

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

Subtask 1.1-Expand Monitoring Network

Draft 2013 Annual Grant Data Report

Submitted to

The Virginia Department of Environmental Quality
Agency Award Number: 15427

by

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May 2014

2013 Key Findings

- Phytoplankton blooms exceeding seasonal James River numeric CHL_a criteria were observed in the Lower James River and its major tributaries throughout 2013 although levels in the mainstem James River segments were much lower in 2013 compared to 2012.
- James River Oligohaline (JM_{SOH})
 - Lowest CHL_a levels were observed in the JM_{SOH} segment of all the lower James river segments monitored in 2013.
 - Less than 10% of the surface area had CHL_a concentrations exceeding 10 µg l⁻¹ during the period.
- James River Mesohaline (JM_{SMH})
 - A strong spring bloom of *Heterocapsa triquetra* lasting from February until April 2013 was centered in this segment.
 - During peak periods in March bloom concentrations exceeding 40 µg l⁻¹ covered less than 20% of the open water area.
 - The spring bloom was slightly greater in intensity than observed in 2012, although the bloom distribution into the JM_{SOH} and JM_{SPH} segments was less.
 - Approximately 17.6% of the JM_{SMH} exceeded the existing standard of 12 µg l⁻¹ during March 2013. This was up from 12.7 µg l⁻¹ during March of 2012.
 - Summertime bloom concentrations in August and September 2013 were lower than in 2012 with <10% of the surface area exceeding the 12 µg l⁻¹ standard.
 - Cumulative Frequency Distribution (CFD) plots of the summer seasonal criteria (10 µg l⁻¹) showed that exceedences were below a 10% reference curve for allowable exceedences during that time.
 - Continuous measurements of salinity at the ConMon monitoring station indicated that salinities were consistently lower in 2013 compared to the same periods in 2012. These lower salinities suggest higher river flows and potentially lower residence times for bloom development in 2013.
- James River Polyhaline (JM_{SPH})
 - As in 2012 the spring bloom dominated by *Heterocapsa triquetra* did not generally affect a large area of the JM_{SPH} segment with less than 10% of the segment area exceeding 10 µg l⁻¹ during any one cruise, and no measurable areas exceeding 20 µg l⁻¹ during the spring period of 2013
 - Late summer *Cochlodinium polykrikoides* dominated bloom intensities in the JM_{SPH} segment were greatly reduced compared to 2012 and not generally present until September.

- Mean monthly percent of area that exceeded the existing summer standard was less than 10% for July, August and September.
During the period of maximum bloom intensity in late July, <10% of the segment area exceeded $40 \mu\text{g l}^{-1}$. This was in contrast to approximately 60% of total surface area exceeding $40 \mu\text{g l}^{-1}$ during one cruise in 2012.
- Elizabeth River Polyhaline (ELIPH)
 - During March and April 2013, approximately 15% of the segment had concentration exceeding the $12 \mu\text{g l}^{-1}$ standard.
 - *Cochlodinium polykrikoides* dominated summer blooms in the lower ELIPH segment were not evident until mid-August.
 - Bloom intensity and distribution were similar to 2012 levels.
 - Segment median concentrations peaked in September at nearly $75 \mu\text{g l}^{-1}$.
 - During July-August-September 14-37% of the segment had concentrations exceeding the $10 \mu\text{g l}^{-1}$ standard.
- Lafayette River Mesohaline (LAFMH)
 - Summertime CHL_a concentrations in the LAFMH segment were highest and of longest duration of all the segments sampled in 2013 and the summer bloom occurrence was first observed there.
 - As with all the other segments the bloom initiation was delayed in 2013 compared to 2012.
 - When the blooms were present in 2013, approximately 20-40% of the segment exceeded $40 \mu\text{g l}^{-1}$. This is similar to the intensity and distribution of the longer duration blooms observed in 2012.
- Monthly integrated salinities at the JMSMH ConMon monitoring site show that salinities were significantly lower from May through August of 2013 as compared to 2012.
- Continuing (both 2012 and 2013) high blooms levels observed in the Lafayette and Elizabeth rivers suggest that conditions in the mainstem James segments which did not promote large blooms in 2013, were not evident in these tributaries and blooms here may be more related to local conditions.

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 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 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 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,

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).

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 Reece 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 and 2013 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 described above. Additional samples were collected during bloom conditions by VIMS and HRSD for toxicity bioassays. 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 2 data report summarizes 2013 in comparison to 2012 CHL_a monitoring data measured by VIMS and also monitoring data provided to VIMS by HRSD for the JM_{SOH}, JM_{SMH}, JM_{SPH}, LAF_{MH} and ELIP_H 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, 2013. 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 JM_{SMH} 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 2013 was conducted by VIMS in one Chesapeake Bay Program segment, the JM_{SOH} using identical procedures followed for sampling in 2012. Collection of data from 0.25-0.5m below the surface was performed three times a month in

February and March and then once a month from April through 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.

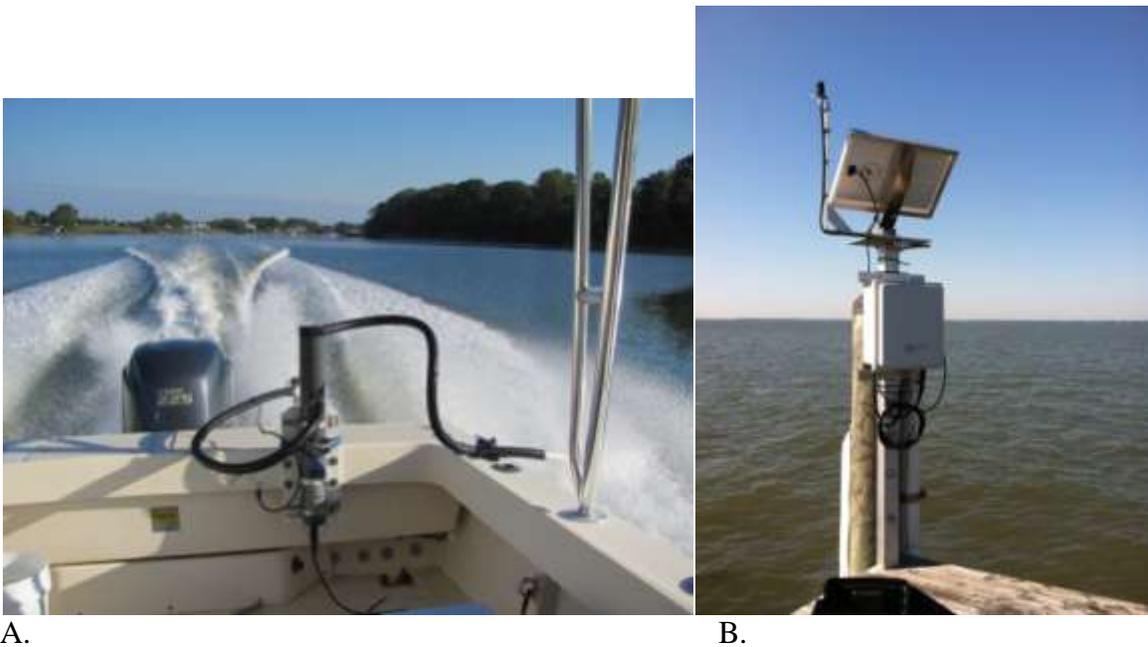


Figure 1. DATAFLOW (A.) and James River Mesohaline Continuous Monitoring (ConMon) (B.) Sampling Systems.

