Proposed Assessment Methodology for James River Chlorophyll Criteria
Virginia Department of Environmental Quality

Introduction

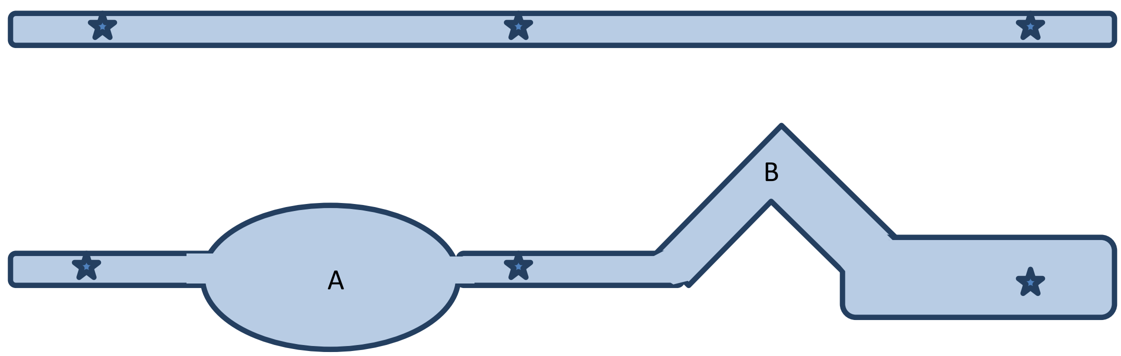
The highly variable nature of pollutants and response parameters in both space and time complicates the implementation of water quality criteria. Assessment methodologies are developed with pollutant variability in mind, but only rarely are they are tailored to the nature of individual pollutants in specific waterbodies. This would be ideal, since variability informs the certainty of assessment results. Methodology which does not fully account for pollutant variability can lead to the under- or overestimation of water quality criteria exceedances. EPA (2001) recommends a number of sampling strategies and data analyses for addressing variability in nutrient indicators like chlorophyll in estuaries and coastal waters.

VADEQ believes that the current assessment method for James River chlorophyll does not adequately account for the "patchy and flashy" nature of this indicator and proposes to move away from the error-prone, assumption-laden framework of the Cumulative Frequency Diagram (CFD). Rather than predicating criteria attainment upon the distribution of spatial-temporal exceedance rates—for which a threshold linked to aquatic life impacts has yet to be determined empirically—the replacement method would be based on a more literal interpretation of the water quality standard. Data would be spatially averaged over a segment for each monitoring run and temporally averaged over a season—resulting in a single value to be directly compared to the appropriate criterion. This method has the advantage of being easier to implement than the current method, as well as being more consistent with how the criteria were derived. However, VADEQ recognizes that the desire for procedural simplicity should not come at the expense of designated use support. Aggregating monitoring data too aggressively can lead to an inaccurate characterization of water quality and thus inadequate protection of resources.

EPA (2005) provides guidance on partitioning waterbodies for assessment purposes. States are advised to subdivide complex waters into discrete assessment units (segments) to maintain homogeneity in physical, biological or chemical conditions. A number of factors are to be considered before setting boundaries, such as the expected natural variability of the pollutant/indicator of concern, changes in residence time, land use influences, and channel morphology. Segments are always larger than an individual sampling location, but should be small enough to represent a relatively homogenous parcel of water. The ability to accurately characterize a system using a small number of samples diminishes when segments are not homogenous. Thus, partitioning maximizes the efficiency of a monitoring program.

The boundaries of the Chesapeake Bay segments correspond roughly to salinity regimes, with little consideration given to the factors listed above. Currently, all monitoring stations in a segment are treated as if they are equally representative of that segment's condition. If this assumption is indeed true, aggregating data generated at these locations does not pose a problem. Samples taken at different locations during the same monitoring event would essentially be replicate measurements. But if a particular Bay segment is relatively uniform with regard to salinity while consistently non-uniform with respect to another variable—one that can also affect the pollutant of concern—then it cannot be assumed that the same parcel of water is being sampled at different locations. Indiscriminate averaging of monitoring data could create a false impression of the overall condition of that segment. Moreover, as shown in Figure 1, a sampling design that fails to appreciate a segment's non-uniformity can result in uneven protection of designated use(s).

Figure 1. An illustration of two segments with different degrees of uniformity. The segment shown at the top is relatively homogenous in terms of channel morphology. One would expect observations at the individual sampling locations (stars) to be quite similar, and thus these samples can be simply aggregated to characterize overall water quality at a specific point in time. In contrast, the segment on the bottom is much more non-uniform. Because the dynamics at its sampling locations are likely quite different, one would expect observations taken at these locations to also be quite different, resulting in high sampling error when data are aggregated and thus assessment results with low confidence. Furthermore, there are neglected habitats (A and B) in this segment. Aquatic life inhabiting these areas may not be adequately protected. Ideally, this waterbody would be subdivided into five segments, rather than assessed as a single unit.

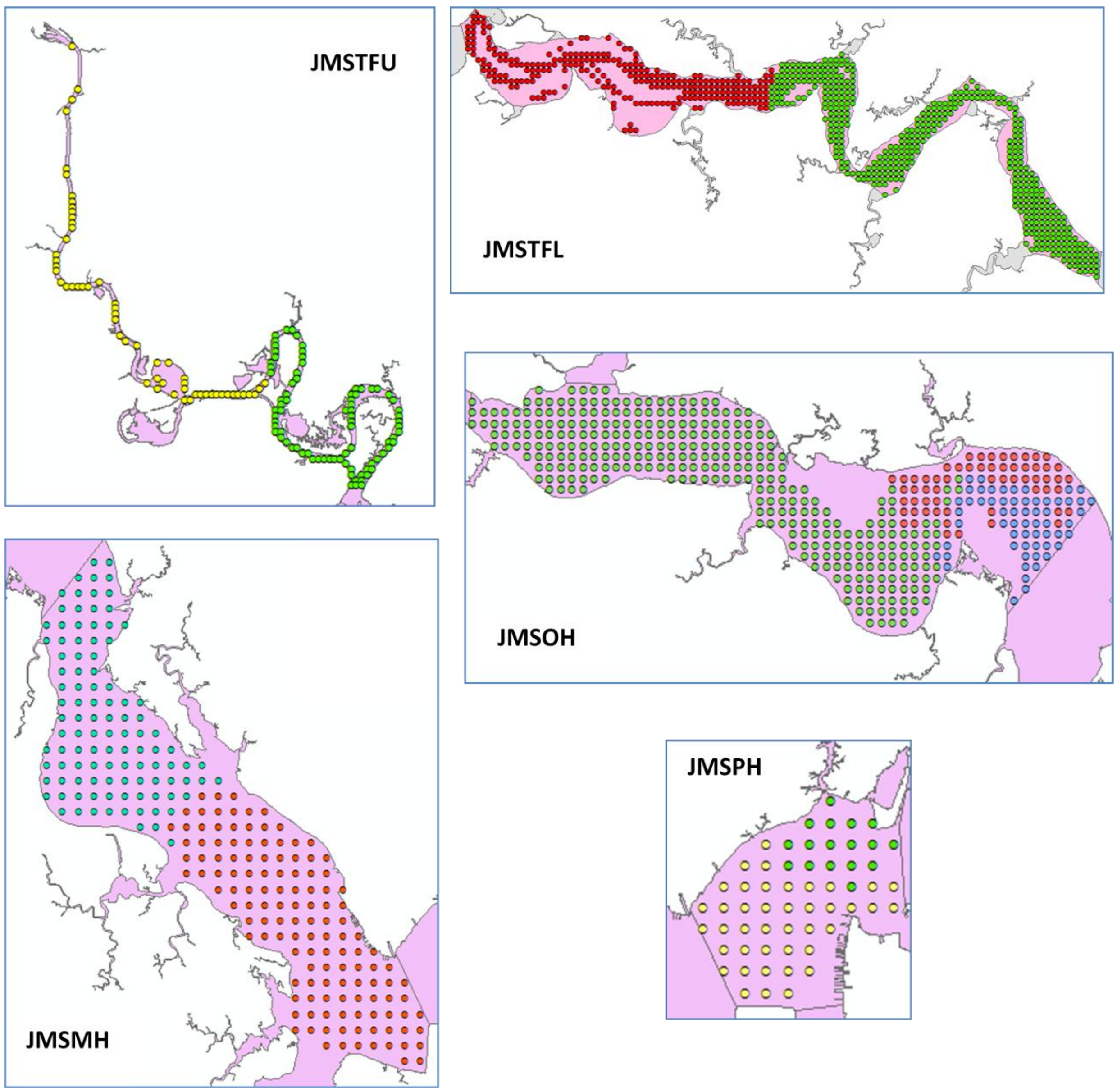


VADEQ believes it is important to test the assumption of segment homogeneity before embarking on any proposed assessment procedure revisions. The agency has no intention of altering the Bay segmentation scheme. Rather, VADEQ wants to ensure that the assessment procedure it employs for chlorophyll criteria assessments accounts for variability better than the current procedure does.

