APPENDIX 1 – Western Branch

Appendix 1. Data and metadata on the ten Western Branch Patuxent River Tidal Freshwater segment transects as reported by MDE. Note: Only stations #1-6 were located within the WBRTF segment.

River Name:	Western Branch
Station Code:	Station #1
Date:	9/7/2001
Scientist(s):	DJR/SGL
Riverbed Description:	Soft mud
Site Location:	N 38 47.139
	W 76 42.794
	25 yds upstream of pier at Calvert Manor
Digital Photo Series:	Folder 113, images 1-2
Comments:	165 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	7.5	0.00
15	2.50	15	37.50
30	4.50	15	67.50
45	5.00	15	75.00
60	5.00	15	75.00
75	5.00	15	75.00
90	5.30	15	79.50
105	5.30	15	79.50
120	4.50	15	67.50
135	3.50	15	52.50
150	1.50	15	22.50
165	0.00	7.5	0.00

Sum of (depth*width) = Area of streambed = 631.50 (sq.feet)

River Name: Western Branch

Station Code: Station #2

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Soft mud

Site Location: N 38 47.305

W 76 42.898

10 yds downstream of Horse Cavern Branch

Digital Photo Series: Folder 113, images 3-5

Comments: 135 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	5	0.00
10	3.00	12.5	37.50
25	3.50	15	52.50
40	5.20	15	78.00
55	6.30	15	94.50
70	7.30	15	109.50
85	7.10	15	106.50
100	5.00	15	75.00
115	3.00	15	45.00
130	2.00	10	20.00
135	0.00	2.5	0.00

Sum of (depth*width) = Area of streambed = 618.50 (sq.feet)

River Name: Western Branch

Station Code: Station #3

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Harder more solid mud

Site Location: N 38 47.490

W 76 43.022

Digital Photo Series: Folder 113, images 6-8

Comments: 150 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	7.5	0.00
15	3.00	15	45.00
30	6.20	15	93.00
45	5.50	15	82.50
60	5.00	15	75.00
75	4.75	15	71.25
90	4.50	15	67.50
105	4.00	15	60.00
120	3.00	15	45.00
135	1.75	15	26.25
150	0.00	7.5	0.00

Sum of (depth*width) = Area of streambed = 565.50 (sq.feet)

River Name: Western Branch

Station Code: Station #4

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Harder more solid mud

Site Location: N 38 47.485

W 76 43.239

Downstream of small unnamed trib

Digital Photo Series: Folder 113, images 9-11

Comments: 135 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	5	0.00
10	2.00	12.5	25.00
25	3.00	15	45.00
40	3.50	15	52.50
55	4.25	12.5	53.13
65	5.50	10	55.00
75	6.50	10	65.00
85	8.00	12.5	100.00
100	2.70	15	40.50
115	2.00	12.5	25.00
125	2.00	10	20.00
135	0.00	5	0.00

Sum of (depth*width) = Area of streambed = 481.13 (sq.feet)

River Name: Western Branch

Station Code: Station #5

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Sand/Mud, hard bottom

Site Location: N 38 47.777

W 76 43.316

Digital Photo Series: Folder 113, images 12-13

Comments: 120 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	6	0.00
12	1.50	12	18.00
24	5.00	12	60.00
36	4.00	12	48.00
48	4.00	12	48.00
60	4.25	12	51.00
72	4.50	12	54.00
84	4.00	12	48.00
96	3.50	12	42.00
108	1.75	12	21.00
120	0.00	6	0.00

Sum of (depth*width) = Area of streambed = 390.00 (sq.feet)

River Name: Western Branch

Station Code: Station #6

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Sandy hard mud

Site Location: N 38 47.832

W 76 43.746

50 yds downstream of WSSC outfall

Digital Photo Series: Folder 113, images 14-18

Comments: 66 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	2.5	0.00
5	4.00	7.5	30.00
15	4.50	12.5	56.25
30	5.25	10	52.50
35	6.00	5	30.00
40	6.50	5	32.50
45	7.50	5	37.50
50	8.00	5	40.00
55	4.00	5	20.00
60	3.00	5.5	16.50
66	0.00	3	0.00

Sum of (depth*width) = Area of streambed = 315.25 (sq.feet)

River Name:	Western Branch	
Station Code:	Station #7	
Date:		9/7/2001
Scientist(s):	DJR/SGL	
Riverbed Description:	Sandy hard mud	
Site Location:	N 38 47.858	W 76 44.046 700 yds upstream of effluent
Digital Photo Series:	Folder 113, images 19-21	
Comments:		48 ft wide

Orientation: Looking downstream measurements were collected left to right

Length	Depth
0	0.00
6	4.25
12	4.50
18	5.00
24	5.00
30	5.25
36	5.25
42	4.50
48	0.00

Sum of (depth*width) = Area of streambed = 202.50

River Name: Western Branch

Station Code: Station #8

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Sandy hard mud

Site Location: N 38 47.957

W 76 43.874

Digital Photo Series: Folder 113, images 22-24

Comments: 48 ft wide

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	2.5	0.00
5	2.50	7.5	18.75
15	3.25	7.5	24.38
20	3.50	7.5	26.25
30	4.50	10	45.00
40	4.00	7.5	30.00
45	3.00	4	12.00
48	0.00	1.5	0.00

Sum of (depth*width) = Area of streambed = 156.38 (sq.feet)

River Name: Western Branch

Station Code: Station #9

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Hard mud

Site Location: N 38 48.550

W 76 44.435

Route 301 crossing

Digital Photo Series: Folder 113, images 25-26

Comments: 47 ft. wide. Had to do the geometry off the bridge

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	2.5	0.00
5	1.00	5	5.00
10	1.00	5	5.00
15	1.60	5	8.00
20	1.60	5	8.00
25	1.70	5	8.50
30	2.30	5	11.50
35	2.50	5	12.50
40	2.90	5	14.50
45	2.50	3.5	8.75
47	0.00	1	0.00

Sum of (depth*width) = Area of streambed = 81.75 (sq.feet)

River Name: Little Patuxent River

Station Code: RM-28, LTX0248

Date: 7/1/2002

Scientist(s): DJR,GWL,RKN

Riverbed Description: 10% Silt, 70% Sand, 10% Gravel, 10% Cobble

Site Location: N 39 12.555

W 76 51.359

Digital Photo Series: N/A

Comments: 29.5 ft. wide

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width	
				Low
0.5	0.10	0.25	0.03	Bank
1	1.00	0.75	0.75	
2	3.00	1	3.00	Water's Edge, Left Bank
3	4.50	2	9.00	
6	4.00	3	12.00	
9	3.50	3	10.50	
12	3.40	3	10.20	
15	3.40	3	10.20	
18	3.20	3	9.60	
21	3.20	3	9.60	
24	3.30	3	9.90	
27	3.00	2.5	7.50	Water's Edge, Right Bank
29	2.70	1.5	4.05	
30	0.10	0.5	0.05	High Bank

Sum of (depth*width) = Area of streambed = 29.50 (sq.feet)

Appendix 2

Centroid coordinates for the 45 grid cells used to define WBRTF segment. The coordinates are in the UTM Zone 18 NAD83 projection.