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 CHL_a 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 2013 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 CHL_a, phaeophytin, total suspended solids (TSS) and volatile suspended solids (VSS). Vertical profiles of 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.

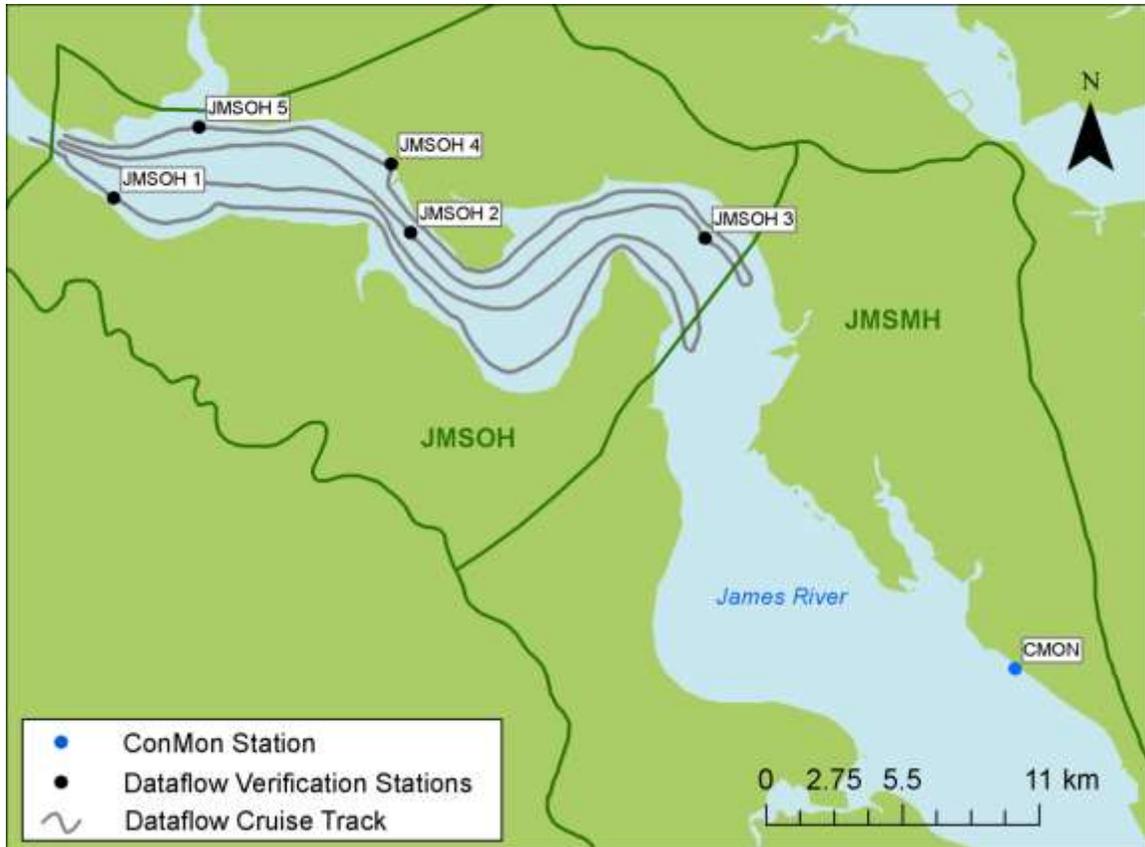


Figure 2. James River Oligohaline DATAFLOW Cruise track, verification sampling stations and Fixed Continuous Monitoring in James River Mesohaline segment.

Table 1. James River Oligohaline Verification stations 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 February through October 2013. 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. This 2013 study follows that of similar 2012 sampling. In 2013 sampling was initiated in February 2013. This is in contrast to 2012 when water quality sampling could not be initiated until May due to delay in grant approval.

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 in 2013 (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) in 2013. 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.

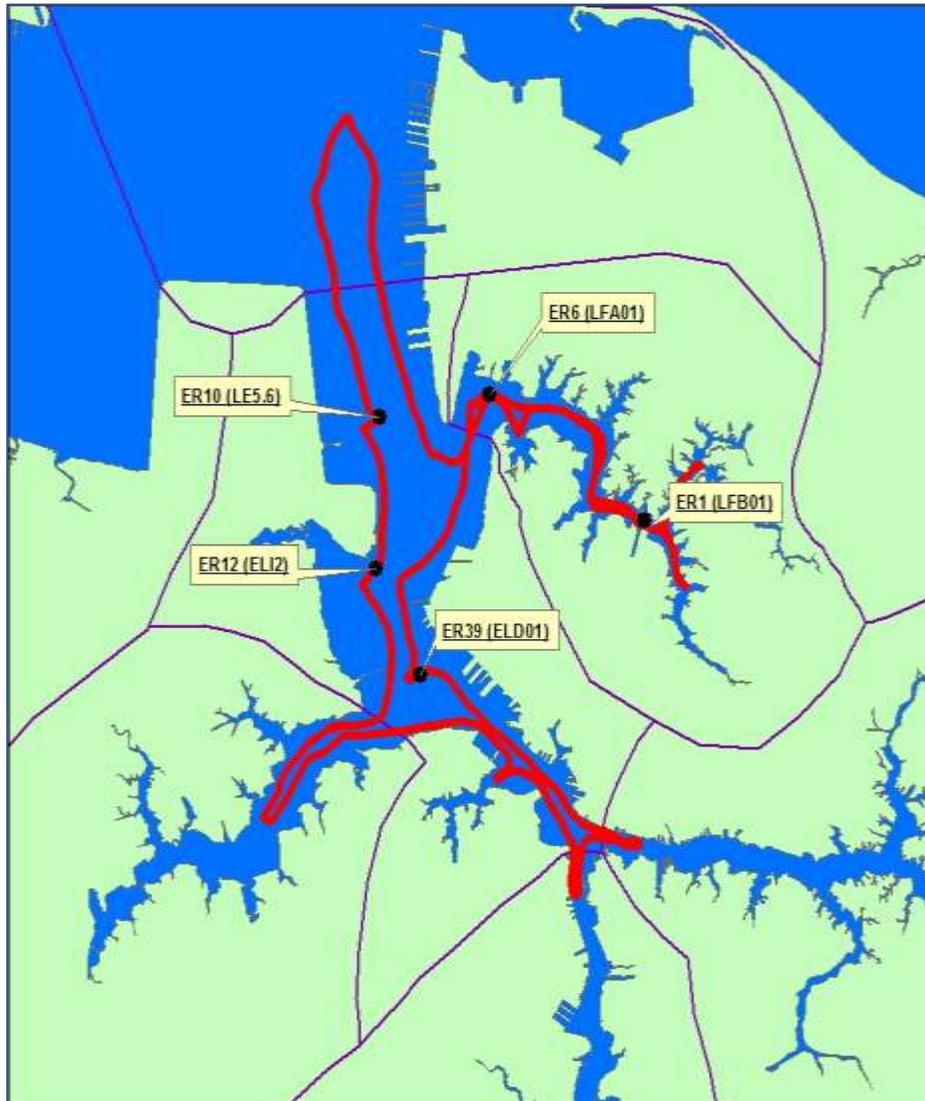


Figure 5. Lafayette Mesohaline and Elizabeth Polyhaline DATAFLOW Cruise track and verification sampling stations.

