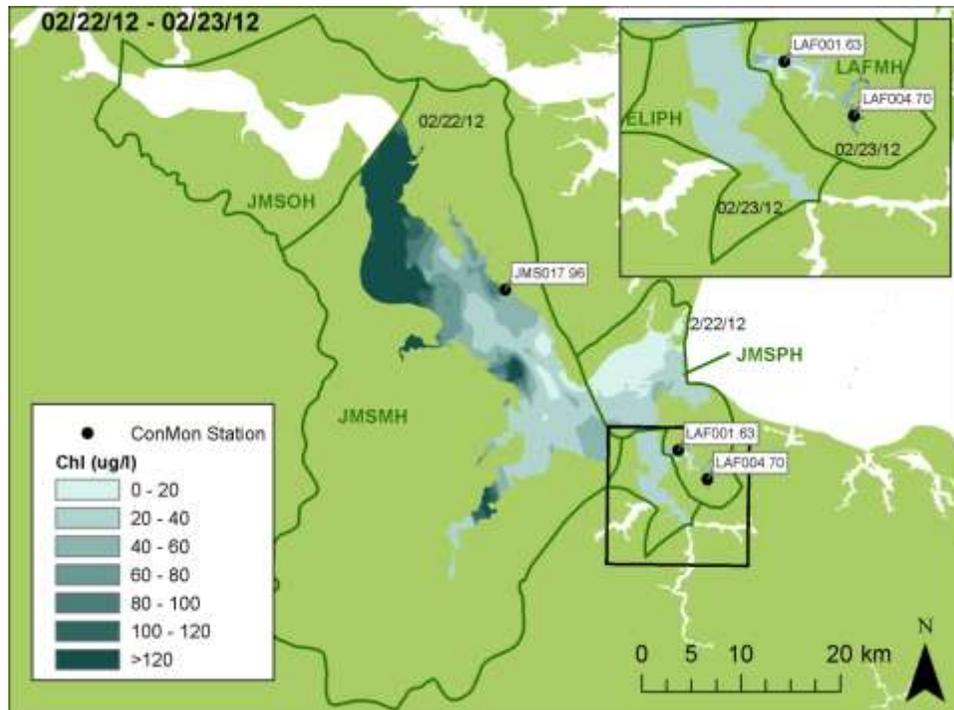


Figure 6. Spatially interpolated CHL_a sampled over two days in the lower James River during a spring CHL_a bloom event dominated by *Heterocapsa triquetra*. JMSOH did not begin to be sampled until May 14th, 2012.

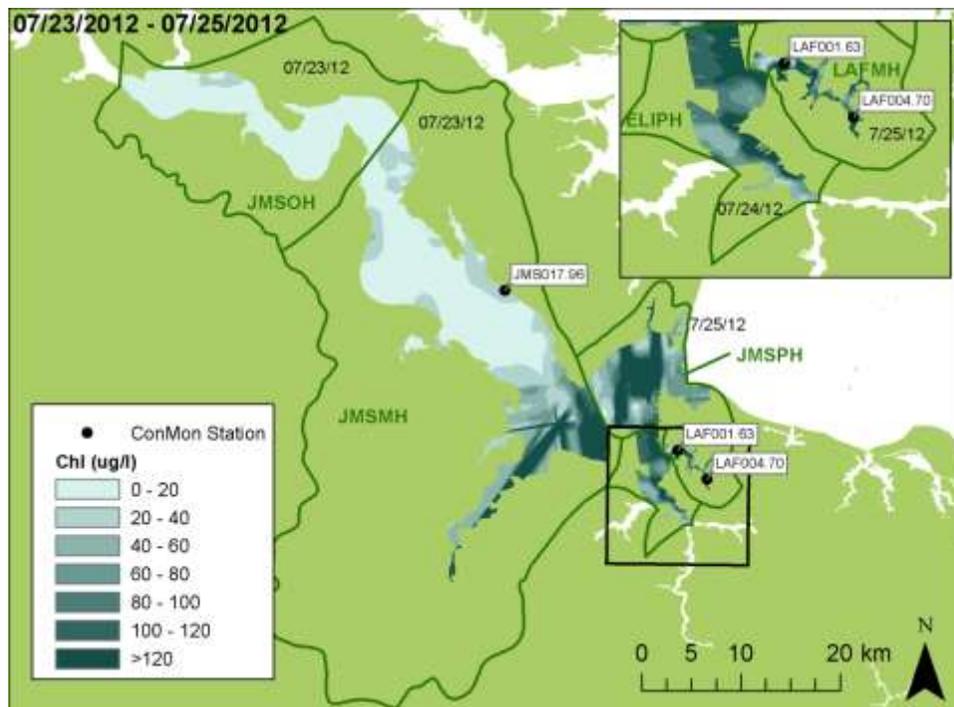


Figure 7. Spatially interpolated lower James River during a summer CHL_a bloom event dominated by *Cochlodinium polykrikoides*

Results

Due to late funding approval, the JMSOH segment was not sampled before May 2012, therefore the February-March period of the spring bloom which has been typically dominated by *Heterocapsa triquetra* was not sampled in this segment in 2012 (Fig. 6). Overall, from May until October 2012 the concentrations of CHL_a were relatively low (Fig. 8) with some evidence of bloom occurrence in this region in August (concentrations up to 300 µg l⁻¹). Typically, less than 10% of the segment waters exceeded 10 µg l⁻¹ CHL_a (Fig. 9), less than 5% exceeded 20 µg l⁻¹, and bloom areas exceeding 40 µg l⁻¹ were only observed during August when they covered only 1-2 percent of the segment area.