Id	X	Y	Depth
1	351200	4294300	1
2	351200	4294350	1
3	351150	4294400	1
4	351150	4294450	1
5	351150	4294500	1
6	351100	4294550	1
7	351100	4294600	1
8	351050	4294650	1
9	351050	4294700	1
10	351050	4294750	1
11	351000	4294800	1
12	351000	4294850	1
13	351000	4294900	1
14	351000	4294950	1
15	350550	4295000	1
16	350600	4295000	1
17	350650	4295000	1
18	350700	4295000	1
19	350750	4295000	1
20	350800	4295000	1

21	350850	4295000	1
22	350900	4295000	1
23	350950	4295000	1
24	350550	4295050	1
25	350550	4295100	1
26	350550	4295150	1
27	350550	4295200	1
28	350550	4295250	1
29	350550	4295300	1
30	350600	4295350	1
31	350600	4295400	1
32	350600	4295450	1
33	350550	4295500	1
34	350450	4295550	1
35	350500	4295550	1
36	350350	4295600	1
37	350400	4295600	1
38	350250	4295650	1
39	350300	4295650	1
40	350100	4295700	1
41	350150	4295700	1
42	350200	4295700	1
43	349950	4295750	1
44	350000	4295750	1
45	350050	4295750	1

APPENDIX 3

EVOLUTION OF CHESAPEAKE BAY PROGRAM SHALLOW WATER MONITORING PROGRAMS AND RELATED SCIENCE IN CHESAPEAKE BAY

In the late 1990s and early 2000s shallow water sampling efforts across Chesapeake Bay and its tidal tributaries intensified by a variety of agencies and institutions with an emphasis on understanding nearshore water quality conditions. While short term (commonly 3-day to 1 week), fixed site deployments of continuous monitoring sensors in offshore waters were conducted for programs such as U.S. EPA EMAP efforts in the 1980s and early 1990s (see Chapter V in U.S. EPA 2004), long-term, seasonal scale deployments of water quality sensors in shallow water habitats took hold in Chesapeake in the late 1990s. In 1998, MD DNR used fixed site continuous water quality monitoring to track lower Pocomoke River conditions in a region of repeated fish kills (http://www.dnr.state.md.us/bay/cblife/algae/dino/pfiesteria/97v98.html). These rapid expansion of temporally and spatially intensive shallow-water focused monitoring efforts arose in response to a wide range of factors coalescing in time including 1) the improvement of in-situ water quality sensor packages for long-term deployments, 2) affordability of the in-situ technology, 3) 1999-2002 pilot studies demonstrating sampling of water quality using in-situ samplers in fixed station, continuous monitoring mode and in DATAFLOW or underway sampling mode mapping conditions of estuarine surface waters (U.S. EPA 2007a), 4) computer data storage abilities to handle high density data streams from in-situ data loggers, 5) fish kill distributions in Chesapeake Bay (Maryland Department of the Environment, Chris Luckett, pers. Comm.), 6) increasing science that linked harmful algal bloom plankton species (HABs) found in estuaries with the potential to produce toxins coincidently capable of negatively affecting fish and human health (Burkholder and Glasgow 1997, Grattan et al. 1998, Stow 1999), 7) identification of such toxigenic HAB species of concern in Chesapeake Bay and its tidal tributaries (Marshall 1996, Deeds et al. 2002, Marshall 2003, Tango et al. 2004, Tango and Butler 2008), 8) toxigenic HAB species found at Chesapeake Bay fish kill sites in shallow water environments (Tango et al. 2006), 9) human health incidences from water contact at locations with *Pfiesteria, Pfiesteria*-like organisms or potential *Pfiesteria*-related fish kills in shallow estuarine tributaries or embayments (Oldach 1999, Glasgow et al. 2001, Schmecl and Koltai 2001, Shoemaker 2001, Shoemaker and Hudnell 2001), 10) lack of understanding about the water quality conditions associated with coincidence of HABs, fish kills, fish health and human health events in Chesapeake Bay and other estuaries (Tango et al. 2005, Tango and Butler 2008, Tango et al. 2008), and 11) NOAA CSCOR grant funding to Chesapeake Bay Program partners supporting expanded monitoring for gaining greater understanding into water quality and living resource linkages in Chesapeake Bay (Tango et al. 2006).

In July 2001, the Chesapeake Bay Program Monitoring and Analysis Subcommittee's Tidal Monitoring and Analysis Workgroup formed a Tidal Monitoring Design Team. Over 2 years, the team developed recommendations for implementing a monitoring network that addressed the primary objective of supplying the water quality information needed to assess the suite of new water quality criteria for dissolved oxygen, water clarity and chlorophyll *a* – ultimately with the goal of supporting measurement and assessment protocols that would remove the Chesapeake Bay and its tidal rivers from the list of impaired waters (U.S. EPA 2007a). The design of the expanded Tidal Monitoring Network emphasized monitoring of the shallow-water designated use areas. To capture temporal variability in dissolved oxygen, the new Tidal Monitoring Network incorporated high-frequency monitoring stations in surface waters at nearshore locations.

In 2003 the U.S. EPA Chesapeake Bay Program formally initiated a Shallow-Water Monitoring Program to complement the long term water quality monitoring program fixed site, mid-channel assessments. The resulting shallow-water monitoring program uses 1) a network of fixed site, high temporal frequency sensors located throughout shallow water habitats of the Bay and its tidal tributaries to collect local water quality measurements on scales of 15 minutes to 1 hour, and 2) monthly or biweekly Dataflow (i.e., high-density spatial mapping of surface water quality conditions where measurements are taken in-situ while underway and recorded at 3-4 second intervals).