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 $CHLa$ (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 $CHLa$ using verification samples taken from the combined Lower James River segments (JMSPH, JMSMH, ELIPH, LAFMH). The 2013 daily mean, minimum, and maximum $CHLa$ 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 *CHLa* were used To determine *CHLa* (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 *CHLa* surface for each cruise (Fig. 6 & 7). Monthly mean *CHLa* surfaces were calculated and compared to seasonal *CHLa* criteria (Table 3). *CHLa* surfaces were also compared to *CHLa* 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 *CHLa* equivalent values were below each threshold or criteria. The *CHLa* regression models were also applied to the DATAFLOW pre-calibration chlorophyll measurements prior to interpolation for boxplot visualizations

Table 3. James River Seasonal *CHLa* 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

Results

The JMSOH segment was sampled beginning in February 2013, to capture the February-March period of the spring bloom which has been typically dominated by *Heterocapsa triquetra* in this region. The bloom period for 2013 in this region was characterized by very patchy development with CHL_a concentrations exceeding 150 $\mu\text{g l}^{-1}$ in late February and early March. After the blooms were no longer observed in this segment, sampling periods were extended to monthly intervals due to budget constraints. From May until October 2013 the concentrations of CHL_a were relatively low (Fig. 6) with little evidence of bloom occurrence in this region as previously observed in August 2012 (Moore et al. 2013). Throughout 2013 less than 20% of the segment waters exceeded 10 $\mu\text{g l}^{-1}$ CHL_a (Fig. 7), less than 10% exceeded 20 $\mu\text{g l}^{-1}$, and bloom areas exceeding 40 $\mu\text{g l}^{-1}$ were only observed during late February and when they covered less than 5 percent of the segment area.

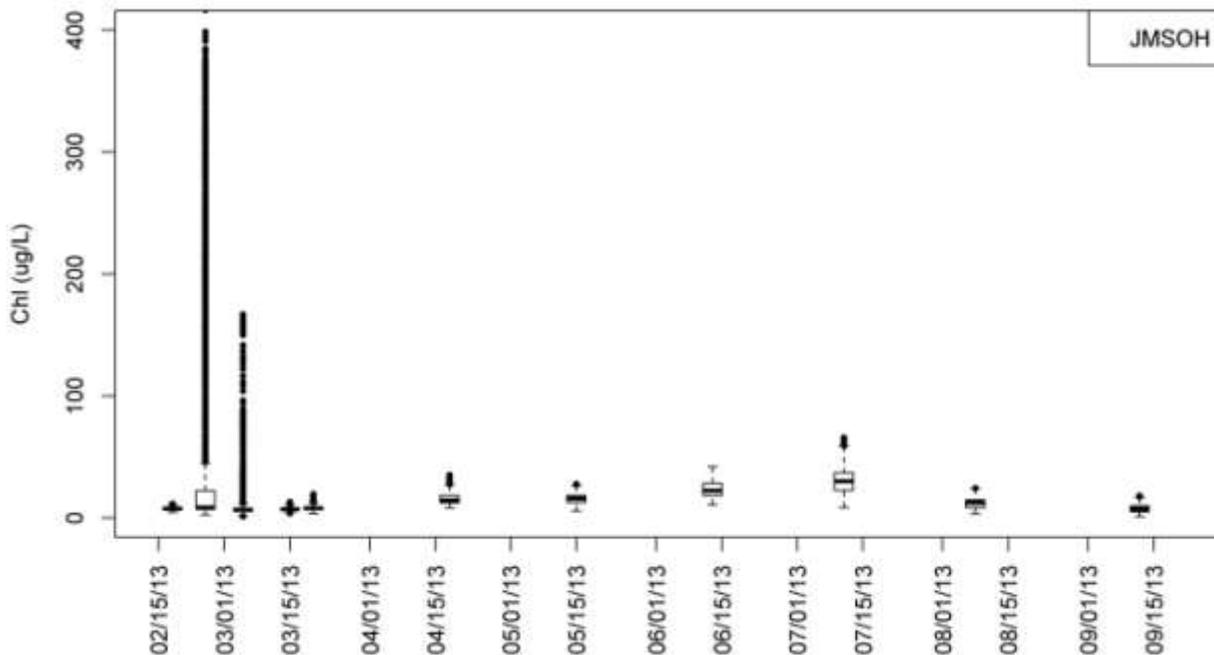


Figure 6. CHL_a (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Oligohaline segment (JMSOH) from February to October 2013. Occasional extremely high chlorophyll values were excluded from the plot image to permit use of a consistent y-axis scale for visual comparison among cruises and segments.