Analysis of Segment Uniformity

For each segment, Dataflow cruises—each containing at least ten observations of chlorophyll concentrations greater than 25 µg/l—were randomly selected and interpolated via kriging. Chlorophyll estimates were generated for the same set of point locations used by the Bay Interpolator (restricted to the mainstem). Only "bloom cruises" were analyzed since one would expect non-uniformity in chlorophyll distribution to be more apparent when chlorophyll concentrations are significantly elevated. There were fewer bloom cruises available for the upper estuary because there were fewer Dataflow monitoring runs conducted there compared to the lower estuary. The eight cruises that were *not* analyzed in JMSTFU and JMSTL lacked a sufficient number of "bloom" observations. For each segment, the chlorophyll estimates from each cruise were compiled into a flat file, with each cruise treated as a different variable. This file was run through a grouping analysis program (ArcMap version 10.1, Environmental Systems Research Institute) which uses the average spatial variance over multiple variables to form groupings. Chlorophyll concentrations clustered most strongly into two groups for all segments except JMSOH. Three groups were suggested for this segment, as shown in Figure 2.

Figure 2. Suggested within-segment groupings based on the average variance structure of chlorophyll observed during "bloom condition" Dataflow monitoring runs. The Calinski-Harabasz pseudo F-statistic was used to determine the ideal number of groupings within each segment.



While groupings were created for each segment, not all groupings were deemed statistically meaningful. Two criteria were used to determine whether the clustering in a particular segment is consistent and pronounced enough to be of concern for assessment. First, the average pseudo-R^2 of all the analyzed cruise data had to be at least 0.60. A cruise characterized by a high R^2 had an observed variance structure that corresponded closely to the grouping suggested by the full model shown in Figure 2. It is safe to conclude that a segment is consistently non-uniform (with respect to chlorophyll concentration) when a similar pattern of chlorophyll "clumping" was frequently observed. Secondly, for the majority of the "high R^2" cruises, the percent difference between group medians was at least 100%. It is assumed that a difference of this magnitude would likely lead to inaccurate assessment results if the assessment methodology (including sampling design) does not account for non-uniformity. Using the aforementioned criteria, the only segments determined to have a consistent pattern of *meaningful* non-uniformity were the upper and lower tidal fresh segments (see results shown in Table 1). This is not a surprising result, since these two segments feature more prominent channel heterogeneity compared to the other segments. It appears that chlorophyll tends to concentrate in stretches with reduced velocities (Isenberg, 2012) and, at least in the case of JMSTFL, shallower depth (NOAA, 1998; see Appendix I) relative to adjacent stretches.

Aggregating Data with Respect to Segment Non-Uniformity

The assessment procedure under consideration is relatively straightforward in JMSOH, JMSMH, and JMSPH. Samples collected within each of these segments during the same monitoring run would be averaged, and then the composite samples would be averaged geometrically over a season to represent the temporal central tendency of chlorophyll expression for that segment. This "pooling" approach is used by other states, such as Florida (FDEQ, 2013), to assess chlorophyll in estuaries and coastal waterbodies. It is also similar to how Virginia implements site-specific chlorophyll criteria in lakes and reservoirs with nutrient criteria (although in these waters, chlorophyll criteria are expressed as 90^{th} percentiles [VSWCB, 2011]).

The assessment method for JMSTFU and JMSTFL would be fundamentally the same as described above, except that observations in these segments would be aggregated based on where they are taken within the segment. As shown in Figure 4 (under "non-uniform segment"), averaging of data collected on the same date would occur within the respective zone. A seasonal geometric mean would be calculated separately for each zone, and then these values would be averaged together to represent the seasonal mean for the entire segment.

When rolling up into a single "segment-wide" seasonal mean, each "zone-specific" seasonal mean would be weighted based on the aerial size of its respective zone. The upstream and downstream zones of JMSTFU are 5.8 km^2 (41% of the total area) and 8.3 km^2 (59% of the total area), respectively[1]. The upstream and downstream zones of JMSTL are 33.0 km^2 (49% of the total area) and 34.0 km^2 (51% of the total area), respectively. The boundaries of the tidal fresh "subsegments" which VADEQ intends to use are shown in Figure 5.

[1] The area of Hatcher Island (1.5 km^2) was excluded from the estimate of total area for mainstem JMSTFU.

Table 1. Grouping statistics for each cruise by segment. The R^2 describes the goodness-of-fit of the "cruise-specific" grouping compared to the full model grouping shown in Figure 2. A segment with a high average R^2 (greater than 0.60) is assumed to have a high degree of "consistent non-uniformity" for chlorophyll. Dataflow cruise data provided by Ken Moore/VIMS and Will Hunley/HRSD.

JMSTFU			JMSTFL			JMSOH			JMSMH			JMSPH		
cruise date	R^2	percent difference between group medians	cruise date	R^2	percent difference between group medians	cruise date	R^2	median percent difference between group medians	cruise date	R^2	percent difference between group medians	cruise date	R^2	percent difference between group medians
7/27/2006	0.60	117	7/26/2006	0.57	103	3/28/2006	0.42	142	3/6/2006	0.02	11	8/6/2009	0.14	72
8/24/2006	0.77	94	5/23/2007	0.82	104	8/20/2007	0.29	63	3/8/2006	0.20	131	3/18/2010	0.19	29
4/26/2007	0.56	167	7/25/2007	0.77	126	8/11/2008	0.01	8	8/14/2007	0.01	12	4/22/2010	0.51	29
5/24/2007	0.70	179	8/22/2007	0.89	108	8/20/2012	0.56	66	8/22/2007	0.09	42	8/4/2010	0.01	6
7/26/2007	0.71	100	9/19/2007	0.70	126	3/5/2013	0.42	95	3/10/2008	0.08	11	8/24/2011	0.05	27
9/22/2007	0.77	79	7/1/2008	0.75	109	7/11/2013	0.49	22	7/7/2009	0.17	52	3/15/2012	0.42	27
7/2/2008	0.72	120	8/13/2008	0.89	89				7/12/2010	0.09	40	3/19/2012	0.14	17
8/14/2008	0.78	97							4/25/2011	0.13	45	7/18/2012	0.16	81
									4/6/2011	0.29	86	7/25/2012	0.02	19
									3/7/2012	0.16	92	7/31/2012	0.01	20
									7/17/2012	0.17	95	8/17/2012	0.05	25
									7/23/2012	0.11	51	3/13/2013	0.12	37
									8/1/2012	0.34	152	4/3/2013	0.12	35
									8/12/2013	0.18	97	8/28/2013	0.31	81
									8/19/2013	0.00	12	9/4/2013	0.24	71
median	**0.72**	**109**		**0.77**	**108**		**0.42**	**65**		**0.09**	**40**		**0.14**	**27**

Figure 3. Spatial distribution of chlorophyll as observed on selected Dataflow cruises in JMSTFU and JMSTFL. Group statistics apply to the groupings shown in Figure 2.