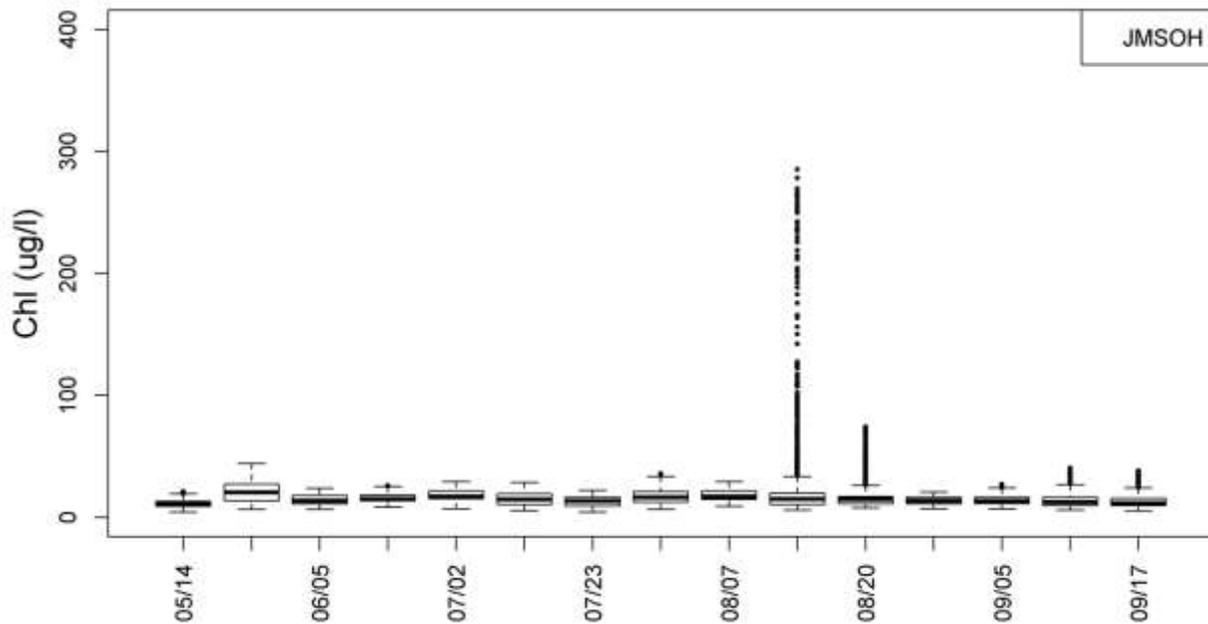


Figure 8. CHL_a (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Oligohaline segment (JMSOH) from May to October 2012.

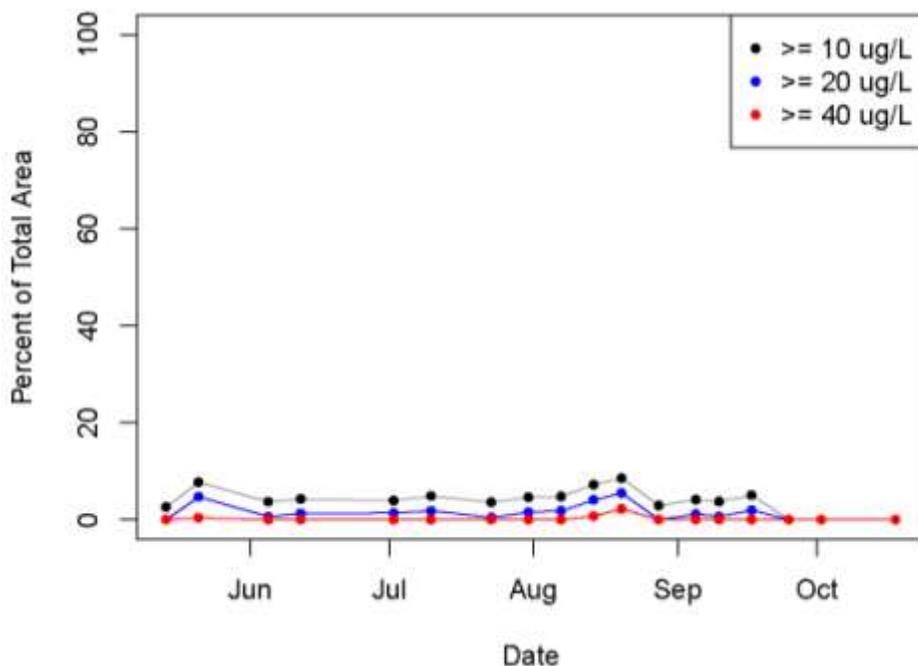


Figure 9. Integrated percent of total water surface area in James Oligohaline (JM SOH) segment that is greater than or equal to CHLa concentration on each sampling date in 2012.

CHLa concentrations in the JMSMH segment showed evidence of bloom formation lasting four weeks or more in both the spring and summer (Fig. 10). In the late winter and early spring segment median bloom concentrations here were typically $25 \mu\text{g l}^{-1}$ or less, although individual measurements within bloom patches exceeded $300 \mu\text{g l}^{-1}$. Segment-wide the bloom concentrations exceeding $40 \mu\text{g l}^{-1}$, covered approximately 18% of the segment area during March and 20% during August (Fig. 11). An additional 2-3% of the segment area had blooms of concentrations between 20 and $40 \mu\text{g l}^{-1}$ and an additional 1-2% had concentrations between 10- $20 \mu\text{g l}^{-1}$. Blooms of *Cochlodinium polykrikoides* and other species during August reached their maximum during one weekly cruise period in August (Fig. 11). The continuous monitoring sampling record (Fig. 12) for the ConMon station in this segment paralleled the temporal pattern of the DATAFLOW spatial sampling. The maximum daily mean concentrations at the ConMon site during the July-August bloom event approached $20 \mu\text{g l}^{-1}$ and were similar to the median concentrations sampled by dataflow cruises during that period (Fig. 10). These measurements highlight and quantify both the spatial (Fig. 7) and temporal (Figs. 10, 11, and 12) variability in the blooms with daily mean concentrations at one site varying from 20- $30 \mu\text{g l}^{-1}$ from one day to the next (Fig. 12), or daily maximum and minimum measurements varying up to $100 \mu\text{g l}^{-1}$.