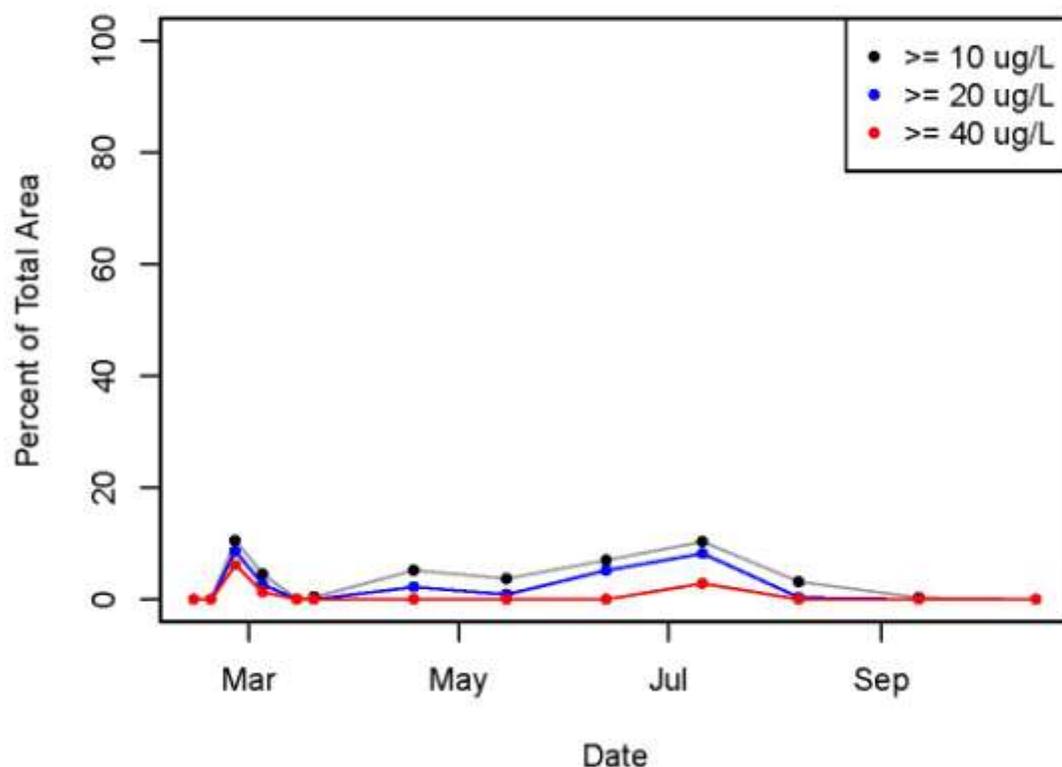


Figure 7. Integrated percent of total water surface area in James Oligohaline (JMSOH) segment that is greater than or equal to CHL a concentration on each cruise sampling date in 2013.

CHL a concentrations in the JMSMH segment showed strong evidence of *Heterocapsa triquetra* spring bloom formation lasting from February until April 2013 (Fig. 8) and a *Cochlodinium polykrikoides* dominated bloom during August. In the late winter and early spring of 2013 segment median bloom concentrations were 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 which exceeded 40 $\mu\text{g l}^{-1}$ covered approximately 18% of the segment area during March. This distribution and intensity was similar to that observed in 2012. However, unlike 2012 when blooms dissipation occurred in April, the blooms persisted in 2013 until May (Fig. 9).

Blooms of *Cochlodinium polykrikoides* and other species were recorded in this segment from August until September (Fig. 9). In 2013 they were less pronounced than those measured in

2012 (Moore et al. 2013), and were initiated in August rather than July. Additionally they covered less than 10% of the segment area in 2013 vs. 30% in 2012.

The continuous monitoring sampling record (Fig. 10) for the ConMon station in this segment paralleled the temporal patterns of the DATAFLOW spatial sampling for the segment. This suggests that continuous fixed station monitoring can provide an index of overall segment bloom condition. During the spring bloom mean concentrations exceeded $200 \mu\text{g l}^{-1}$ which was markedly larger than those observed in 2012 (Moore et al. 2013). The daily mean concentrations at the ConMon site during the July-August bloom event were smaller and of shorter duration than those observed in 2012. The varying concentrations at the sampling site were again evident in 2013 with concentrations increasing or decreasing an order of magnitude in a few hours.

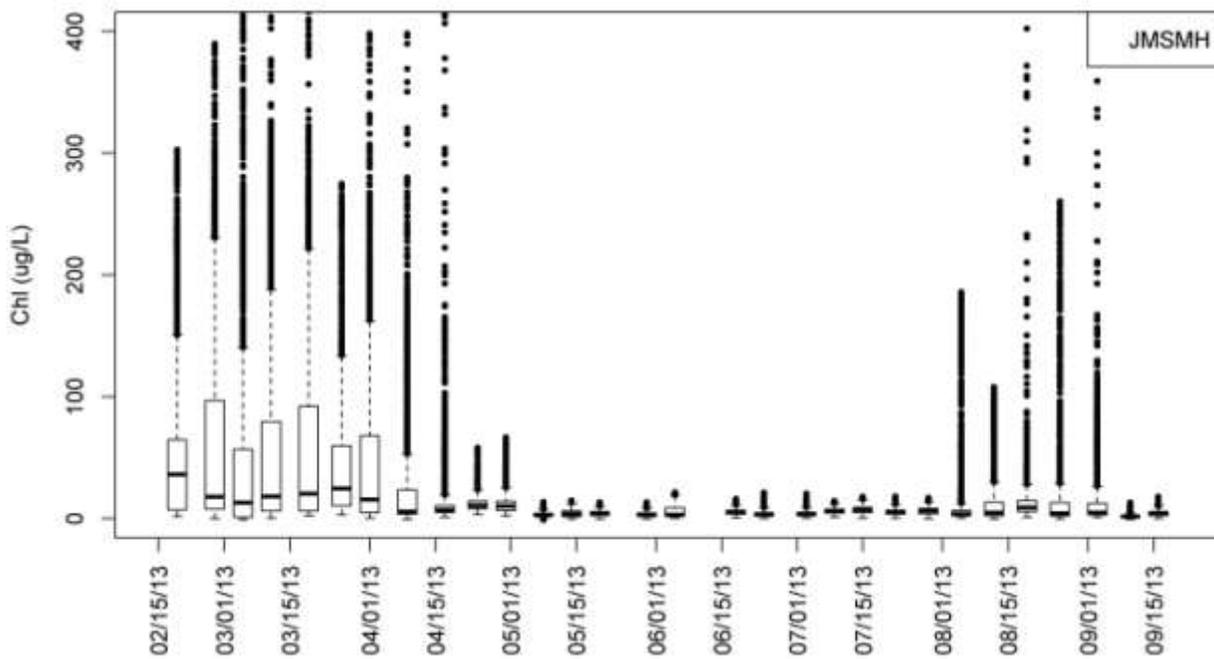


Figure 8. CHLa (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Mesohaline segment (JMSMH) from February to October 2013. Data courtesy of HRSD. Occasional extremely high chlorophyll values were excluded from the plot image to permit use of a consistent y-axis scale for visual comparison among cruises and segments.

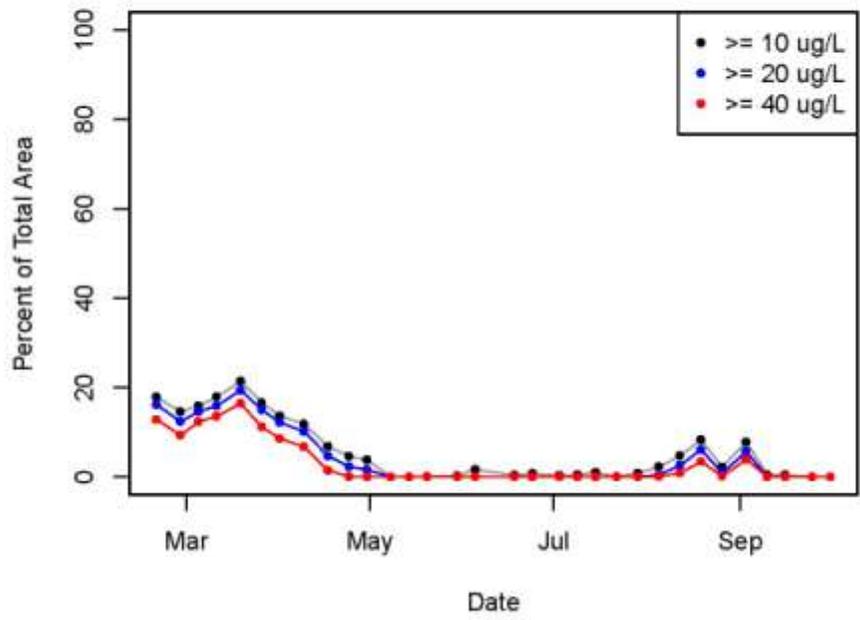


Figure 9. Integrated percent of total water surface area in James Mesohaline (JMSMH) segment that is greater than or equal to CHLa concentration on each cruise sampling date in 2013. Data courtesy of HRSD.