More recently, the Chesapeake Bay tidal water monitoring networks have grown to include extended, season-long deployments of offshore, high frequency vertical water quality monitoring profilers at two sites in Virginia (York mesohaline and Rappahannock mesohaline) and at short term deployment sites in other Maryland waters (e.g. Potomac River, Harris Creek of the Choptank River). The high density measurements for continuous water quality monitoring complement information collected from the mid-channel long term biweekly to monthly water quality profiles of Bay and tributary conditions. Other monitoring resources that have come online to potentially support nearshore-offshore water quality behavior comparisons now or in the future include: a NOAA surface water, high frequency water quality buoy data network, a NOAA bottom water quality sensor at Gooses Reef, Virginia Institute of Marine Science tests of an underwater towed sensor package, and U.S. Navy tests of Autonomous Underwater Vehicles. This variety of new, high-frequency water quality data streams provide new opportunities for understanding habitat condition comparisons with dissolved oxygen.

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APPENDIX 4

DISSOLVED OXYGEN (DO) CRITERIA ATTAINMENT ANALYSIS FOR SHALLOW WATER HABITATS USING CONTINUOUS MONITORING DATA SETS.

[UMCES Technical Series No. TS-606-10-CBL]. Boynton, W.R., E.M. Bailey, L.A. Wainger and A.F. Drohan. 2010. In: Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 27. Jul. 1984 - Dec. 2009. Ref. No. [UMCES] CBL 10-098.

Part 1. Dissolved Oxygen (DO) Criteria Attainment Analysis for Shallow Water Habitats Using ConMon Data Sets

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Introduction

Until the last decade, water quality monitoring in Chesapeake Bay and tributary rivers was largely based on monthly or bi-monthly sampling at fixed stations located over the deeper (channel) portions of these systems. Such a design had many benefits, especially those related to developing seasonal to inter-annual scale indices of water quality status and trends. However, as in virtually all environmental science activities, a single measurement scheme is not adequate for addressing all questions. Thus, about a decade ago, a new program was initiated, first on a pilot-scale basis, to add measurements of water quality for shallow near-shore habitats. Concern for SAV habitat quality was a prime consideration in developing this program.

The program was named ConMon to indicate the near-Continuous Monitoring feature of this activity. The program used in-situ sensor systems (YSI Sondes) programmed to take measurements of a suite of water quality variables every 15 minutes. Included in the water quality suite was water temperature, salinity, pH, DO, turbidity and chlorophyll-a. In most instances ConMon sites were active from April – October (the SAV growing season) and in most cases sites remained active for three years. In a few cases, sites have remained active for up to 9 years, thus serving as long-term or sentinel sites. To place this sampling intensity in perspective, at a typical main channel site about 16 measurements of water quality variables were collected per year. In contrast, at a ConMon site about 20,500 measurements per year are obtained, an intensity of measurement about three orders of magnitude higher than traditional monitoring.

There have been about 60 sites in the Maryland Bay and Maryland Coastal Bays where ConMon data have been collected. The program is continuing although at somewhat fewer sites than in the recent past. The considerable spatial extent (encompassing sites with water quality varying from quite good to very poor) of these data sets allows for comparative analyses wherein it is likely that relationships between near-shore water quality and management actions can be found.

There are several prime uses of ConMon data sets. First, they have been used as a guide in selecting and monitoring SAV habitat restoration sites. Second, these data have "opened our eyes" to a new scale of hypoxia, namely diel-scale hypoxia wherein DO concentrations can reach critically low levels at night (and especially in the immediate post-dawn hours). Third, these data can be used to make estimates of community production and respiration, both of which are fundamental ecosystem features known to be related to nutrient loading rates. Fourth, these data can be used in DO criteria assessments for shallow open water sites (EPA 2010).

It is the last ConMon use that is the focus of this chapter. In an earlier portion of this report the strategy and details of making DO criteria assessments using ConMon data have been described. In this section we provide examples of DO criteria % non-attainment for three sites in the Bay system. It remains unclear as to which of several approaches best captures meaningful DO non-attainment; we present results of all approached in this section. There is a STAC-sponsored DO criteria workshop scheduled for the fall of 2010 and we will participate in this workshop and hopefully arrive at a consensus approach for computing this metric.

Methods

Continuous monitoring data was obtained from Maryland Department of Natural Resources Tidewater Ecosystems Assessment division in electronic (.txt file) format (dnr_cmon_sonde_2001-08). This file contained all the collected ConMon data from 2001 to 2008. A SAS® (www.sas.com) program was written to allow selection of dissolved oxygen data by station and year. The program then calculated 6 different methods/averages (Table 4-1) and gave each occurrence of dissolved oxygen (instantaneous or averaged) a score of 1 if lower than the criteria and a score of 0 if equal to or above (based on Chesapeake Bay Program guidelines and discussions with MDDNR and TWMAW). Criteria were chosen prior to selecting specific stations and we selected the higher DO value to make this analysis more "conservative."

Table 1. Calculation methods, file names, descriptions and criteria used for DO criteria % non-attainment calculations.

Calculation Method	SAS Filename	Description	DO Criteria
Instantaneous	doyyyST_allcrit	Uses every available data point (~every 15 minutes per annual data set).	4 mg L^{-1}
Daily Mean	doyyyST_daycrit	Takes the mean DO for all measurements over the course of 24 hours. No data point is reused in the calculation.	4 mg L^{-1}
7 Day Moving Average	doyyyyST_wkcrit	Takes the mean DO for a 7 day chunk of data moving forward 15 minutes for each iteration. Measurements are reused.	4 mg L^{-1}
1 Average per 7 Days	doyyyyST_1perwk	Takes a mean DO for all measurements over the course of 7 days. No data point is reused in the calculation.	4 mg L^{-1}
30 Day Moving Average	doyyyyST_moncrit	Takes the mean DO for a 30 day chunk of data moving forward 15 minutes for each iteration. Measurements are reused.	5 mg L^{-1}
1 Average per 30 Days	doyyyyST_1pmo	Takes a mean DO for all measurements over the course of 30 days. No data point is reused in the calculation.	5 mg L^{-1}

Exact criteria values will be refined in FY2011 in consultation with MDDNR for each specific station and month. SAS output files were named DO(dissolved oxygen), yyyy (year), ST (two-letter station code), underscore followed by an identifier for the calculation method used. Percent non-attainment was calculated as: (sum of the non-attainment score)/(total # of observations) * 100. Percent non-attainment was calculated for the entire available annual dataset, June-August and July.