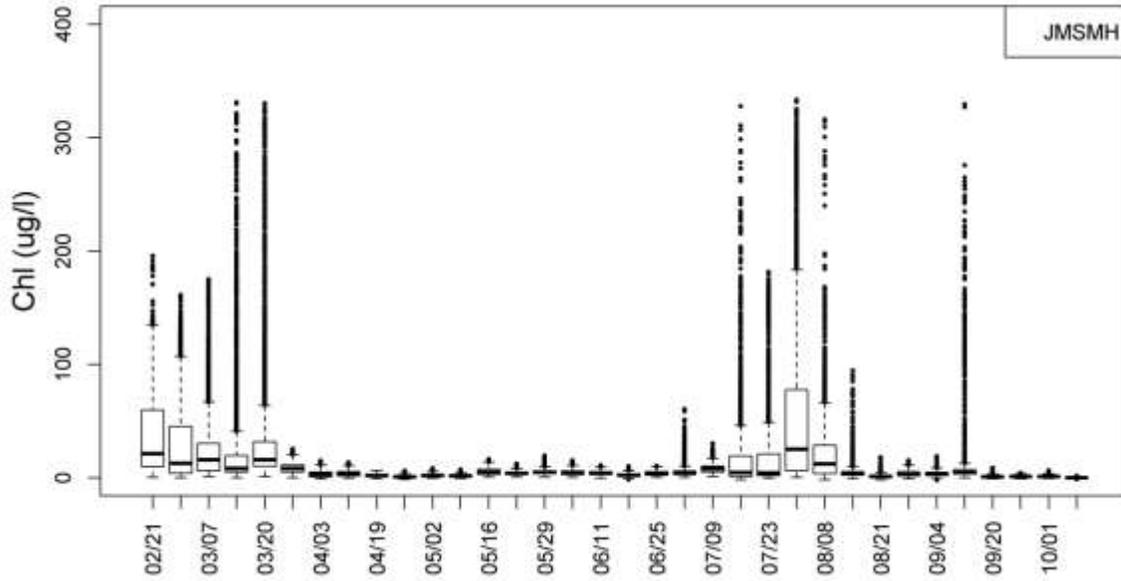


Figure 10. CHL_a (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Mesohaline segment (JMSMH) from February to October 2012. Data courtesy of HRSD.

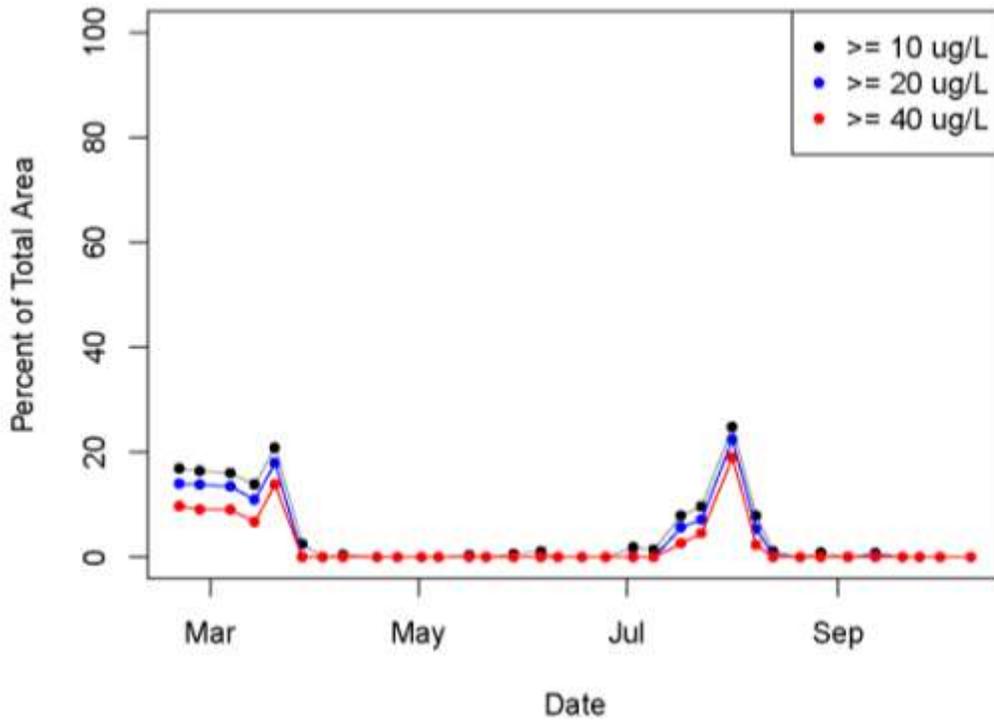


Figure 11. Integrated percent of total water surface area in James Mesohaline (JMSMH) segment that is greater than or equal to CHL_a concentration on each sampling date in 2012. Data courtesy of HRSD.

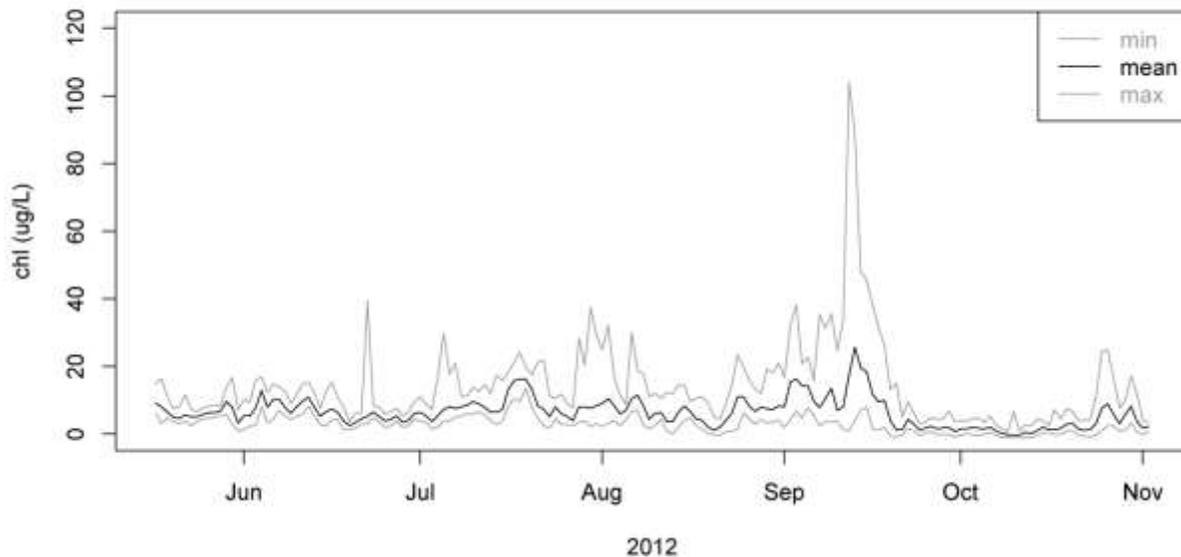


Figure 12. Daily minimum, maximum and mean CHLa concentrations at the James River Mesohaline continuous monitoring (ConMon) station. May to October 2012.