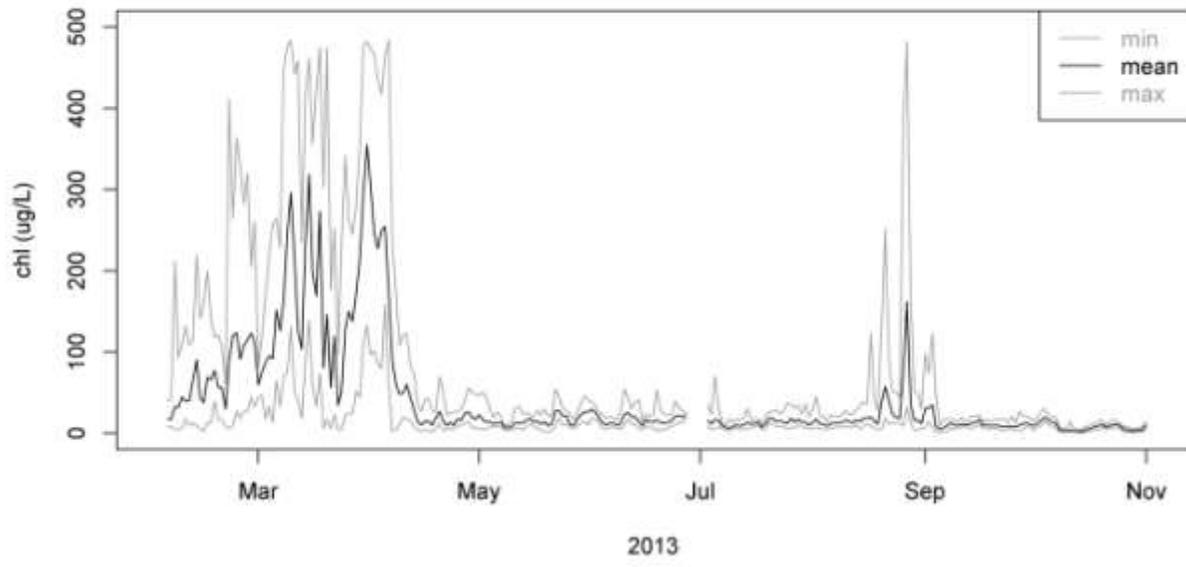


Figure 10. Daily minimum, maximum and mean CHLa concentrations at the James River Mesohaline continuous monitoring (ConMon) station. March to October 2013.

As in 2012 the spring bloom dominated by *Heterocapsa triquetra* did not generally affect a large area of the JMSPH segment (Fig. 11) with less than 10% of the segment area exceeding $10 \mu\text{g l}^{-1}$ during any one cruise and no measurable areas exceeding $20 \mu\text{g l}^{-1}$ during 2013 (Fig. 12). Late summer *Cochlodinium polykrikoides* dominated bloom intensities in the JMSPH segment were small and not present until September. 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, $<20\%$ of the segment area exceeded $40 \mu\text{g l}^{-1}$ (Fig. 12). This was in contrast to approximately 60% exceeding $40 \mu\text{g l}^{-1}$ during one cruise in 2012.

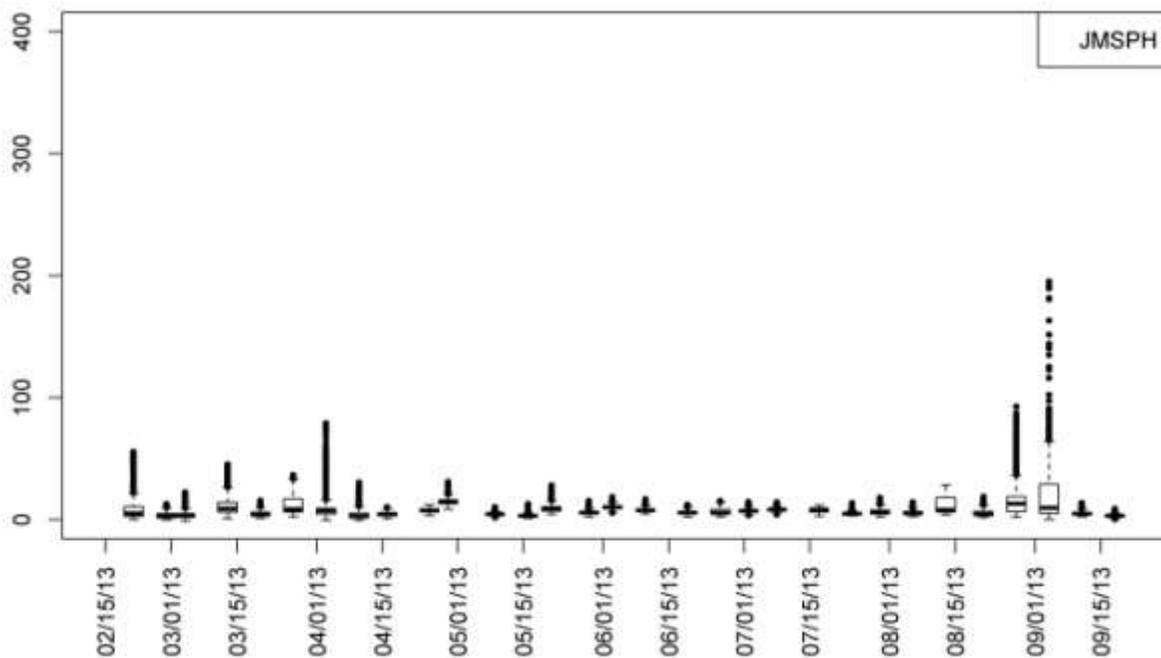


Figure 11. CHLa (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Polyhaline segment (JMSPH) from February to October 2013. Data courtesy of HRSD. Occasional extremely high chlorophyll values were excluded from the plot image to permit use of a consistent y-axis scale for visual comparison among cruises and segments.