Results from Selected Sites

Estimates of DO % non-attainment have been developed for three sites in the Bay system. The first site was St George's Island (XBF7904), located in a small embayment of the lower portion of the Potomac River estuary. This site was chosen for initial analysis because water quality at this site is relatively good compared to many other Maryland tributary sites. Water quality here was good enough for this site to be selected for SAV restoration work. ConMon data are available for this site for the years 2006-2008. The second site selected was Sycamore Point (XHH3851), located in the upper portion of the Corsica River estuary. Multi-year monitoring of this site indicates poor to very poor water quality and there are indications from Dataflow mapping that some water quality conditions have been deteriorating further in recent years. Data for the years 2005-2008 were available for this analysis. The third site was the Fort McHenry site

(XIE5748) located in the Patapsco River estuary, adjacent to the city of Baltimore, MD. This site was selected because it is an urban site and because there is a considerable ConMon record available from this site.

Low Impact Site (St. George's Island, Lower Potomac River: XBF7904)

Results of DO % non-attainment are summarized for the St George's Island site (2006-2008) in Table 4-1 and Figures 4-1 to 4-3. For each year, 6 different averaging schemes were employed; these have been described earlier in this chapter. Across the top of Table 4-2 a simple average DO concentration was calculated for three time periods, including: 1) the whole year (Jan-Dec); 2) summer period (Jun – Aug) ; and 3) just the month of July. Further to the right in Table 1 DO % non-attainments were calculated for each time period using all 6 averaging schemes. Several patterns are readily evident.

First, % non-attainment consistently increases with smaller time period evaluations. For example, during 2006, the "All Data" computation indicated 4% non-attainment for the whole year evaluation, 8% for the summer evaluation and 10% for the July evaluation. At this site, the July evaluation for all % non-attainment approaches was the highest and this was also true for all three years evaluated. It is interesting to note that hypoxia/anoxia in the mainstem Bay reaches a maximum in July of most years since the monitoring program began in 1985. It may be that the single most critical water quality month is July in most years. Further analysis will clarify this issue.

Second, it is not completely clear which of the averaging techniques provides the most sensitive metric of DO non-attainment. For data collected during 2006 and 2007 it appears that the "All Data" approach detected more non-attainments than any other approach (i.e., it was the most protective). However, during 2008 the same pattern did not emerge. In fact, some counter-intuitive results emerged. The highest July % non-attainment emerged from the 30 day moving average approach, a considerably larger % non-attainment than that obtained from all other approaches, including the "All Data" approach. The fact that the 30 day average had a higher criteria threshold (5 mg/l vs 4 mg/l for other averaging schemes) probably played into this result. Based on results from this single site, it appears that the 7-day moving average and the 1 average per 30 days did not detect DO non-attainment as frequently as did other averaging schemes.

Another way of visualizing these computations is shown as a sequence of three box and whisker plots (Figures 4-1–3; 2006, 2007 and 2008, respectively). In these figures data for the entire annual ConMon data set were included (whole year). What is clear in these diagrams is that the mean of the full data set were always above criteria thresholds (5 and 4 mg L^{-1}). However, instances of non-attainment were most frequently observed using the "all Data", daily mean and, to a lesser extent, the 7-day moving average approaches. The final three computation methods detected no criteria violations during 2006 (Figure 4-1), only a few during 2007 (Figure 4-2) and a few more during 2008 (Figure 4 3), the year with the poorest water quality.

Table 2. A summary of DO % non-attainment estimates from the St George's Island ConMon site for the period 2006-2008. The various methods of computing % DO non-attainment were described in the methods section of this chapter. The "whole year" columns used data for the period April-October. Other calculation periods are as indicated in the table.

St. George's Island (XBF7904)

Year	Method	Available Annual Dataset Mean	June through August Mean	July Mean	Available Annual Dataset % Non-Attainment	June through August % Non-Attainment	July % Non-Attainment
2006	Instantaneous	6.69	5.78	5.68	4	8	10
	Daily Mean				1	2	3
	7 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 7 Days				0	0	0
	30 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 30 Days				0	0	0
2007	Instantaneous	7.05	5.73	5.35	5	9	17
	Daily Mean				2	4	13
	7 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 7 Days				0	0	0
	30 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 30 Days				0	0	0
2008	Instantaneous	7.11	5.33	5.07	10	21	27
	Daily Mean				4	9	17
	7 Day Moving Average (15 min. increment)				1	1	4
	1 Average per 7 Days				4	8	25
	30 Day Moving Average (15 min. increment)				12	25	40
	1 Average per 30 Days				0	0	0

Perhaps the strongest "take-home" messages from analyses at this site is that DO criteria violations occur even at sites with relatively good water quality and that substantial inter-annual variability exists relative to DO non-attainments…some years are clearly better than others. To a large degree this finding is consistent with findings using the historical Cory data set collected from 1964-1969 in the Patuxent River estuary.