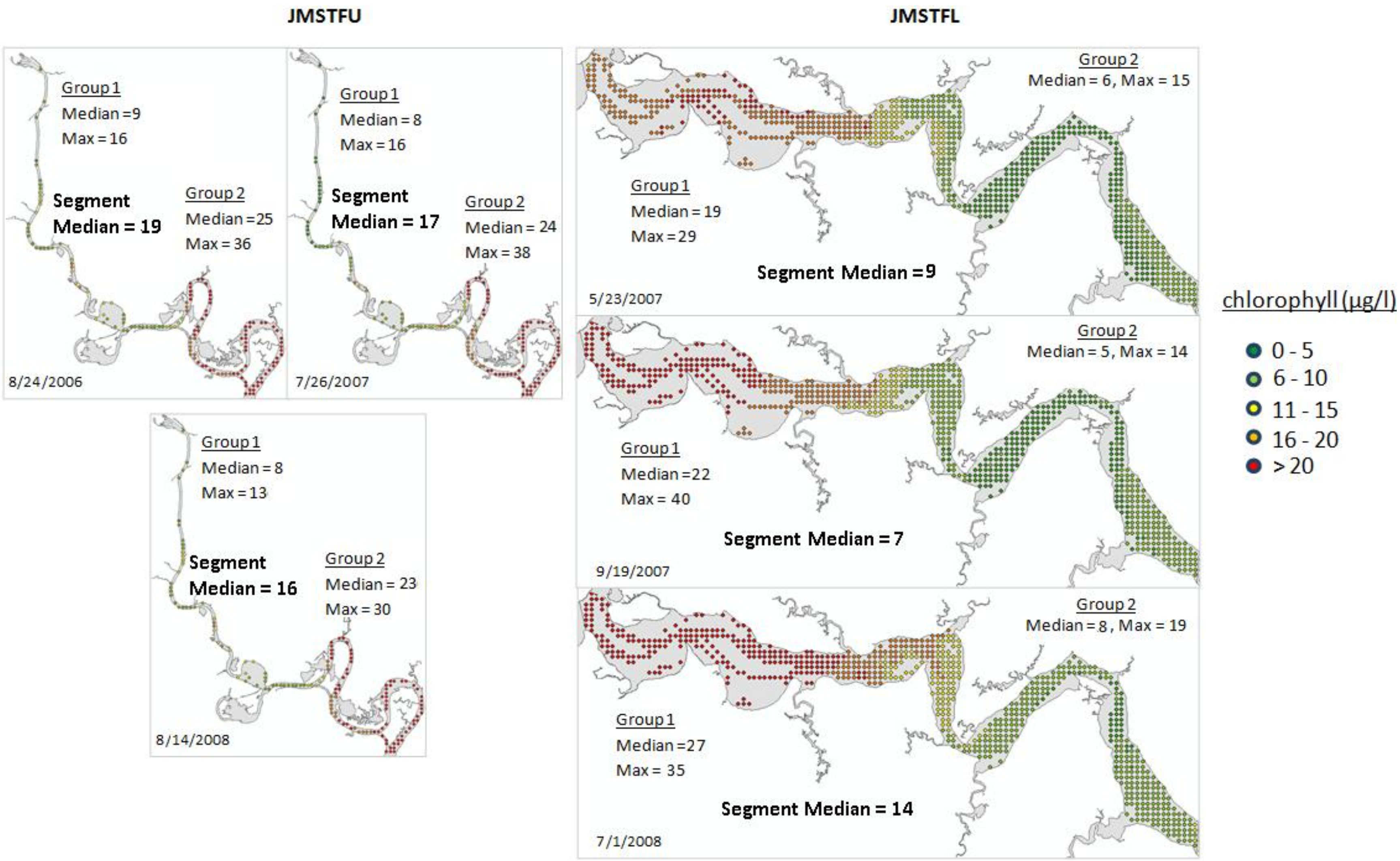


Figure 4. Illustration of the proposed method on a hypothetical chlorophyll dataset (discrete samples). *Steps for a uniform segment*: 1) Calculate median of same-day observations. 2) Calculate the segment seasonal geometric mean by averaging the natural logs of the spatial medians and backtransforming the result. 3) Compare this value (rounded to the nearest whole number) to the appropriate season-segment criterion. *Steps for a non-uniform segment*: 1) Calculate the median of same-day observations taken within each pre-determined zone. 2) Calculate the seasonal geometric mean within each zone. 3) Calculate the segment seasonal geometric mean by adding the two zone-specific means multipled by their respective area-derived weights. Compare the resulting value (rounded to the nearest whole number) to the appropriate season-segment criterion.

Uniform Segment

	FIXED STATION SAMPLES				
Sampling Date	Station A	Station B	Station C	Station D	Spatial Median
1-Jul	10	12	43		**12**
30-Jul				30	**30**
1-Aug	10	8	30		**10**
1-Sep	9	5	56		**9**
30-Sep				50	**50**

Segment seasonal geometric mean (value to be compared to the criterion) = **17**

Non-Uniform Segment

Zone 1

	FIXED STATION SAMPLES		
Sampling Date	Station A	Station B	Spatial Median
1-Jul	10	12	**11**
1-Aug	10	8	**9**
1-Sep	9	5	**7**

Zone seasonal geometric mean = **9**

Zone 2

	FIXED STATION SAMPLES		
Sampling	Station C	Station D	Spatial Median
1-Jul	43		**43**
30-Jul		30	**30**
1-Aug	30		**30**
1-Sep	56		**56**
30-Sep		50	**50**

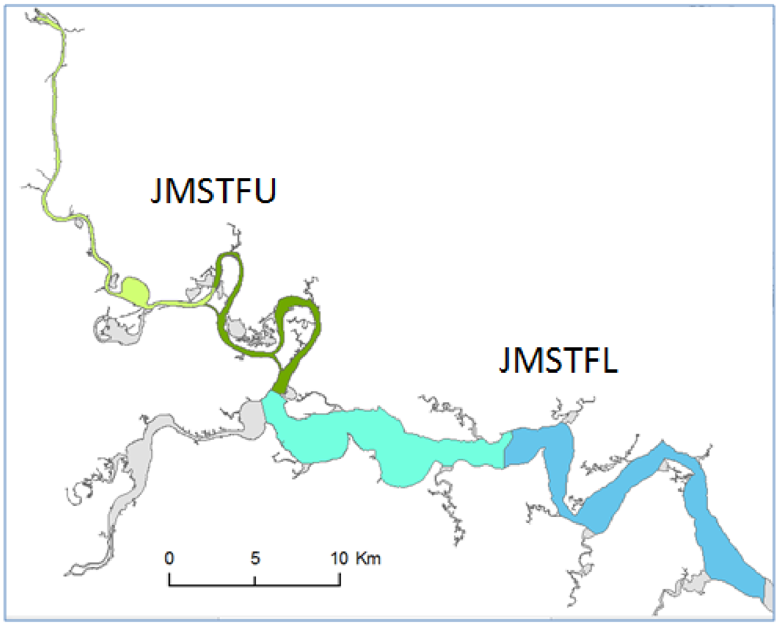
Zone seasonal geometric mean = **40**

Segment seasonal geometric mean (value to be compared to the criterion) = (Zone 1 Seasonal Mean) * 0. 41 + (Zone 2 Seasonal Mean) * 0.59 = **28**

Measures of Central Tendency

The best statistic to gauge central tendency is not a trivial concern. The use of an arithmetic mean on a distribution that departs substantially from Gaussian can lead to erroneous conclusions about the long-term exposure of aquatic life to pollutants. The lognormality of chlorophyll is well-established. Though the geometric mean is not specified explicitly in the water quality standard for James River chlorophyll (only "seasonal mean" is stipulated), the Chesapeake Bay Program published a technical document (EPA, 2010) prior to releasing the Bay TMDL that provided scientific justification for using the geometric mean

Figure 5. Proposed sub-segmentation of JMSTFU and JMSTFL for the purposes of chlorophyll criteria assessments.



for evaluating the seasonal central tendency of chlorophyll in the James River. VADEQ agreed with the report's findings and inserted a reference to the document in Virginia's Water Quality Standards (VSWCB, 2011). Since that time, VADEQ has used the geometric mean to characterize James River chlorophyll in both space and time. However, the Bay Program's analysis only focused on the temporal distribution of James River chlorophyll. Its spatial distribution should be explored as well, since the difference between a geometric mean and an arithmetic mean can be substantial enough to affect attainment determinations.

To accomplish this, distribution tests were performed on 15 interpolated Dataflow datasets per segment to detect signs of normality (for which an arithmetic mean is indicated) or lognormality (for which a geometric mean is indicated). The relative proximity of the two means to the dataset's median was used as an additional piece of evidence. When the geometric mean and the median are close, a lognormal distribution is suggested. Continuous monitoring (ConMon) data were also analyzed in this way to verify that the geometric mean is suitable for characterizing seasonal chlorophyll expression. The details of these analyses are presented in Appendix II.

The results show that while the geometric mean is indeed superior to the arithmetic mean at capturing the temporal central tendency of chlorophyll in the James River, evidence of its superiority in space is more mixed. The arithmetic mean actually performed better overall in two segments (JMSTFU and JMSOH). Even in segments where a general lognormal pattern was indicated, normality in the spatial distribution was found occasionally. Thus, VADEQ proposes a median for aggregating data spatially (as demonstrated in Figure 4), as this statistic does not presume a particular distribution.

Treatment of Spatially-Intensive Monitoring Data

Though VADEQ anticipates that the Bay Program-funded fixed stations will continue to be the primary source of data for much of the estuary, it also believes that the characterization of chlorophyll is significantly enhanced when datasets such as Dataflow are brought into the analysis. The proposed assessment method would be fully compatible with this type of monitoring data. These data would be interpolated, as is the current practice. But VADEQ proposes to do this is a manner that 1) incorporates more spatial variability into chlorophyll estimates while 2) reducing the range of interpolation to reduce uncertainty.

Incorporation of more spatial variability

As with fixed station samples, interpolated Dataflow estimates would be spatially aggregated by cruise and within zone (JMSTFU and JMSTL only). Interpolation estimates, rather than individual Dataflow observations, are to be averaged since interpolation smoothes out the effect of any biased monitoring that may occur while the vessel is underway, such as when the vessel slows down to bring bloom samples shipboard.

The current interpolation procedure, as described in EPA (2008), takes the average (weighted inversely by distance) of the four observations closest to each Interpolator centroid. This means that the great majority of observations taken on a Dataflow cruise are ignored and the full range of chlorophyll's spatial variability is underappreciated.