The spring bloom dominated by *Heterocapsa triquetra* did not generally affect a large area of the JMSPH segment (Figs 6, 13 and 14) with less than 10% of the segment area exceeding $10 \mu\text{g l}^{-1}$ during any one cruise and no measurable area exceeding $20 \mu\text{g l}^{-1}$ during February and March of 2012. Late summer *Cochlodinium polykrikoides* dominated bloom intensities in the JMSPH segment where CHLa concentrations were markedly greater than upriver areas of the mainstem during the period extending from mid-July to mid-August (Figs. 7, 13 and 14). Median concentrations measured over the entire segment area reached $\sim 25 \mu\text{g l}^{-1}$ during August with individual patches exceeding $300 \mu\text{g l}^{-1}$. During the period of maximum bloom intensity in late July, $\sim 60\%$ of the segment area exceeded $40 \mu\text{g l}^{-1}$ (Fig. 14) with nearly 80% of the surface area exceeding the $10 \mu\text{g l}^{-1}$ CHLa standard.

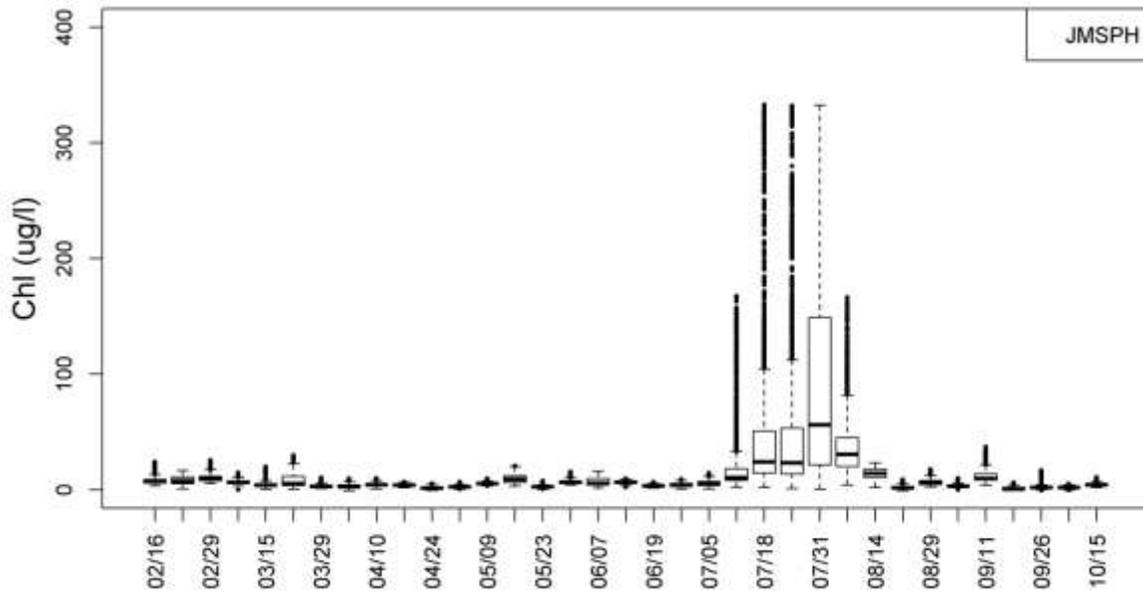


Figure 13. CHLa (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Polyhaline segment (JMSPH) from February to October 2012. Data courtesy of HRSD.

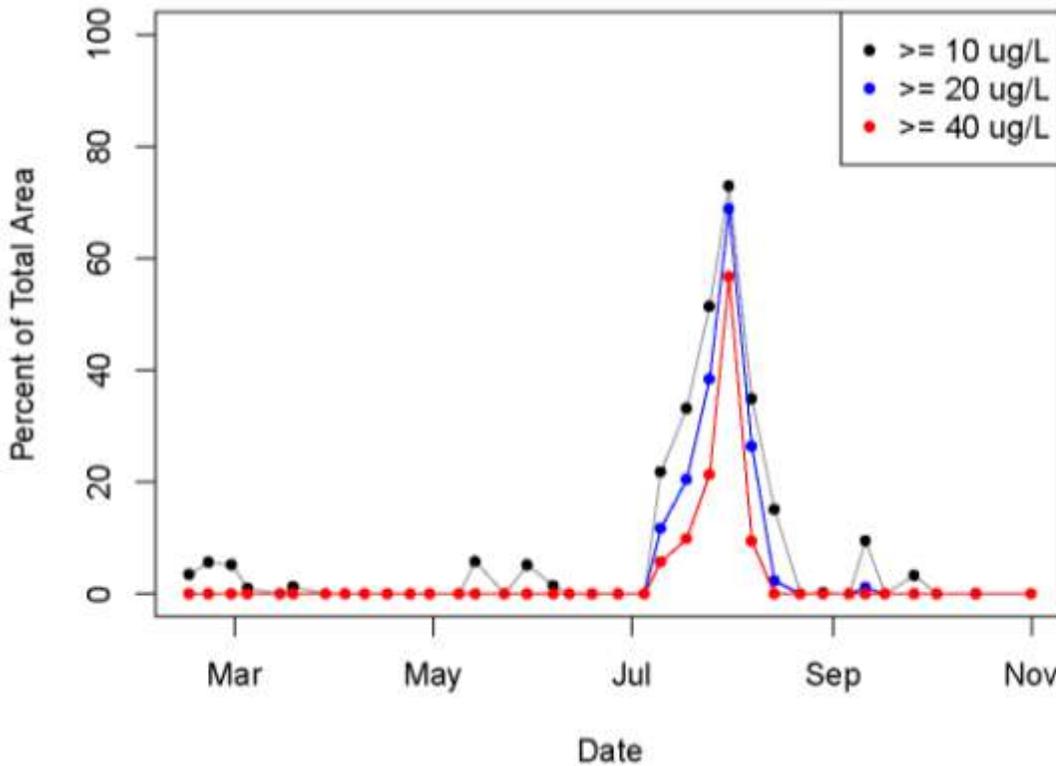


Figure 14. Integrated percent of total water surface area in James Polyhaline segment (JMSPH) that is greater than or equal to CHLa concentration on each sampling date in 2012. Data courtesy of HRSD.