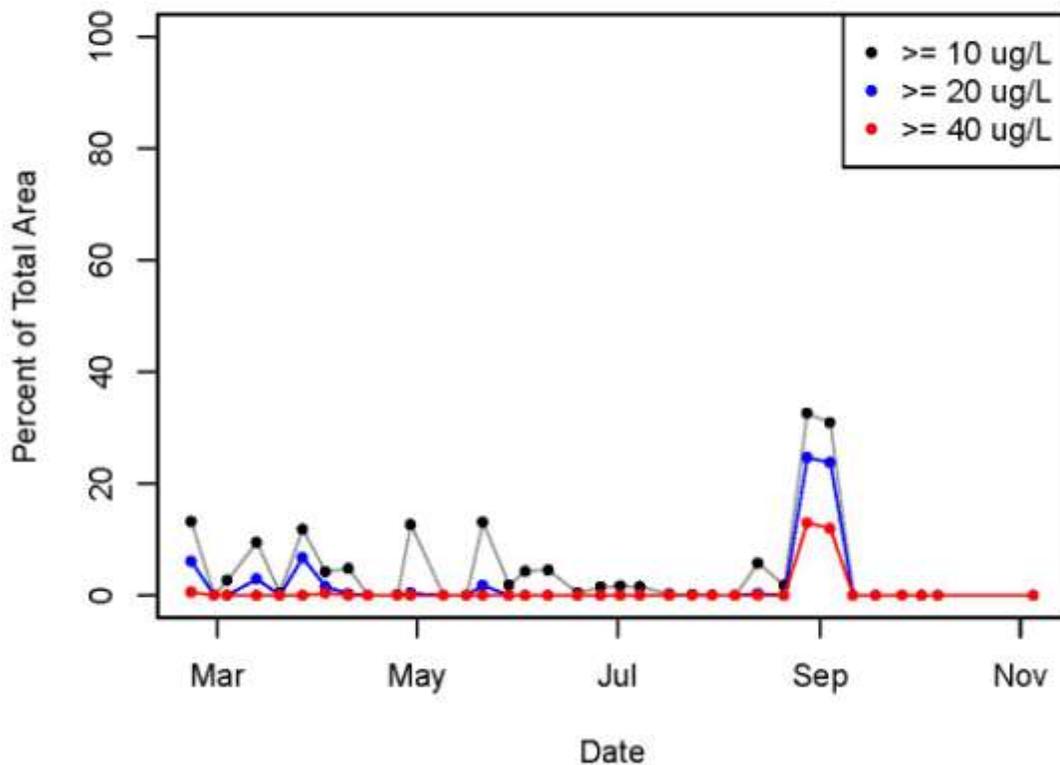


Figure 12. Integrated percent of total water surface area in James Polyhaline segment (JMSPH) that is greater than or equal to CHLa concentration on each sampling date in 2013. Data courtesy of HRSD.

Approximately 18% of the surface area exceeded $10 \mu\text{g l}^{-1}$ during the March period of spring bloom assessment. *Cochlodinium polykrikoides* dominated summer blooms in the lower ELIPH segment (Fig. 13) were not evident until mid-August. Segment median concentrations peaked in September at nearly $75 \mu\text{g l}^{-1}$. During July-August-September 14-37% of the segment had concentrations exceeding the $10 \mu\text{g l}^{-1}$ standard.

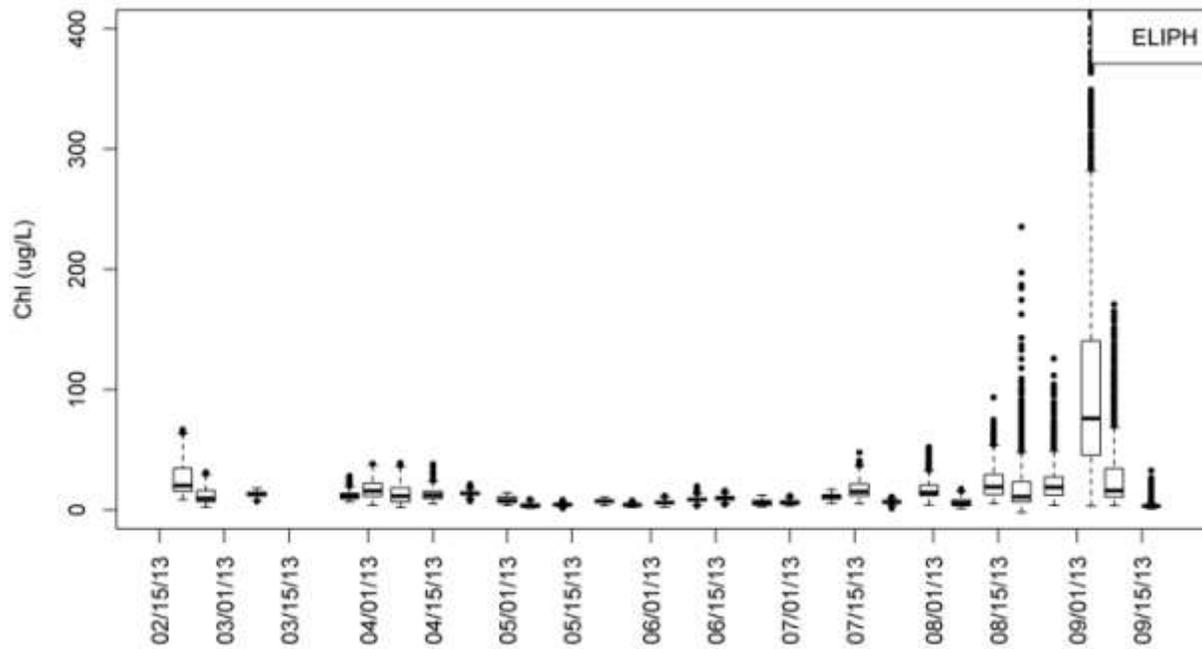


Figure 13. CHL_a (median median, 25th and 75th percentiles are in box, whiskers appear at 1.5 times IQR and the outliers are represented by points out to the minimum and maximum values) for the Elizabeth River Polyhaline segment (ELIPH) from February to October 2013. Data courtesy of HRSD. Occasional extremely high chlorophyll values were excluded from the plot image to permit use of a consistent y-axis scale for visual comparison among cruises and segments.