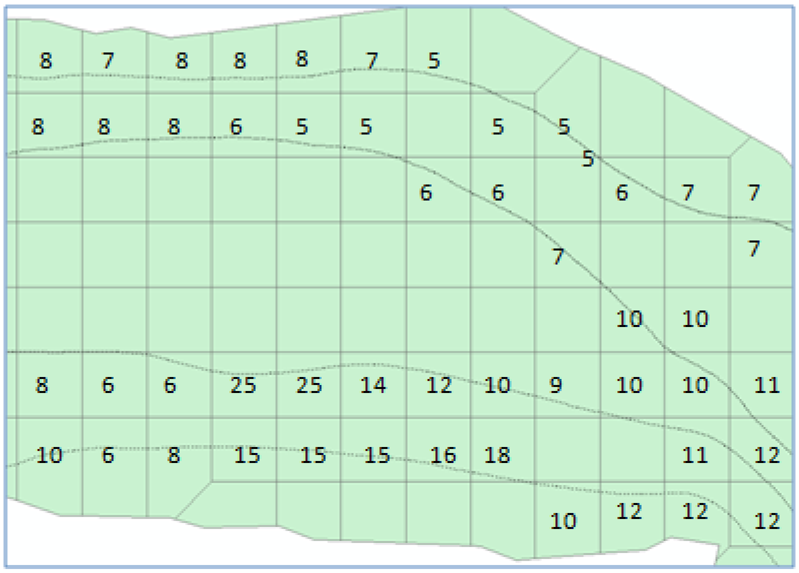
The proposed procedure would require that all observations taken within a grid cell (see Figure 6) be averaged (median), rather than only a small subset. The grid would be similar to the Bay Interpolator grid, except that the cells for the tidal fresh segments would be more regularly shaped and spaced (as compared to the irregular and incomplete layout shown by the point locations in Figure 2).

Reduced Range of Interpolation

Currently, data are interpolated throughout the full extent of a segment, even in areas greater than a kilometer away from where samples were actually taken. Patchiness can occur even in relatively homogenous segments. Thus, overly aggressive interpolation introduces avoidable measurement error.

The proposed procedure would limit the generation of estimates to only those cells containing at least one observation.

Figure 6. A Dataflow cruise-track mapped onto an interpolation grid, with numbers representing the median value of chlorophyll observations taken within each cell. In this example, 20 observations (on average) were used to generate each cell estimate, as opposed to the maximum of four that is currently used. Estimates would only be generated for the cells transversed by the cruise-track. A slightly modified Bay Interpolator grid would be employed. For this segment, each cell is 500m x 500m.



Minimum Data Requirements

Currently, the tidal James River is monitored on a monthly basis at 2-3 mid-channel, fixed stations per segment. This monitoring is funded by the Chesapeake Bay Program Office, and the data collected at these locations supports both chlorophyll and dissolved oxygen assessments (as well as the Bay Program's status and trend analysis). VADEQ-funded sampling, as well as discrete samples and Dataflow data provided by HRSD, supplement the Bay Program fixed station datasets.

An analysis was performed on existing monitoring datasets to determine the capability of the current CBP-funded station network to capture the spatial variability of chlorophyll at the sensitivity needed to render a confident assessment decision using the proposed procedure. The spatial medians derived from selected Dataflow cruise-tracks—processed in accordance with the proposed procedure—were compared to medians derived solely from CBP fixed stations located within a particular segment. The former were treated as "actual" chlorophyll expressions for each segment, while the latter were treated as "estimated" expressions. The closest cruise observation to each CBP station was used to represent a "CBP fixed station" sample. Additionally, the cruise-track was also sampled at a location relatively far away from the existing stations to determine the effect of adding another fixed station to the CBP station-based assessment. The locations of these "supplemental" stations are shown in Figure 7. For each cruise date, "attainment" status was determined by comparing the spatial median to the appropriate season-segment criterion. A fixed station-based assessment was considered erroneous when it resulted in a decision ("criterion attained" or "criterion not attained") that differed from the Dataflow-based outcome.

As shown in Table 2, the error rates of fixed station-based characterization of attainment were found to be relatively low in most segments, indicating that the existing CBP stations are sufficient to implement the proposed assessment procedure for much of the estuary. However, the results indicate that the current CBP stations are inadequate for two segments—JMSTFU and JMSMH. For the former, the addition of the station in the downstream zone (station #1 in Figure 7) greatly improves the accuracy of JMSTFU assessments. Without data from this station (or a nearby location), the CBP station-derived averages will almost always be biased low. Thus, VADEQ will need to ensure that there are samples taken in both zones during each assessment period. In the case of JMSMH, it is apparent that more than three fixed stations are needed to produce a confident estimate of attainment. This segment is currently being assessed with Dataflow data collected by Hampton Roads Sanitation District (HRSD). VADEQ intends to use these data as long as they continue to be available.

Figure 7. Sampling locations used to test the accuracy of the proposed assessment protocol.

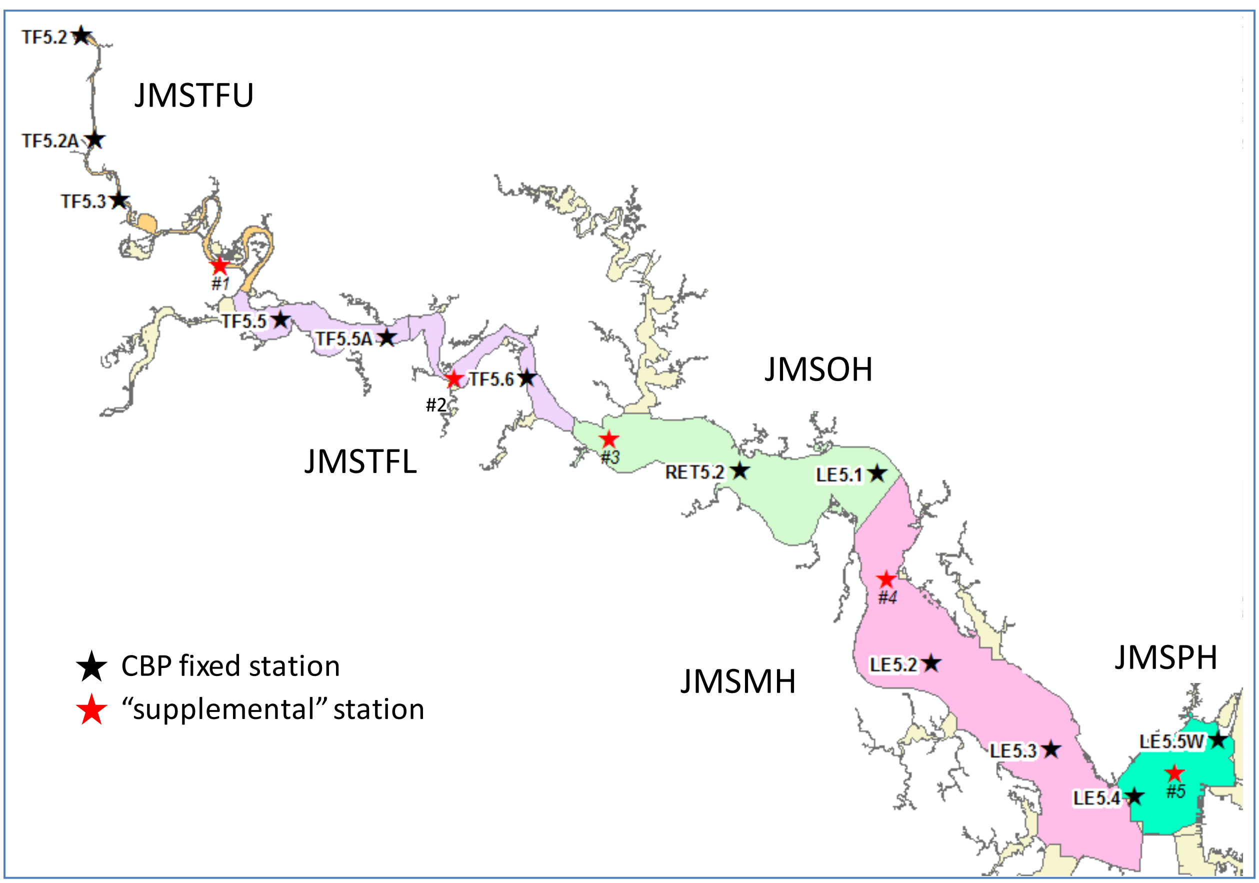


Table 2. Comparison of spatial averages derived from Dataflow and fixed stations. Error rates were calculated by counting the number of conflicting attainment determinations (i.e., the Dataflow-derived median is below the criterion while the fixed stations-derived median is above the criterion or *vice versa*) and dividing by the total number of cruise dates examined. Most Dataflow cruises selected for this analysis contained a moderate to high proportion of "exceedances", thereby allowing for a moderate to high likelihood of an "exceedance" being sampled at any given fixed station. The JMSOH cruises, the majority of which had a relatively low frequency of exceedances, were the exception. Data provided by Ken Moore/VIMS and Will Hunley/HRSD.