Increased bloom intensity in the lower ELIPH segment was observed beginning in mid-June and continuing until mid-August (Fig. 15). Segment median concentrations typically exceeded $30 \mu\text{g l}^{-1}$. During July-August 60-80% of the segment had concentrations exceeding the $10 \mu\text{g l}^{-1}$ standard (Fig. 16) with over 40% of the segment area having concentrations exceeding $40 \mu\text{g l}^{-1}$ during maximum bloom occurrence in August.

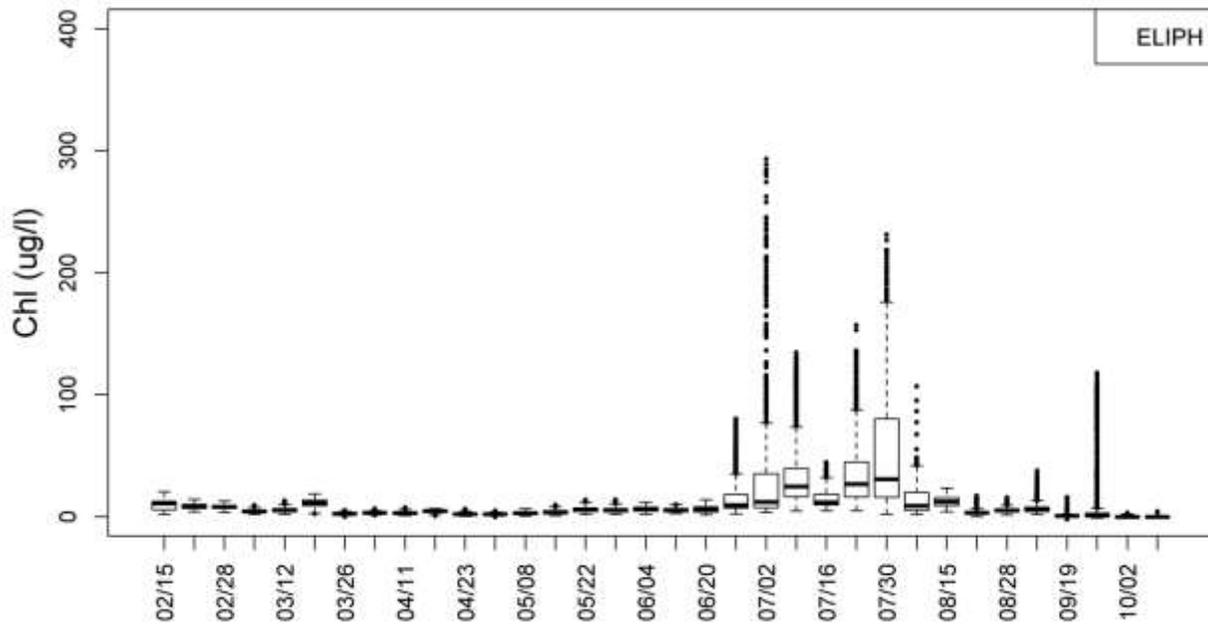


Figure 15. CHL*a* (median median, 25th and 75th percentiles are in box, whiskers appear at 1.5 times IQR and the outliers are represented by points out to the minimum and maximum values) for the Elizabeth River Polyhaline segment (ELIPH) from February to October 2012. Data courtesy of HRSD.

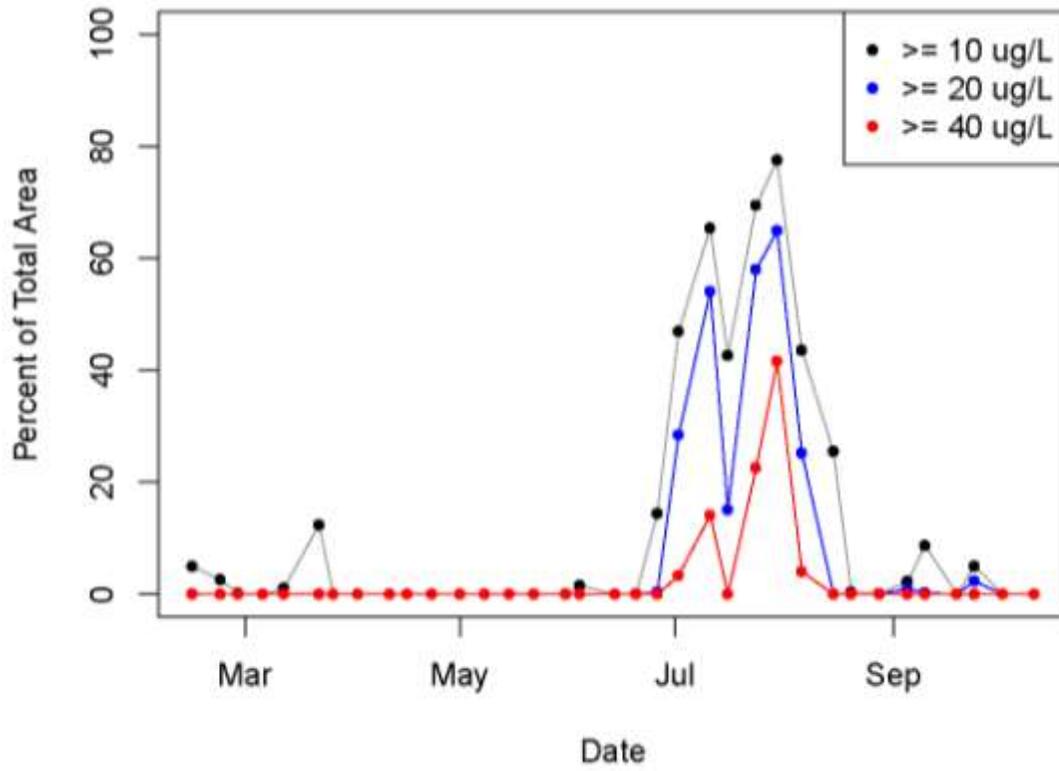


Figure 16. Integrated percent of total water surface area in Elizabeth Polyhaline segment (ELIPH) that is greater than or equal to CHLa concentration on each sampling date in 2012. Data courtesy of HRSD.