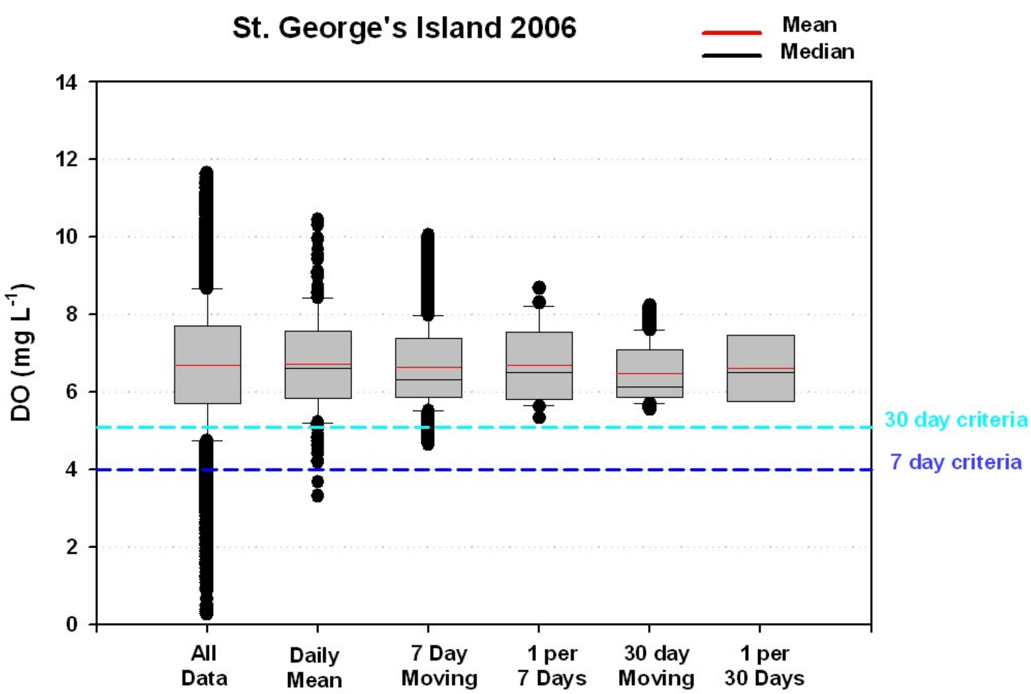

Figure 4-1. Box and whisker plots of DO concentration based on data collected at the St. George's Island ConMon site in the lower Potomac River estuary during 2006. The categories indicated on the x-axis were described in the Method section of this chapter. The two horizontal lines indicate DO criteria concentrations for open water sites.

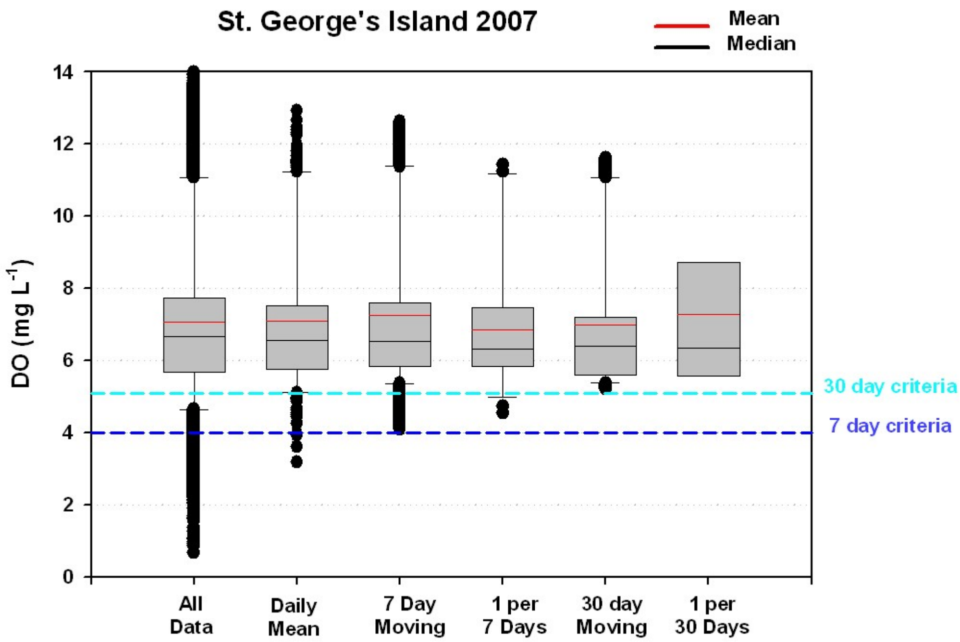

Figure 4-2. Box and whisker plots of DO concentration based on data collected at the St. George's Island ConMon site in the lower Potomac River estuary during 2007. The categories indicated on the x-axis were described in the Method section of this chapter. The two horizontal lines indicate DO criteria concentrations for open water sites.

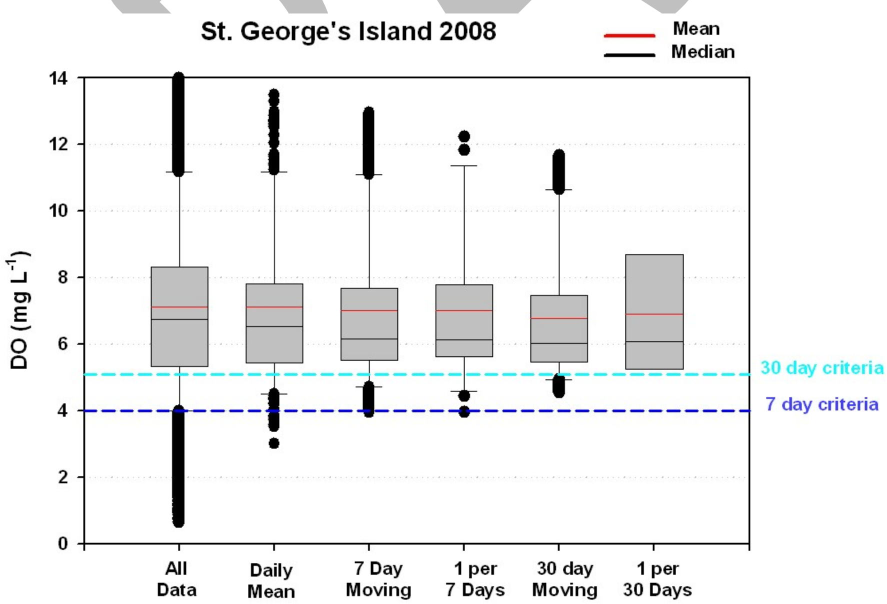

Figure 3. Box and whisker plots of DO concentration based on data collected at the St. George's Island ConMon site in the lower Potomac River estuary during 2008. The categories indicated on the x-axis were described in the Method section of this chapter. The two horizontal lines indicate DO criteria concentrations for open water sites.

High Impact Site (Sycamore Point, Upper Corsica River: XHH3851)

The Sycamore Point site in the upper portion of the Corsica River estuary is heavily impacted by nutrient additions, mainly from the agriculturally dominated watershed (Boynton *et al.* 2009). Results from % DO non-attainment for this site are summarized in Table 4-3. Several important points emerge. First, there were far higher % non-attainment rates observed at this site than at the St. George's Island site, as expected. The St. George's Island site is relatively "clean" compared the Sycamore Point site. In addition, the Sycamore Point site has far higher % non-attainment results than found in the historical data from the Cory ConMon site operated in the 1960s. Thus, it appears that there is considerable range in results consistent with our general impressions of water quality.

As at the previous site, there was not a clear result concerning the metric that might be adopted for general use in criteria attainment or non-attainment. For example, the All Data and the Daily Mean approaches tended to detect the highest failure rates. But, this was not always the case. During 2006 both the 30 day moving average and the 1 average per 30 days produced failure rates higher than the previously mentioned metrics. It may well be that the differences in criteria threshold values (4 versus 5 mg O_2 L^{-1}) were that cause of this result. However, data from both 2005 and 2008 do not support this conclusion.