JMSTFU cruise date	Criteria	Dataflow Spatial Median	CBP Stations Spatial Median	"erroneous" assessment	CBP Stations + Station #1 Spatial Median	"erroneous" assessment
4/27/2006	10	5	2		6	
5/25/2006	10	12	2	x	13	
7/27/2006	15	15	4		9	
8/24/2006	15	17	8	x	16	
4/26/2007	10	5	1		5	
5/24/2007	10	10	1		12	x
7/26/2007	15	13	3		14	
8/23/2007	15	12	3		13	
9/20/2007	15	18	6	x	17	
7/2/2008	15	16	9	x	17	
8/14/2008	15	16	6	x	12	x
			error rate →	**45%**	error rate →	**19%**

JMSTFL cruise date	Criteria	Dataflow Spatial Median	CBP Stations Spatial Median	"erroneous" assessment	CBP Stations + Station #2 Spatial Median	"erroneous" assessment
4/26/2006	15	9	10		9	
5/24/2006	15	11	10		9	
5/23/2007	15	11	12		11	
7/25/2007	23	17	15		13	
8/22/2007	23	15	14		13	
9/19/2007	23	14	14		10	
7/1/2008	23	18	16		14	
			error rate →	**0%**	error rate →	**0%**

JMSOH cruise date	Criteria	Dataflow Spatial Median	CBP Stations Spatial Median	"erroneous" assessment	CBP Stations + Station #3 Spatial Median	"erroneous" assessment
3/28/2006	15	24	52		11	x
8/20/2007	22	8	15		15	
8/11/2008	22	10	16		10	
8/20/2012	22	5	6		5	
3/5/2013	15	4	5		4	
7/11/2013	22	16	15		19	
			error rate →	**0%**	error rate →	**17%**

Table 2 (continued). Comparison of spatial averages derived from Dataflow and fixed stations. Error rates were calculated by counting the number of conflicting attainment determinations (i.e., the Dataflow-derived median is below the criterion while the fixed stations-derived median is above the criterion or *vice versa*) and dividing by the total number of cruise dates examined. All Dataflow cruise-tracks selected for this analysis contained a moderate to high proportion of "exceedances", thereby allowing for a moderate to high likelihood of an "exceedance" being sampled at any given fixed station. Data provided by Ken Moore/VIMS and Will Hunley/HRSD.

JMSMH cruise date	Criteria	Dataflow Spatial Average	CBP Stations Spatial Average	"erroneous" assessment	CBP Stations + Station #4 Spatial Average	"erroneous" assessment
3/16/2006	12	27	45		80	
8/24/2006	10	12	11		11	
3/13/2007	12	6	6		6	
8/8/2007	10	11	8	x	8	x
8/14/2007	10	11	9	x	9	x
9/10/2007	10	9	8		5	
8/18/2008	10	16	87		53	
8/17/2009	10	15	60		14	
7/27/2010	10	8	13	x	3	
4/13/2011	12	8	9		9	
3/14/2012	12	10	6		7	
8/1/2012	10	10	7		4	
8/8/2012	10	8	23	x	28	x
8/19/2013	10	12	8	x	10	x
9/3/2013	10	8	11	x	7	
			error rate →	**40%**	error rate →	**27%**

JMSPH cruise date	Criteria	Dataflow Spatial Median	CBP Stations Spatial Median	"erroneous" assessment	CBP Stations + Station #5 Spatial Median	"erroneous" assessment
3/7/2006	12	7	8		5	
7/19/2006	10	11	11		11	
7/2/2007	12	11	11		11	
7/16/2007	10	11	11		11	
9/5/2007	10	6	11	x	7	
3/19/2008	12	7	6		6	
9/3/2008	10	8	8		9	
7/8/2009	10	12	13		13	
3/1/2010	12	14	12	x	12	x
4/22/2010	12	18	16		20	
5/14/2012	12	14	15		14	
7/18/2012	10	33	16		20	
4/29/2013	12	16	17		17	
7/8/2013	10	11	11		10	x
7/17/2013	10	11	11		11	
			error rate →	**13%**	error rate →	**13%**

Assessment Period and Allowable Exceedances

VADEQ proposes a 6-year assessment period for James River chlorophyll, as opposed to the current 3-year period. Impairment would be predicated on three or more seasonal mean exceedances during the 6-year assessment period.

VADEQ believes a longer assessment period would strengthen attainment determinations because chlorophyll is so highly variable in time, and the ability to adequately characterize this variability through monthly sampling events is so poor. It is quite possible for a single season's worth of samples to under-estimate the true central tendency of chlorophyll values. It is also possible for two or three consecutive seasons' worth of samples to have the same skew, similar to how it is possible to roll the same number three times in a row in a dice game. But it is not as likely that elevated chlorophyll concentrations will escape notice four, five, or six seasons in a row. Thus, a longer assessment period increases the likelihood that water quality impairments will be detected with a low-frequency monitoring effort. Furthermore, it would reduce "flip-flopping" impairment determinations that come with short assessment periods. Such fluctuations damage the credibility of assessments and make it harder to gauge the success of implementation activities. DEQ uses a 6-year assessment period for the majority of its water quality criteria assessments (VADEQ, 2014).

The rationale for an allowable exceedance rate of 30% (2 exceedances out of six seasonal means) is straightforward. A waterbody attaining its seasonal mean criteria over the long-term could still be expected to experience exceedances roughly 50% of the time. Thus, a 30% allowable exceedance rate is a conservative threshold that still allows segments to undergo an occasional "bad season".

Summary

The assessment protocol under consideration offers a number of advantages over the current method:

1) This method is a more direct interpretation of the water quality standards for James River chlorophyll.
2) It is more consistent with how the James River chlorophyll criteria were derived (VADEQ, 2005).
3) It is more consistent with national EPA assessment guidance, as well as other methodologies used by VADEQ.
4) It is free from untested/untestable assumptions about what attainment "looks" like.
5) It is easier to implement and explain to resource managers, stakeholders, and the public.
6) It produces more confident results.
7) It does not appear to produce biased results.
8) It can be supported with a conventional, low-frequency monitoring program.
9) It can also be supported with high-resolution and high-frequency data—such as Dataflow and continuous monitoring data. The latter have not been incorporated into the current procedure. This is an important advantage, since federal regulations require that states and tribes evaluate all existing and readily available information for developing impaired waters lists (40 C.F.R. §130.7(b) (5)).

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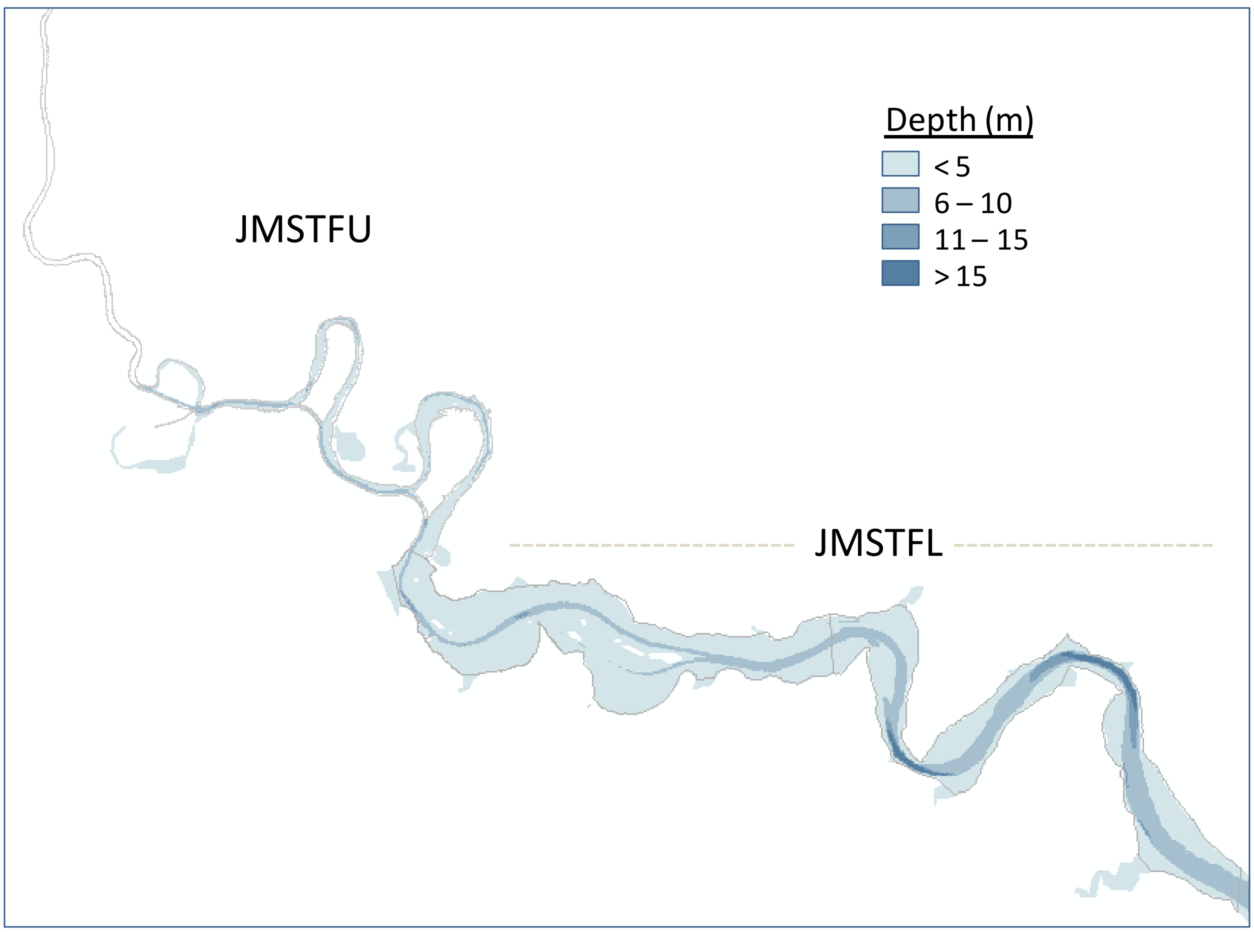
APPENDIX I