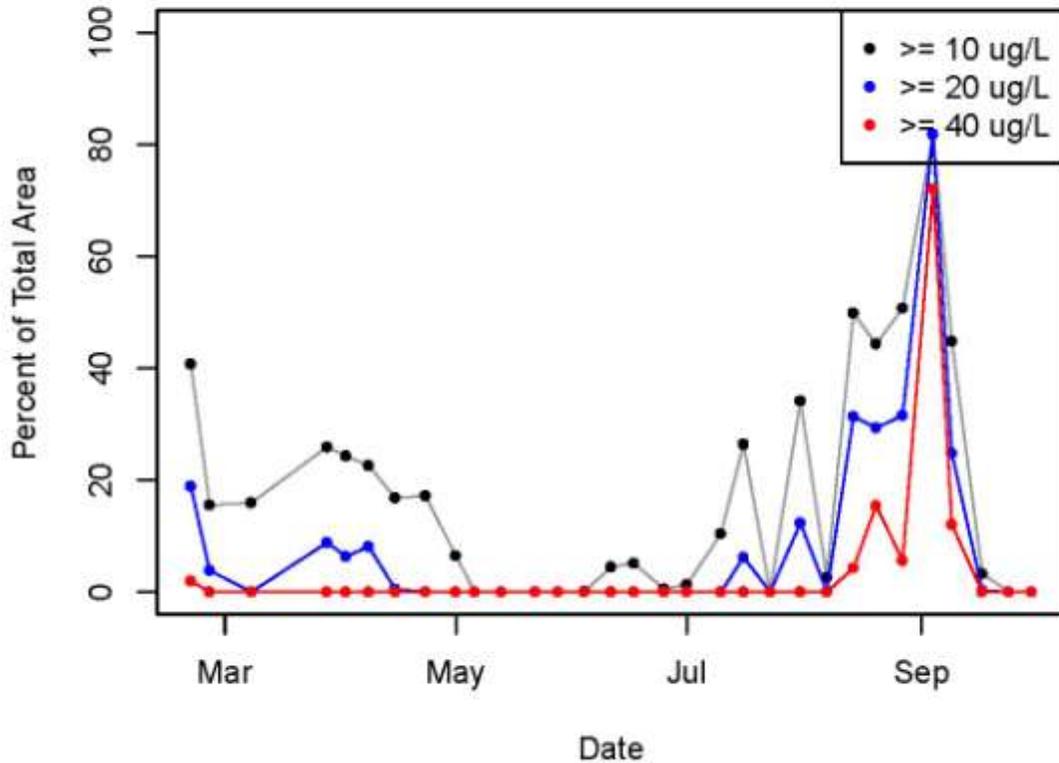


Figure 14. Integrated percent of total water surface area in Elizabeth Polyhaline segment (ELIPH) that is greater than or equal to CHLa concentration on each sampling date in 2013. Data courtesy of HRSD.

Summertime CHLa concentrations in the LAFMH segment were highest and of longest duration of all the segments sampled in 2013, and the summer bloom occurrence was first observed there (Figs. 15). As with all the other segments the bloom initiation was delayed in 2013 compared to 2012 (Moore et al. 2013). During 2012 CHLa increases were first observed in June and elevated levels continued until mid-September. During 2013 the bloom did not begin until August. However concentrations were higher during this period than the previous year with median values exceeding $100 \mu\text{g l}^{-1}$ during one cruise. An earlier smaller bloom was observed in June 2013. When the blooms were present in 2013, approximately 20-40% of the segment exceeded $40 \mu\text{g l}^{-1}$ (Fig. 16). This is similar to the intensity and distribution of the longer duration blooms observed in 2012.

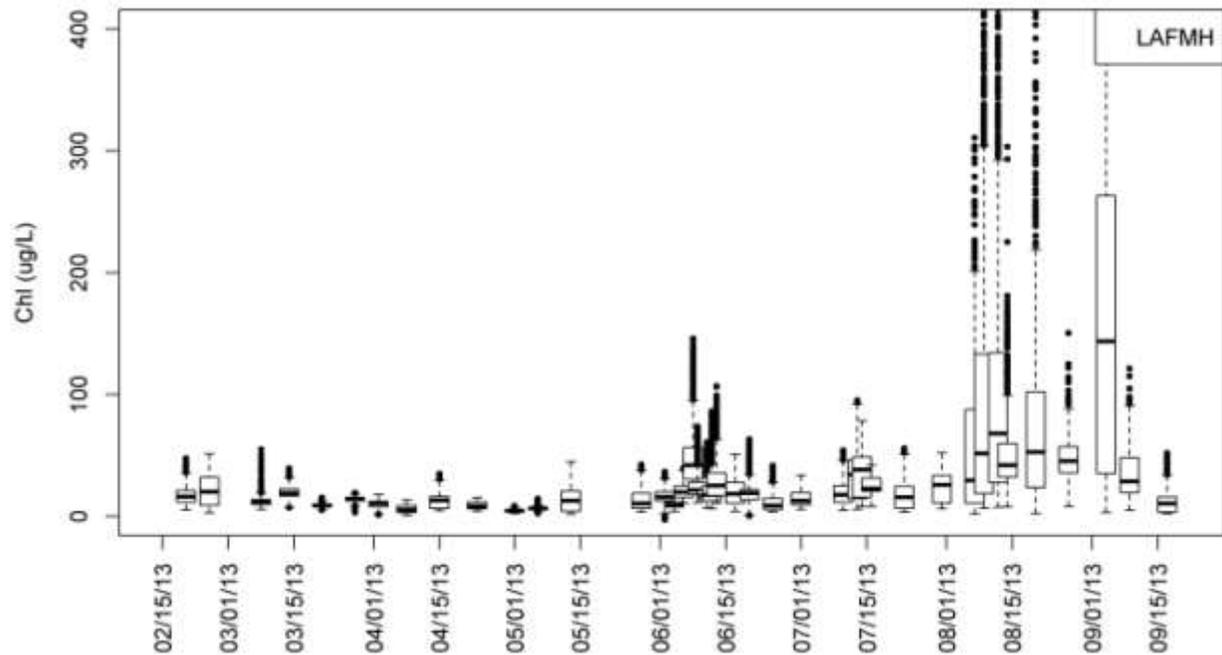


Figure 15. CHL_a (median, 25th and 75th percentiles are in box, whiskers appear at 1.5 times IQR and the outliers are represented by points out to the minimum and maximum values) for the Lafayette River Mesohaline segment (LAFMH) from February to October 2013. Data courtesy of HRSD. Occasional extremely high chlorophyll values were excluded from the plot image to permit use of a consistent y-axis scale for visual comparison among cruises and segments.