Table 3. A summary of DO % non-attainment estimates from the Corsica River, Sycamore Point (XHH3851) ConMon site for the period 2005-2008. The various methods of computing % DO non-attainment were described in the methods section of this chapter. The "whole year" columns used data for the period April-December. Other calculation periods are as indicated in the table.

Sycamore Point (XHH3851)

Year	Method	Available Annual Dataset Mean	June through August Mean	July Mean	Available Annual Dataset % Non-Attainment	June through August % Non-Attainment	July % Non-Attainment
2005	Instantaneous	8.05	5.55	5.51	16	36	39
	Daily Mean				12	25	32
	7 Day Moving Average (15 min. increment)				3	11	16
	1 Average per 7 Days				3	11	0
	30 Day Moving Average (15 min. increment)				3	8	22
	1 Average per 30 Days				0	0	0
2006	Instantaneous	9.10	4.96	5.40	12	37	27
	Daily Mean				8	28	14
	7 Day Moving Average (15 min. increment)				10	36	17
	1 Average per 7 Days				6	29	0
	30 Day Moving Average (15 min. increment)				13	45	29
	1 Average per 30 Days				11	100	ND
2007	Instantaneous	8.57	4.93	5.76	16	47	35
	Daily Mean				13	41	30
	7 Day Moving Average (15 min. increment)				9	29	23
	1 Average per 7 Days				3	9	0
	30 Day Moving Average (15 min. increment)				18	56	6
	1 Average per 30 Days				25	100	ND
2008	Instantaneous	10.03	5.95	5.22	10	29	39
	Daily Mean				6	16	29
	7 Day Moving Average (15 min. increment)				1	4	12
	1 Average per 7 Days				0	0	0
	30 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 30 Days				0	0	0

The time span considered in these evaluations also needs consideration. Without exception, the "Whole Year" computations of % non-attainment were lowest and therefore likely the least protective. When compared to the June-August % non-attainment rates the whole year rates were 2 to 3 times less frequent. However, July alone non-attainment rates were not always higher than those computed from a longer summer period (June – August). We had originally suspected that the July alone computations would yield the highest % non-attainment rates because investigations of hypoxia in deeper waters indicates this month to consistently have the most severe hypoxia. That turns out not to be the case. Of the 24 comparisons that can be made (6 computation schemes for each year and four years of data), 13 times % non-attainment was greater using the June-August data set while on 7 occasions the July only data set yielded higher % non-attainment results (4 cases of zero non-attainment were not included).

Urban Site (Fort McHenry, Patapsco River: XIE5748)

A summary of DO % non-attainment at the urban, Ft. McHenry site is presented in Table 4-4. Here again, results tended to follow many of the patterns seen at the others sites. First, there was substantial inter-annual variability. During 2004 the maximum DO % non-attainment was detected using the instantaneous metric (23%) and four of the remaining five metrics detected no failing DO conditions. During 2007, the instantaneous DO % non-attainment rate was much larger for all time periods (24-39%) and some small failure rates were found with the other metrics. Finally, it is now reasonably clear simple averages (left portion of table; pink background) are not sufficient to detect DO % non-attainment rates. At these relatively shallow sites (<2 m) DO variations on a daily basis can be severe because, in part, the effects of sediment respiration can be large and result in strong DO depressions, especially during the late night and early morning hours. The instantaneous metric appears to capture these events at this site better than any of the other metrics.

Table 4. A summary of DO % non-attainment estimates from the Fort McHenry (XIE5748) ConMon site in the Patapsco River for the period 2004 and 2007. The various methods of computing % DO non-attainment were described in the methods section of this chapter. The "whole year" columns used data for the period April-November. Other calculation periods are as indicated in the table.

Fort Mc Henry (XIE5748)

Year	Method	Available Annual Data Set Mean	June through August Mean	July Mean	Available Annual Data Set % Non-Attainment	June through August % Non-Attainment	July % Non-Attainment
2004	Instantaneous	7.09	6.17	5.65	13	18	23
	Daily Mean				6	10	13
	7 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 7 Days				0	0	0
	30 Day Moving Average (15 min. increment)				0	0	0
	1 Average per 30 Days				0	0	0
2007	Instantaneous	6.85	5.44	5.52	24	39	34
	Daily Mean				18	30	29
	7 Day Moving Average (15 min. increment)				7	7	0
	1 Average per 7 Days				10	9	0
	30 Day Moving Average (15 min. increment)				1	2	0
	1 Average per 30 Days				0	0	0

Relating DO Criteria % Non-Attainment to Other Water Quality Variables

One major goal of this work is to simply compute rates of % DO criteria non-attainment for shallow areas of the open water zone. As with many ecological issues, this one turns out to be not so simple. There are a variety of ways to compute this metric and it remains to be seen which might be the most appropriate method. There is also the issue of merging the DO criteria assessment associated with ConMon based data sets collected in shallow waters relative to open water assessments made with the traditional, low frequency monitoring data. It remains unclear as to just how this will be accomplished.

Finally, since there are not ConMon sites at all locations in the Bay and tributary rivers it would be useful to have some simple water quality variable(s) that could be used as a surrogate for data collected at a ConMon site. It would also be useful to link, in some quantitative fashion, % DO non-attainment results to other ecosystem features to explain the apparent large degree of inter-annual variability observed at some stations.

We are at early stages of this effort. However, data collected at the St George's Island ConMon site can serve as an example of future, and more thorough, efforts to link criteria results with management actions and general understanding. The % DO non-attainment results (developed using 4 different approaches) computed from 2006-2008 ConMon data were plotted as a function of Potomac River flow (Figure 4-4). In this analysis, two metrics of % DO non-attainment increased in a near-linear fashion as a function of river flow. Two other DO % non-attainment metrics remained very low until river flow was quite high at which point one increased slightly while the other exhibited a very large increase, threshold-like in nature. In this simple case the conceptual model supporting this analysis is based on the fact that river flow adds both freshwater (and buoyancy) as well as sediments and nutrients to these systems. Nutrients, in turn, tend to support higher rates of primary production. Organic matter resulting from this nutrient-stimulated production can cause increased respiration rates (utilization of DO) by the heterotrophic community. The net result, in this example, would be higher DO% non-attainment rates. We expect to continue this effort using a variety of water quality variables in addition to freshwater flow and nutrient loading rates. Variables such as TN, TP and chlorophyll-a concentration will be considered in an effort to better understand and predict levels of inter-annual variability of DO % non-attainment rates.