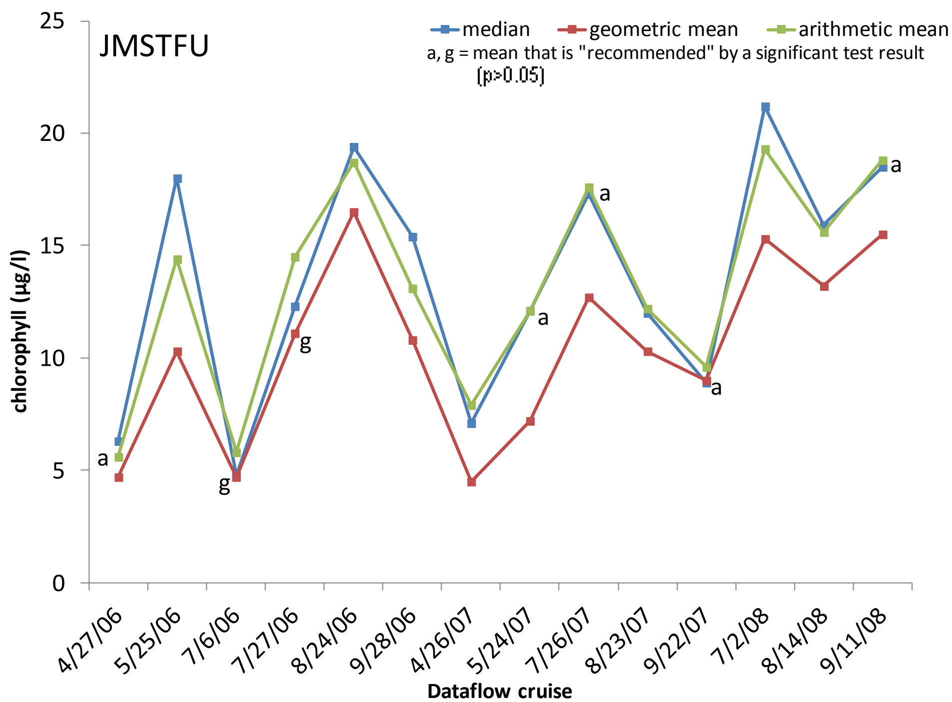
Bathymetry for the tidal fresh James, based on National Ocean Service survey data (NOAA, 1998). The upstream zone of JMSTFL has a mean and median depth of 4 meters and a maximum of 14 meters. The downstream zone has a mean and median depth of 8 and 6 meters, respectively, and a maximum of 28 meters. Higher hydrologic retention would be expected in the upstream zone relative to the downstream zone due to the former's lower gradient and shallower depth. Differential retention may explain the pattern of chlorophyll observed during multiple "bloom" Dataflow cruises (shown in Figures 2 and 3, Table 1).

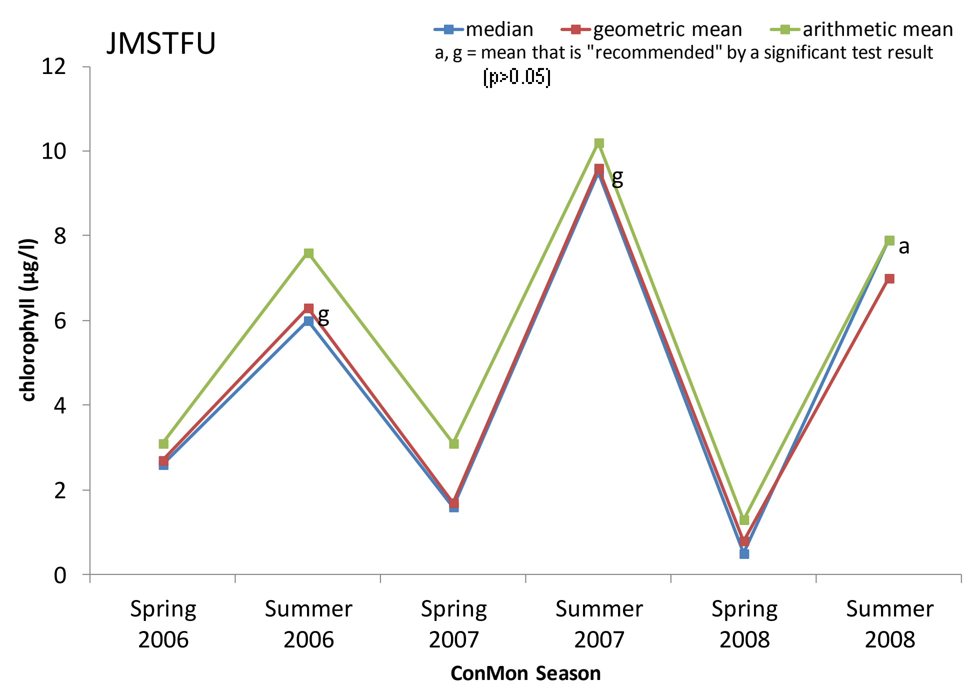
The NOAA bathymetry data are incomplete for JMSTFU.