Summertime CHL_a concentrations in the LAFMH segment were highest and of longest duration of all the segments sampled, and the summer bloom occurrence was first observed there (Figs. 17, 18). CHL_a increases were first observed in June and elevated levels continued until mid-September. During the period of mid-July to Mid-August median concentrations of 40 $\mu\text{g l}^{-1}$ or more were recorded with individual measurement exceeding 300 $\mu\text{g l}^{-1}$. For much of the entire March to October sampling period CHL_a concentrations exceeding 10 $\mu\text{g l}^{-1}$ covered at least 20% of the segment (Fig. 18), with ~60% of the segment exceeding this concentration threshold during much of the mid-July to Mid-August period. Forty percent of the segment area had blooms exceeding 40 $\mu\text{g l}^{-1}$ during numerous cruises in July and August (Fig. 7).

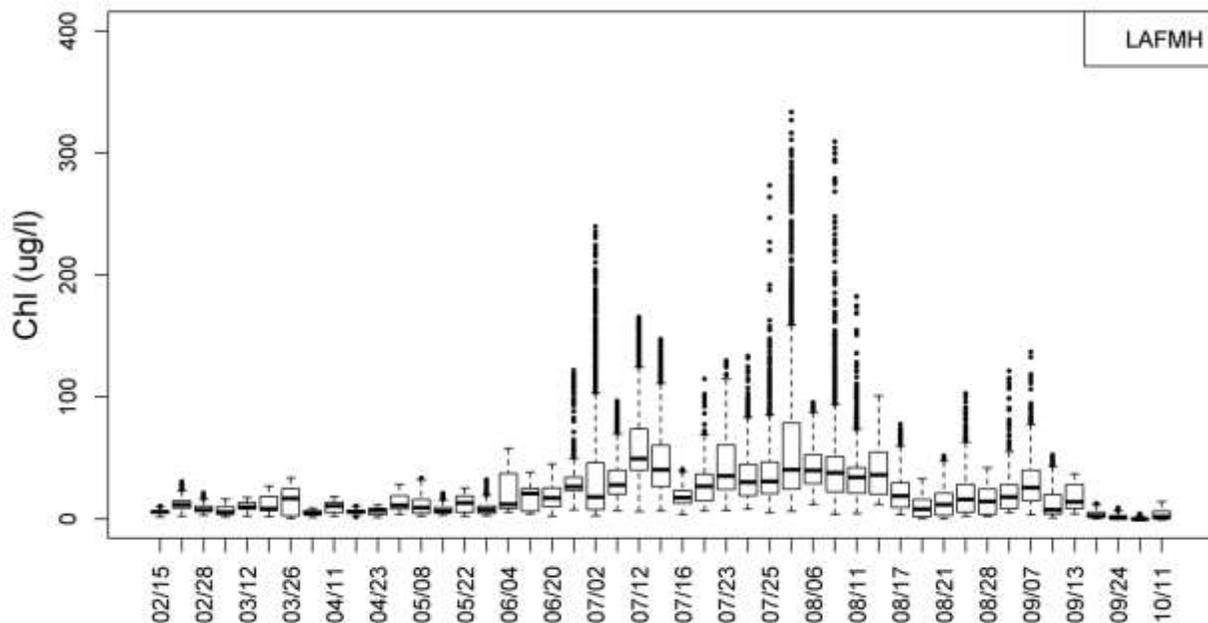


Figure 17. CHL_a (median, 25th and 75th percentiles are in box, whiskers appear at 1.5 times IQR and the outliers are represented by points out to the minimum and maximum values) for the Lafayette River Mesohaline segment (LAFMH) from February to October 2012. Data courtesy of HRSD.