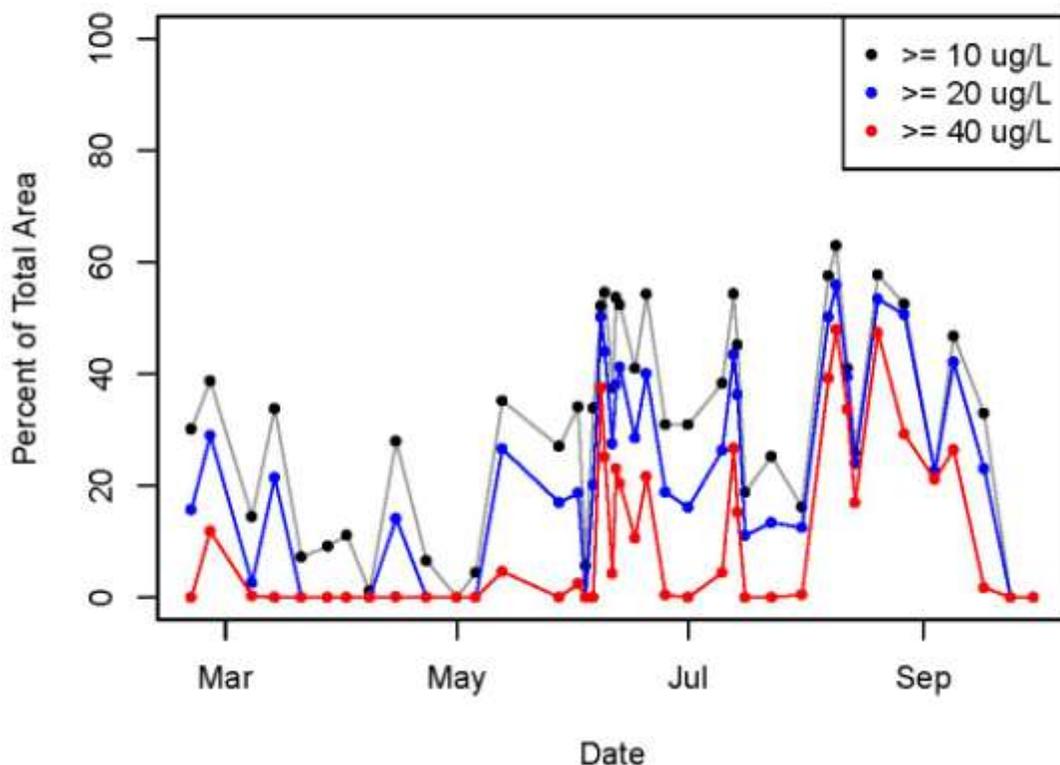


Figure 16. Integrated percent of total water surface area in Lafayette Mesohaline segment (LAFMH) that is greater than or equal to CHLa concentration on each sampling date in 2013. Data courtesy of HRSD.

Discussion/Conclusions

Significant phytoplankton blooms exceeding James River numeric CHLa criteria (Table 4) were observed in the Lower James River and its tributaries throughout 2013. 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 and allow us to compare to 2012.

A spring bloom, dominated by *Heterocapsa triquetra*, was again centered in the JMSMH for 4-5 weeks during late February and March of 2013. Although the segment was not monitored during this period in 2012, surface maps of CHLa suggest that this spring bloom extended into the JMSOH as well. 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 JMSOH. From the observations of low areal exceedences in 2013 almost all of the JMSOH appears well within the standards throughout the year. The spring bloom areas were patchy and individual patches were quite dense with concentrations reaching 100-300 $\mu\text{g l}^{-1}$. In both 2012 and 2013 exceedences were low and only during March did >10% of the surface area of any segment in the mainstem James exceed current standards (Table 4).

Table 4. Mean Monthly Percent Areas Exceeding James River (JMSOH, JMSMH, JMSPH) 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. RED >10% of segment area exceeding standard on average for that month.

2012								
Segment	Spring			Summer			Summary	
	Mar	Apr	May	Jul	Aug	Sep	Spring	Summer
ELIPH	1.4	0.0	0.0	60.4	17.4	4.0	0.5	27.2
LAFMH	18.3	2.9	18.9	52.6	47.8	25.2	13.4	41.9
JMSPH	0.1	0.0	1.3	35.8	12.6	3.2	0.5	17.2
JMSMH	12.7	0.0	0.1	5.2	6.9	0.2	4.3	4.1
JMSOH	ND	ND	3.7	0.7	2.5	0.6	3.7	1.3

2013								
Segment	Spring			Summer			Summary	
	Mar	Apr	May	Jul	Aug	Sep	Spring	Summer
ELIPH	15.4	15.4	0.2	14.4	36.9	26.0	10.3	25.8
LAFMH	12.8	8.7	14.9	32.7	49.6	20.5	12.2	34.3
JMSPH	5.4	3.3	2.8	0.7	10.0	7.7	3.8	6.2
JMSMH	17.6	7.7	0.0	0.5	4.4	2.2	8.4	2.4
JMSOH	1.1	3.8	2.5	7.8	0.0	0.0	2.5	2.6

CHL_a standards were exceeded in the LAFMH segment from March and April in up to 15% of the segment area (Table 4). This was similar to 2012 and shows that the spring bloom occurs in that part of the James system. The Elizabeth appears intermediate between the JMSPH and the LAFMH and was markedly higher during the spring in 2013 than 2012. The summer

bloom, dominated by *Cochlodinium polykrikoides*, was greatly reduced in 2013 compared to 2012 in the mainstem James and was localized in the LAFMH and ELIPH. As with 2012, the summer bloom appeared to originate in these tributaries where it largely remained during 2013.

Further environmental analyses and modeling should investigate the specific differences in environmental conditions which might be related to the marked differences in bloom intensity and duration observed between 2012 and 2013. Monthly integrated salinities at the JMSMH ConMon monitoring site during May-September (Fig. 2) demonstrate that salinities were significantly lower from May through August of 2013 as compared to 2012 (Fig.17). These lower salinities suggest higher river flows and potentially lower residence times for bloom development. Continuing (2012 and 2013) high blooms levels observed in the Lafayette and Elizabeth rivers suggest that conditions in the mainstem James segments which did not promote large blooms in 2013, were not evident in these tributaries; perhaps their bloom forming conditions are more strongly related to local features than the mainstem James River itself.

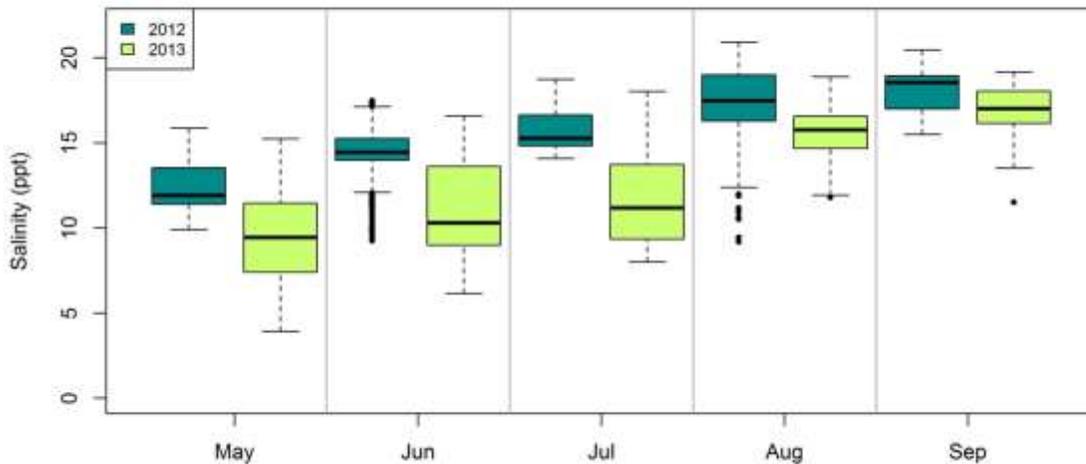


Fig. 17 Monthly (median, 25th and 75th percentiles, and the minimum and maximum) for the James River Mesohaline ConMon station from May to September 2013.

Literature Cited

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