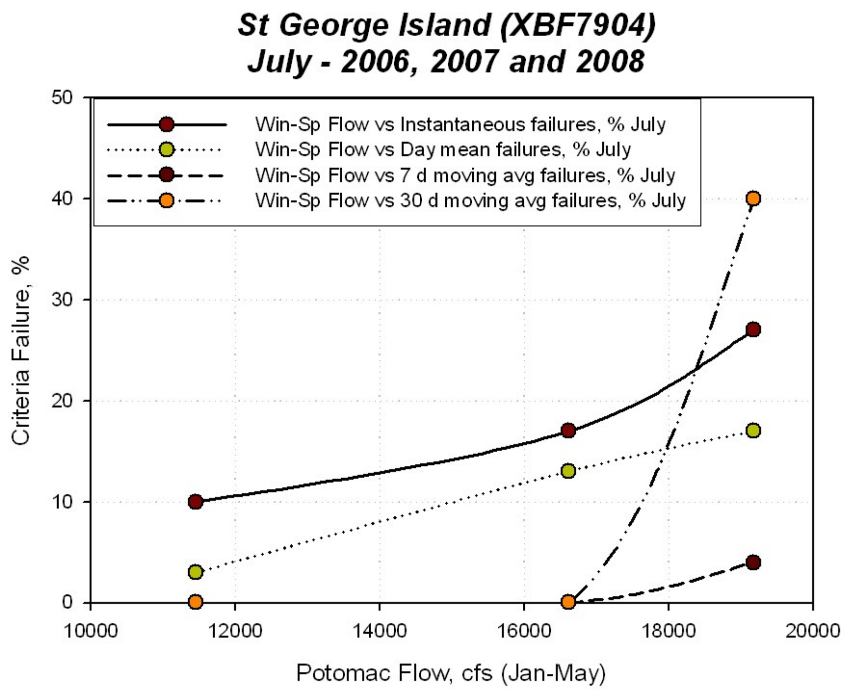

Figure 4. A multiple scatter plot of July DO % criteria non-attainment as a function of Potomac River flow (Jan-May flow period). Different DO % non-attainment calculation methods are indicated on the diagram.

References

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USEPA. 2010. Ambient water quality criteria for dissolved oxygen, water clarity and chlorophyll-a for the Chesapeake Bay and its tidal tributaries: 2010 technical support for criteria assessment protocols addendum. EPA 903-R-10_002 CBP/TRS 301-10. May 2010.

Appendix 5

PART 2. Shallow Water, High Frequency Measurements and the 30 Day Mean Umbrella Approach: Two Preliminary Computations

W. R. Boynton, E. M. Bailey, M. Hall and E. Perry

Background: The traditional water quality monitoring program, in place since 1984, obtains water quality measurements once or twice a month during daylight periods, generally between 0800 and 1500 hours, at many stations in the mainstem Bay and tributary rivers. These stations, for many good reasons, are generally located over the deeper channel areas of the Bay and tributary rivers. Over a decade ago, pilot studies were conducted to see if these main channel (or off-shore) measurements accurately represented water quality conditions in the shallow waters (< 2 m depth) of the Bay and tributary rivers. The answers to this question ranged, in some instances, from generally yes to, in other instances, generally no. Other evaluations concluded that deep versus shallow water quality conditions were inconsistent and little in the way of firm generalities could be developed. In addition, there was a continuing focus in the Bay Program on SAV restoration and these communities were, of course, centered in these shallow water habitats. With these questions and goals in mind, two programs were added to the monitoring program, one focused on obtaining a much finer spatial scale data set of water quality conditions with particular attention paid to actual or potential shallow water SAV habitat (dataflow program) and the other to obtaining both long-term (3 years or more) and temporally detailed (15 minute intervals) water quality measurements in shallow waters (ConMon program). This section deals with ConMon data.

At the present time a very large data base of ConMon measurements has been generated. Some 98 different sites have had ConMon measurements (for at least 3 years) in the Maryland portion of the Bay and tributary rivers and others have been made in Virginia. One of the central findings to emerge from this data set is that there is yet another temporal scale of hypoxia in the Bay in addition to the seasonal scale hypoxia chronic to the deeper portions of the Bay. ConMon data often indicate a diel-scale (24 hour period) of hypoxia, severe at some locations, wherein dissolved oxygen concentrations drop to low levels during the hours of darkness and sometimes reach dangerously low concentrations at and just after sunrise. Qualitative inspection of these data indicate that the most severe diel-scale hypoxia is observed at sites experiencing severe eutrophication. More quantitative analyses of diel-scale hypoxia related to nutrient conditions are in progress.

Given the above observations it became apparent that ConMon data would be especially useful in at least two ways: 1) these data could be used in a variety of ways to assess trends in water quality conditions in shallow waters and SAV habitat and 2) time high frequency nature of these measurements could be used to directly evaluate surface water DO criteria attainment or failure. The latter of these items is addressed in this section with two different approaches.

ConMon Measurements and the 30-day mean: How protective is it?: The general arguments concerning application of the 30 day DO mean as a protective DO standard have been fully discussed earlier. Here we provide some sample analyses wherein for a variety of shallow water ConMon sites the summertime (Jun-Aug) 30 day mean is directly compared to the rate of DO criteria (instantaneous criteria) failure (Figure 1). In this example ConMon data were assembled from nine different locations, ranging from those having severe water quality issues to those having relatively good water quality conditions. The procedure for computing the DO means, percent failure rates and criteria values are provided in Table 1. In all there were 104 months of data included in this analysis. Several issues are apparent. First, when the 30 day mean is below the 30 day criteria value (DO < 5.0 mg/l) the rate of instantaneous DO criteria (<3.2 mg/l) failure rare is often quite high (>25%). In this case, both results signal a DO criteria failure. However, there were approximately 22 months (of 104) where the 30 day mean DO criteria was satisfied but the instantaneous criteria was not satisfied. Similar analyses have been conducted by C. Buchanan (see Appendix 6 of this report) focused on the ConMon sites along the Potomac River estuary and similar results were obtained. We also conducted this same type of analysis but used the 7 day failure rate and in that case the 30 day mean was more protective but not completely protective. As a part of the Maryland Chesapeake Bay Biomonitoring Program we will continue to use ConMon data and make these computations for additional sites in the Maryland Bay. At this point it seems safe to tentatively conclude that for shallow water areas the 30 day mean is not protective of short-term DO criteria in many instances during summer periods (Jun – Sep).