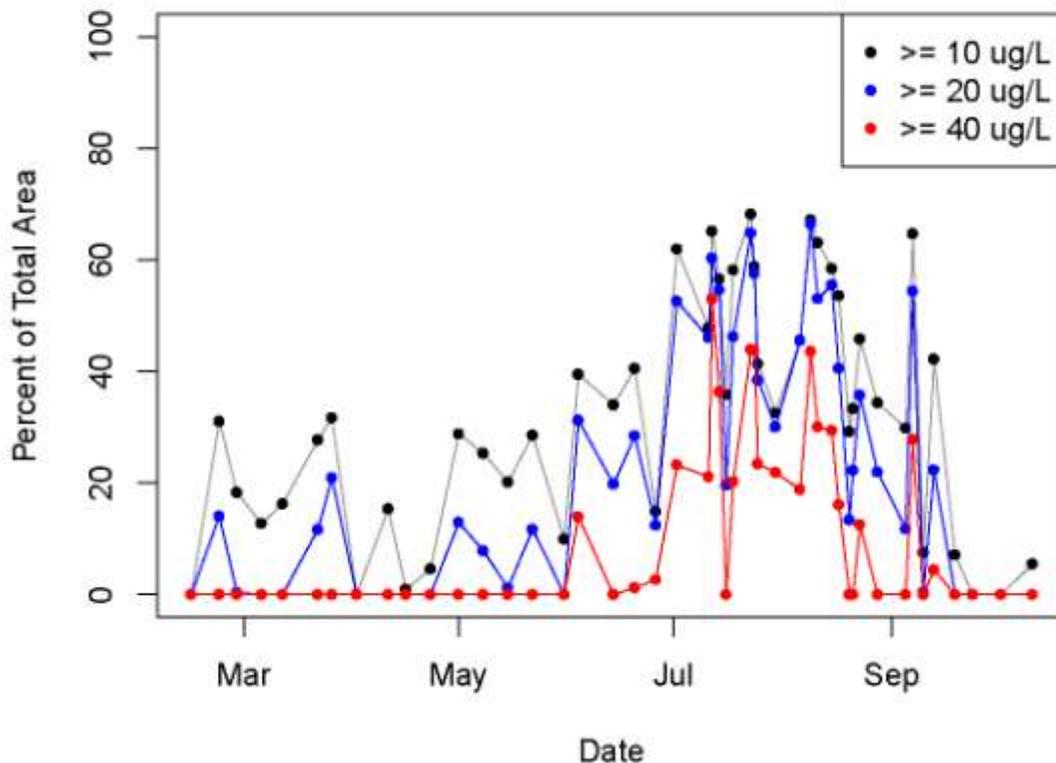


Figure 18. Integrated percent of total water surface area in Lafayette Mesohaline segment (LAFMH) that is greater than or equal to CHLa concentration on each sampling date in 2012. Data courtesy of HRSD.

Discussion/Conclusions

Significant phytoplankton blooms exceeding James River numeric CHLa criteria (Tables 3 and 4) were observed in the Lower James River and its tributaries throughout 2012. Use of DATAFLOW monitoring data generated by HRSD in addition to the VIMS monitoring funded by DEQ enabled us to evaluate the magnitude, duration and frequency of blooms for much of the year.

A spring bloom, dominated by *Heterocapsa triquetra*, was centered in the JMSMH for 4-5 weeks during late February and early March of 2012. Although the segment was not monitored during this period, surface maps of CHLa suggest that this spring bloom extended into the JMSOH as well (Fig. 6). It is unknown if this will vary from year-to-year depending on river

flow as higher turbidities upriver will likely limit the bloom extent in the JMISOH. The spring bloom areas were patchy and individual patches were quite dense with concentrations reaching 100-300 $\mu\text{g l}^{-1}$, however the integrated data indicate the total JMSMH area exceeding the spring criteria was less than 13% of total segment area during March with virtually no areas of exceedence in April and May (Table 4). Further analysis could quantify the exceedences across the spatial extent of the segment; as patterns of circulation and wind likely affect the bloom distribution and persistence within the segment and determine how effective the existing long term Bay monitoring stations are in capturing the bloom event.

Table 4. Mean Monthly Percent Areas Exceeding James River (JMISOH, JMSMH, JMHPH) Seasonal CHL_a Criteria. Elizabeth River Polyhaline (ELIPH) and Lafayette Mesohaline (LAFMH) Exceedences Are Based on James River Mesohaline and James River Polyhaline Segment Criteria Respectively. Note that ELIPH and LAFMH will not be included in VA assessment, but included here for comparison purposes. ND – Not Determined.

Segment	Spring			Summer		
	Mar	Apr	May	Jul	Aug	Sep
ELIPH	1.4	0.0	0.0	60.4	17.4	4.0
LAFMH	18.3	2.9	18.9	52.6	47.8	25.2
JMSPH	0.1	0.0	1.3	35.8	12.6	3.2
JMSMH	12.7	0.0	0.1	5.2	6.9	0.2
JMISOH	ND	ND	3.7	0.7	2.5	0.6

CHL_a standards were exceeded in the LAFMH segment from March through May in up to 19% of the segment area (Table 4). The summer bloom, dominated by *Cochlodinium polykrikoides*, was first observed in the Lafayette River in June, where bloom duration was greatest of all areas monitored in the Lower James River region. This suggests that the bloom may originate in the LAFMH segment and then spread to other areas in the Lower James, or that conditions that were possibly a result of system hydrodynamics and nutrient loading, caused it to bloom in the summer earlier than other areas. Significant exceedences were observed in the summer with approximately 25 to 53 percent of the LAFMH segment area exceeding the standards from July through September. Given this long duration and extent of bloom formation, this tributary is likely to be the most greatly impacted by bloom effects of all the segments monitored.

The late summer bloom occurrence in the JMSPH and JMSMH segments was progressively later and of shorter duration, intensity and distribution than in the LAFMH and ELIPH. Again this may be due to later bloom initiation, movement of blooms from areas of initial formation in the tributaries into the mainstem of the river, or both. Reduced bloom coverage and intensity in the JMSPH could be related to the larger segment area and water residence times in the other Lower James River segments. At maximum bloom development in the ELIPH and JMSPH, concentrations exceeding criteria extended over 50% of segment areas which suggests the potential for significant impacts for resources there. Summer bloom extent in the JMSMH was concentrated in the most downstream segment areas during 2012. Here, concentrations at the continuous monitoring station reached over $100 \mu\text{g l}^{-1}$ and approximately 35% of the segment exceeded the summer criteria in July (Table 4). This suggests that at least a part of this segment may have the potential for effects from summer blooms.

With only one year of measurement it is difficult to say if these patterns are either typical or unusual. However the results here suggest that infrequent single point measurements at fixed locations as have been done in the past for tributary monitoring will provide only the most basic estimate of bloom intensity, frequency and duration for the lower James River and may not be very representative of the conditions the living resources experience.

To highlight a more integrative assessment of Chl *a* attainment, we have taken the results of the DATAFLOW integrated water quality mapping data and used them to develop cumulative frequency distribution (CFD) criteria exceedence curves for comparison with a 10% default reference exceedence curve (EPA 2007) for Chl *a* for the spring (March–May; Fig. 19) and summer (July–September; Fig. 20) 2012 attainment periods for the mainstem JMSOH, JMSMH and JMSPH segments. Chl *a* criteria used to determine exceedence are presented in Table 3. For the spring attainment period of 2012 (Fig.19) the JMSPH segment fell well below the CFD reference curve, indicating that there were no measureable exceedences of the criteria in space or time. During only one cruise did Chl *a* concentration over a portion (approximately 15%) of the JMSPH surface waters exceed the criteria limit of $12 \mu\text{g/l}$. There were insufficient cruises in the JMSOH during the spring to evaluate that segment.