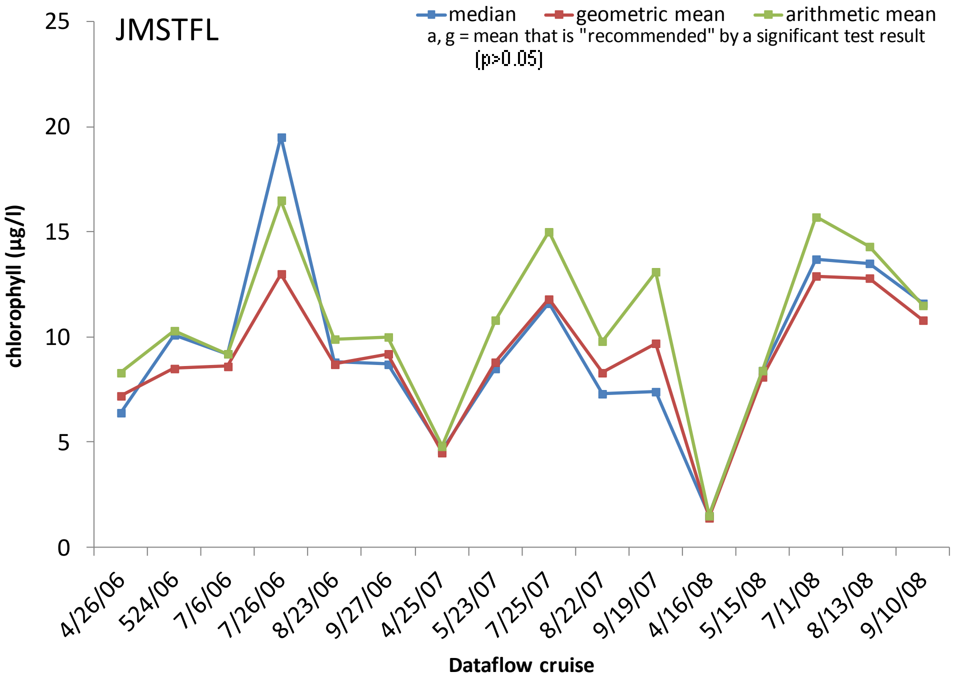


APPENDIX II

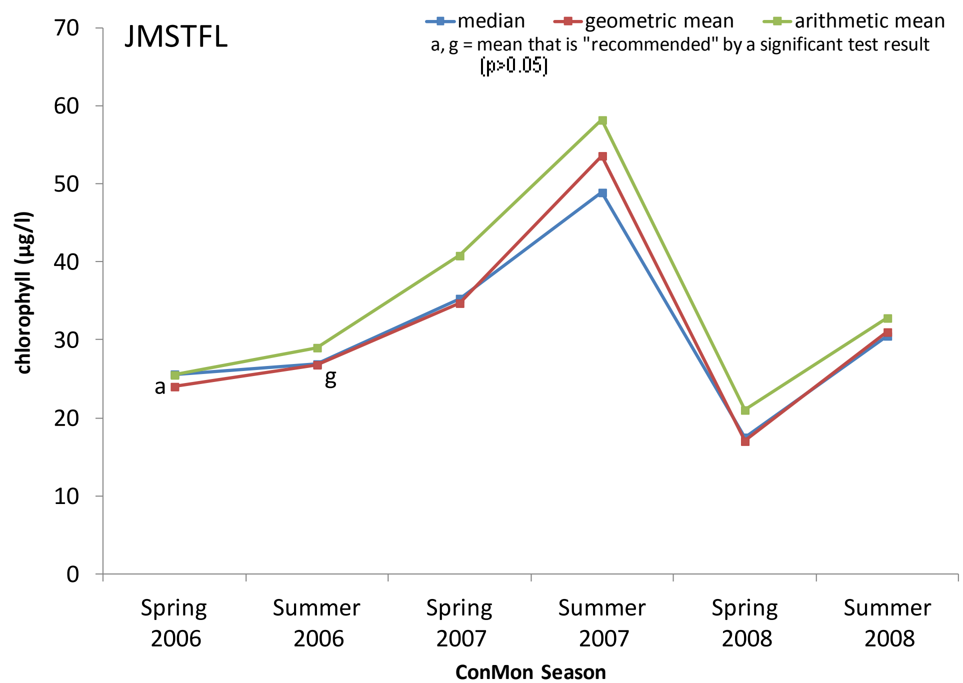
The figures below compare different measures of central tendency for James River chlorophyll by segment. Dataflow chlorophyll measurements were spatially interpolated (via kriging) to Bay Interpolator centroids, and then the resulting estimates were averaged. Midnight (12:00AM) and noon (12:00PM) ConMon measurements taken throughout each season were averaged. The following distribution tests were used to determine the goodness-of-fit with lognormal and normal distributions: Kolmogorov-Smirnov test, Anderson-Darling test, Lilliefors-van Soest test, Cramer-von Mises test, Ryan-Joiner test, d'Agostino-Pearson test, and Shapiro-Wilks test. Lognormality is indicated in all temporal datasets, while spatial lognormality was suggested in only JMSTFL, JMSMH, and JMSPH.


JMSTFU
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result (p>0.05)
chlorophyll (µg/l)
Dataflow cruise
4/27/06
5/25/06
7/6/06
7/27/06
8/24/06
9/28/06
4/26/07
5/24/07
7/26/07
8/23/07
9/22/07
7/2/08
8/14/08
9/11/08

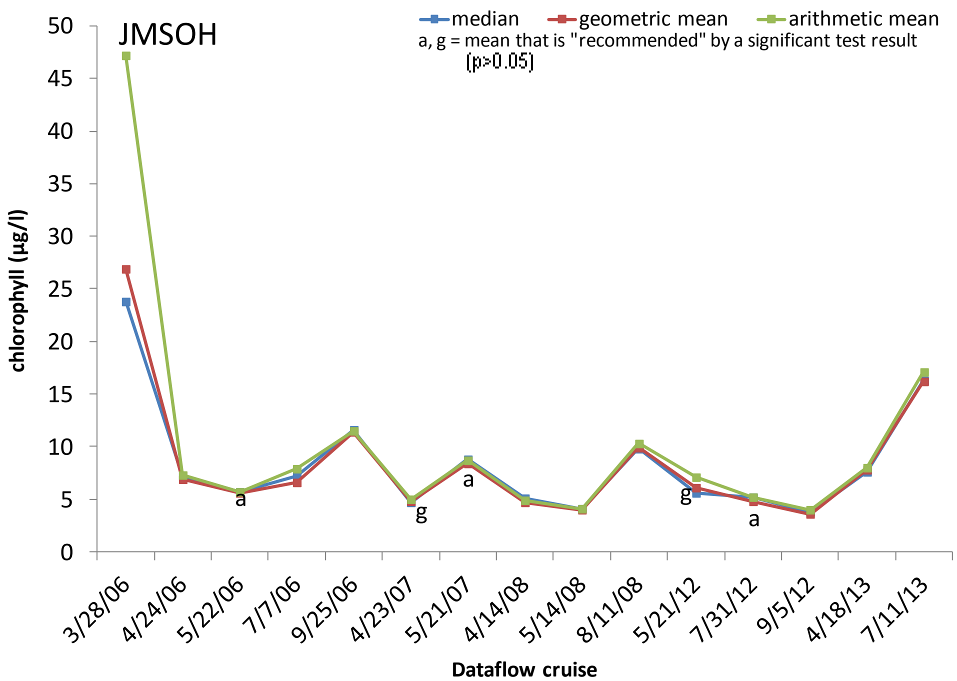

JMSTFU
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result (p>0.05)
chlorophyll (µg/l)
ConMon Season
Spring 2006
Summer 2006
Spring 2007
Summer 2007
Spring 2008
Summer 2008

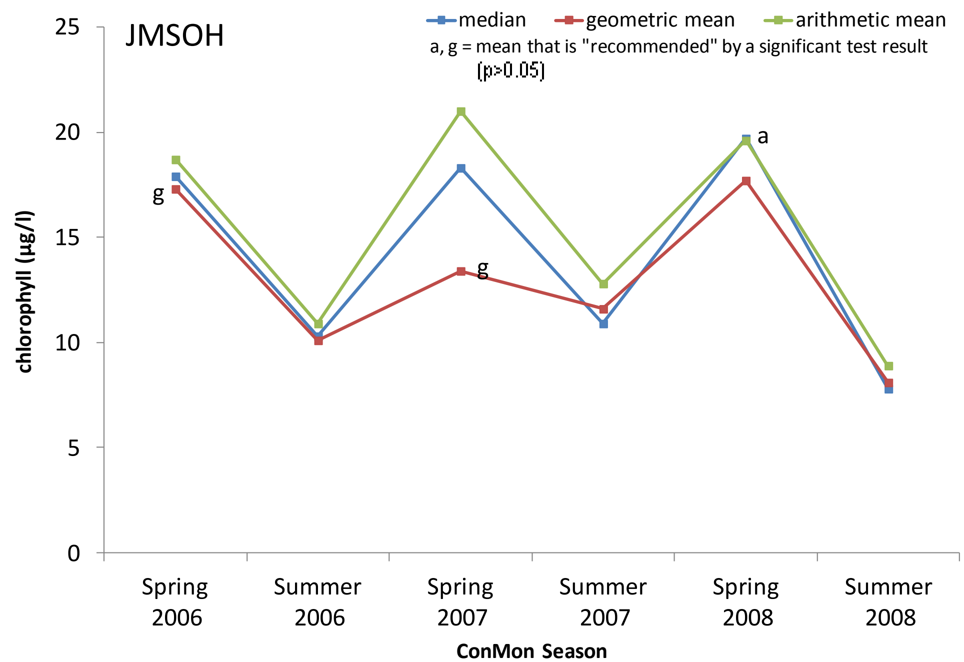


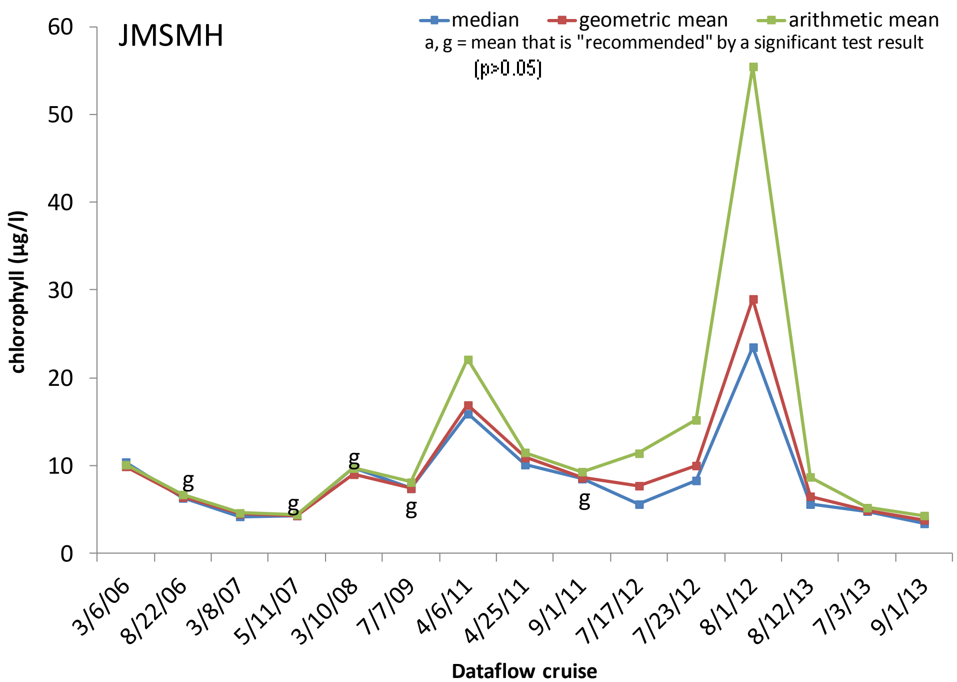
JMSTFL
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
25
20
15
10
5
0
4/26/06
524/06
7/6/06
7/26/06
8/23/06
9/27/06
4/25/07
5/23/07
7/25/07
8/22/07
9/19/07
4/16/08
5/15/08
7/1/08
8/13/08
9/10/08
Dataflow cruise