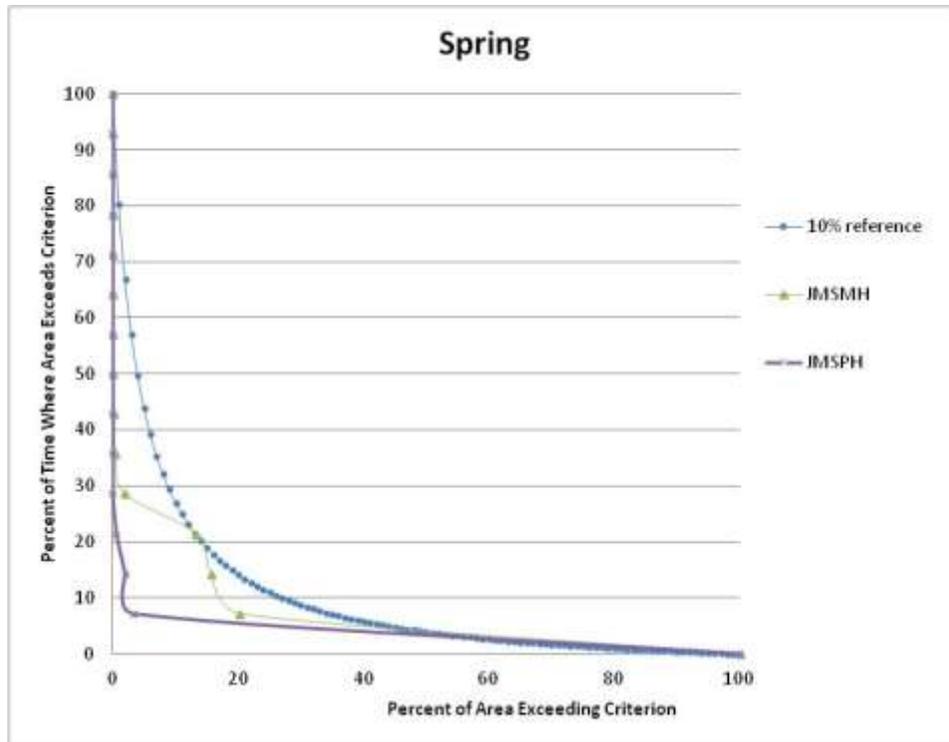


Figure 19. Cumulative Frequency Distribution exceedence plots of spring (March-May) 2012 exceedences of CHLa standards for the JMSMH and JMSPH segments compared to 10% temporal and spatial exceedence reference curve.

For the summer assessment period of 2012 CFDs for both the JMSPH and JMSMH segments fell below the reference curve indicating low exceedences in both space and time. In contrast, high concentrations of Chl *a* in the mainstem JMSPH segment during the summer period of 2012 are quantified by the high exceedences in both space and time in that area which are well beyond the defined 10% allowable exceedence.

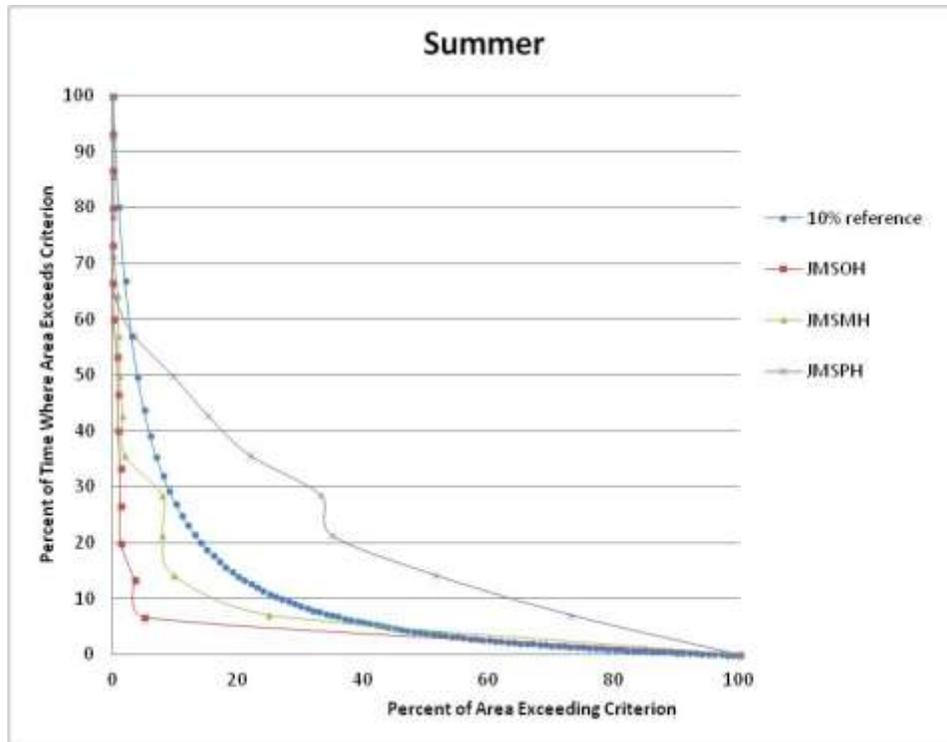


Figure 20. Cumulative Frequency Distribution exceedence plots of spring (July-September) 2012 exceedences of CHLa standards for the JMSOH, JMSMH and JMSPH segments compared to 10% temporal and spatial exceedence reference curve.

Further analyses will be needed to relate bloom intensity and dynamics to phytoplankton species abundances, environmental factors favoring bloom development and persistence throughout the lower James River system as well as bloom intensity/duration and ecosystem effects. Also, results of in situ environmental measures of system health ongoing in 2012 will need to be further evaluated to determine if these directly measured exceedence curves can be used to develop biologically-based reference curves for this region. Finally, the fixed and continuous monitoring results provided here will need to be compared to model simulations of conditions there to determine the capacity of the improved James River models to depict the duration, intensity and distribution of bloom events. Further monitoring will likely be needed to determine if patterns observed in 2012 are replicated in other years and under other climatic and river conditions.

Literature Cited

Environmental Protection Agency 2007. Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries. 2007 Addendum. July 2007. U.S. Environmental Protection Agency Region III, Chesapeake Bay Program Office, Annapolis, Maryland.