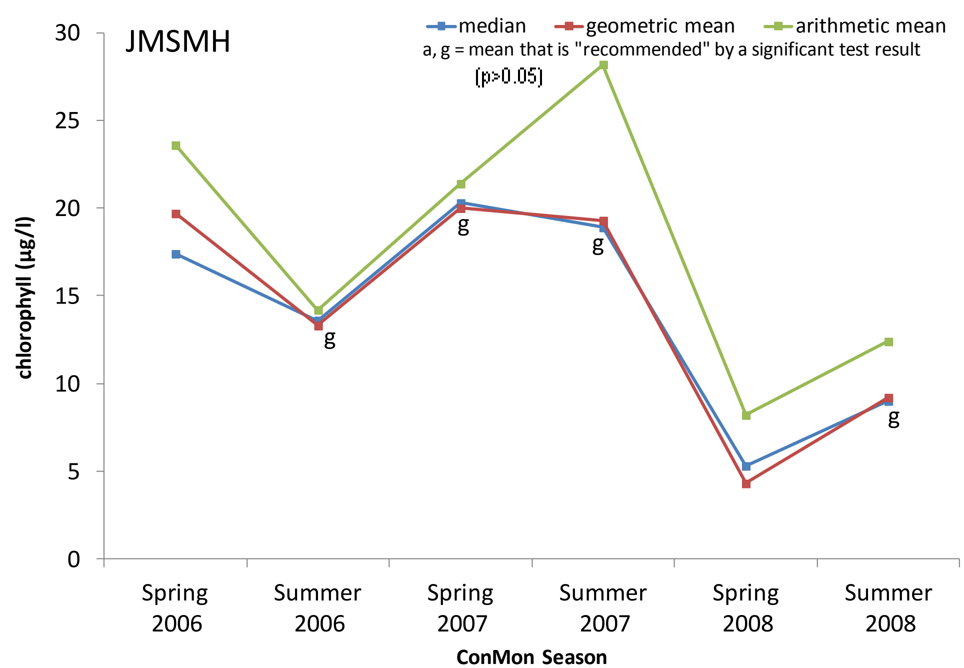


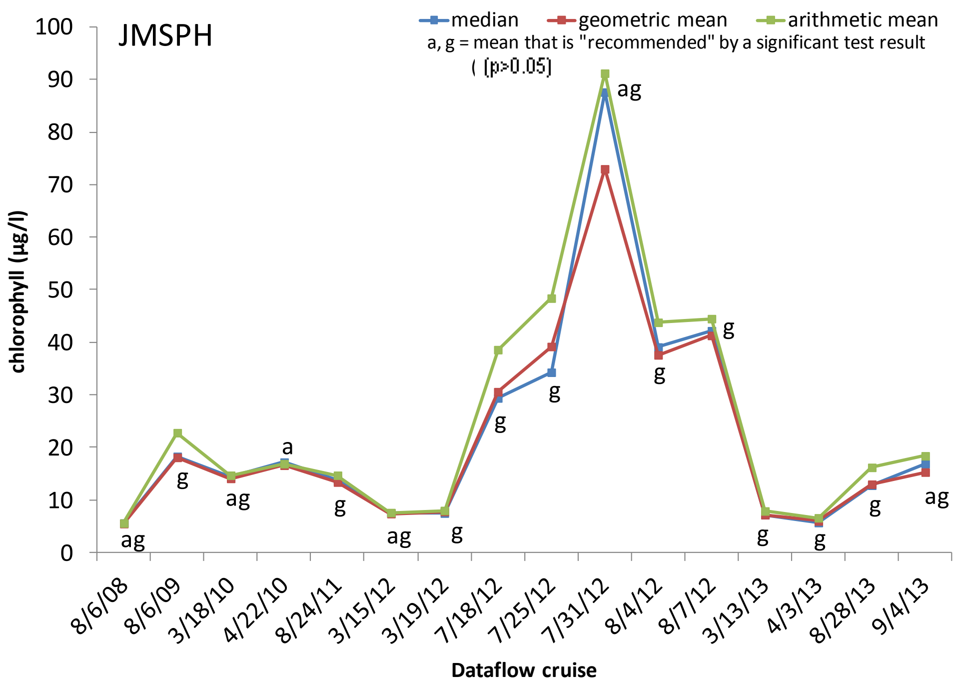
JMSTFL
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
70
60
50
40
30
20
10
0
a
g
Spring 2006
Summer 2006
Spring 2007
Summer 2007
Spring 2008
Summer 2008
ConMon Season

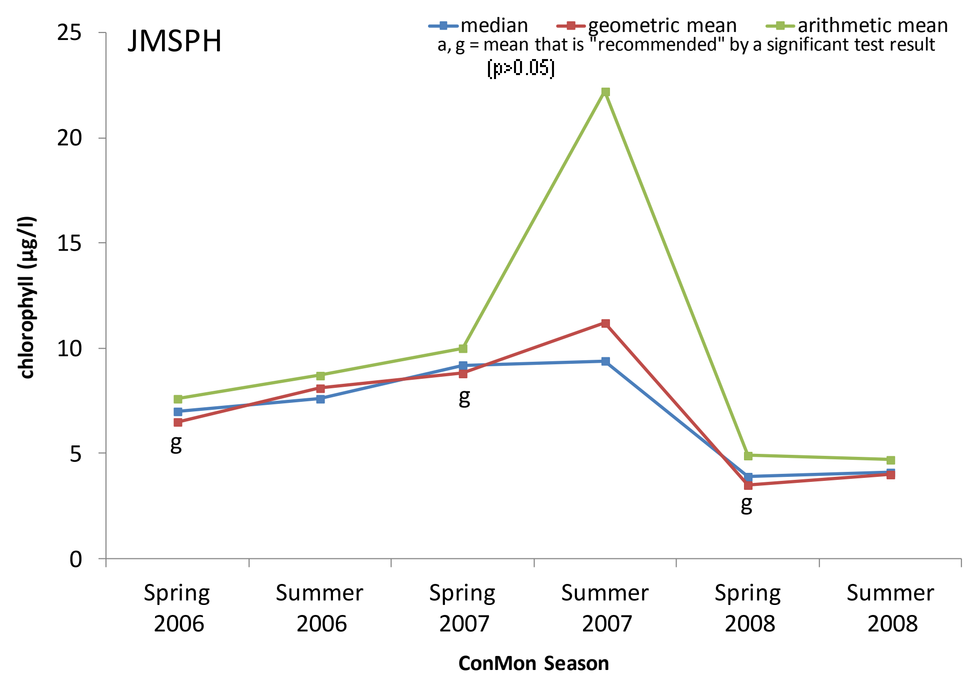

JMSOH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
Dataflow cruise
3/28/06
4/24/06
5/22/06
7/7/06
9/25/06
4/23/07
5/21/07
4/14/08
5/14/08
8/11/08
5/21/12
7/31/12
9/5/12
4/18/13
7/11/13


JMSOH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
Spring 2006
Summer 2006
Spring 2007
Summer 2007
Spring 2008
Summer 2008
ConMon Season


JMSMH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
0
10
20
30
40
50
60
3/6/06
8/22/06
3/8/07
5/11/07
3/10/08
7/7/09
4/6/11
4/25/11
9/1/11
7/17/12
7/23/12
8/1/12
8/12/13
7/3/13
9/1/13
Dataflow cruise


JMSMH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
0
5
10
15
20
25
30
Spring 2006
Summer 2006
Spring 2007
Summer 2007
Spring 2008
Summer 2008
ConMon Season


JMSPH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
((p>0.05)
chlorophyll (µg/l)
100
90
80
70
60
50
40
30
20
10
0
8/6/08
8/6/09
3/18/10
4/22/10
8/24/11
3/15/12
3/19/12
7/18/12
7/25/12
7/31/12
8/4/12
8/7/12
3/13/13
4/3/13
8/28/13
9/4/13
Dataflow cruise


JMSPH
median
geometric mean
arithmetic mean
a, g = mean that is "recommended" by a significant test result
(p>0.05)
chlorophyll (µg/l)
25
20
15
10
5
0
Spring 2006
Summer 2006
Spring 2007
Summer 2007
Spring 2008
Summer 2008
ConMon Season