The Issue of Duration of Low DO Conditions: For the formal DO criteria analysis there are both temporal and spatial considerations. In this analysis, using ConMon data, we are only considering the temporal aspect. However, in the formal analysis there is recognition in both the temporal and spatial domains that there needs to be some degree of "forgivness" of criteria violations and this seems appropriate given the very dynamic nature of estuarine systems. In our analysis of DO conditions in the Patuxent estuary during the 1960s, a period before this system underwent severe eutrophication, there were times (not very frequent) when surface DO criteria were violated. Thus, if a single violation was all it took to fail DO criteria, we would likely always have DO failures in most places for most time periods. That being the case, a 10% failure buffer has been adopted. However, this buffer needs to be considered in the light of just how the 10% acceptable violation rate is distributed in time.

Consider for a minute the breathing rate of a human as an analog of this problem. If we inhale once every 6 seconds we take 10 breaths per minute, 600 hundred breaths per hour and 14,400 per day. If we were to skip 10% of those breaths at a rate of 1 in every 10 breaths we would be fine…maybe a bit inconvenienced, but basically fine. However, if we were to skip all 10% at one time we would be dead…quite the difference.

We have examined the issue of DO criteria violation rate duration at a selection of Maryland ConMon sites and will continue to examine additional sites for the next several months. The data used for dissolved oxygen criteria failure duration calculations was extracted from the 2001 to 2008 Maryland Department of Natural Resources Continuous Monitoring database (www.eyesonthebay.net) provided by Ben Cole (MDDNR). The file was in .txt format and imported into SAS® 9.2 (http://www.sas.com/). Data found to have error codes (http://mddnr.chesapeakebay.net/eyesonthebay/documents/SWM_QAPP_2010_2011_FINALDraft1.pdf) were removed prior to analysis. For this exercise the duration of time a measurement of dissolved oxygen was found below 3.2 mg L^{-1} (instantaneous criteria) and separately for 5.0 mg L^{-1} (30 day mean criteria) was calculated for the period of record at a Con Mon station. Con Mon measurements are made up of a dissolved oxygen reading taken every 15 minutes so each increment of duration of failure is 15 minutes. A duration sequence of failure was calculated as a series of continuous 15 minute intervals where the measured dissolved oxygen value was below the chosen criteria. If a measurement time stamp exceeded 40 minutes (to allow some variance in time stamp intervals due to data sonde set up) or changed dates (data sonde was removed or unavailable for some period of time) the duration sequence was reset to start again. Total duration of dissolved oxygen failure for a sequence was the sum of the 15 minute intervals. In this early version of the duration calculator, failures are terminated at the end of each 24 hour period. We know that in some cases the failure duration continues into the next day. The calculator needs to be up-graded to address this issue as well as several other problems. So, at present the calculator provides a minimum estimate of DO failure duration.

Examples of DO criteria failure duration for two criteria levels are provided in Table 2. We selected sites exposed to very severe eutrophication (Bishopville Prong in the MD Coastal Bays), reasonably good water quality conditions (St. George Island), a tidal freshwater site in an enriched estuary (Jug Bay; Patuxent River) and a mesohaline site exposed to open waters (Pin Oak; Patuxent River). As expected, at the site with severe eutrophication there were many criteria failures and criteria failure durations ranged from 12 to 24 hours (likely longer than this). At the less impacted sites, DO criteria failures were of shorter durations, especially for the instantaneous criteria (< 3.2 mg/l). At the higher DO criteria (< 5.0 mg/l) duration of failures remained long, often up to 24 hours. This evaluation is in early stages and some refinements have already been suggested. The point we make here is that it does not appear that DO failure rates are evenly distributed in time and this needs to be further evaluated to be certain that DO criteria values are as protective as they were intended to be.

APPENDIX 6

A TEST OF THE "UMBRELLA CRITERIA" CONCEPT IN TIDAL POTOMAC RIVER SHALLOW WATERS

Claire Buchanan - ICPRB

Dissolved oxygen criteria for migratory fish spawning and nursery uses and open water fish and shellfish uses are presently applied to shallow waters designated for bay grass use on the assumption that DO conditions are not sufficiently different to warrant criteria for shallow waters. High frequency DO data are suggesting this assumption may be faulty and the "umbrella criteria" that perform in open waters may not necessarily work in shallow waters. The validity of the "umbrella criteria" concept in shallow waters was tested with high frequency data collected at 19 nearshore sites in the tidal Potomac River (**Figure 1**). Specifically, does attainment of the 30-day mean DO criteria protect against failure of the 7-day mean DO criteria, and do both of these criteria protect against failure of the instantaneous minimum DO criteria in shallow waters?

Over 1.1 million dissolved oxygen records were collected by Maryland and Virginia at 19 Potomac shallow water stations during spring, summer, and autumn. Most stations were monitored for two or three years between 2004 and 2008; four were monitored all five years. Sondes were positioned at median depths of 0.2 – 3.0 m below the surface and reading made at 15-minute intervals. The 30-day, 7-day, and instantaneous minimum criteria were applied to each site -year-season subset of CMON data to address the "umbrella criteria" question.

Means derived from high frequency (CMON) data are very close to the true mean for a given location while those derived from low frequency, or point sample, data can diverge from the true mean. To evaluate the sensitivity of low frequency data estimates of the 30-day mean to 7-day and instantaneous DO criteria failures, 30-day means were computed both from the available low frequency (calibration) data and high frequency data. Guidelines for computing and applying the 30-day mean, 7-day mean and instantaneous minimum criteria were established to ensure consistency and avoid artifactual results (**Table 1**). The CMON data, the data analysis methods, and some of the results and conclusions are described in more detail in Buchanan (2009).

Figure 2 shows the frequency per month of failing the 7-day mean criteria, plotted against the 30-day mean derived from high frequency (CMON) data and low frequency (calibration) data.

Figure 3 shows the frequency per month of failing the instantaneous minimum criteria, plotted against the 30-day mean derived from high frequency (CMON) data and low frequency (calibration) data. **Figure 4** shows the frequency per 7-day period of failing the instantaneous minimum criteria, plotted against the 7-day mean. Spring results are separated from summer and autumn results and tidal fresh (TF) and oligohaline (OH) results are separated from mesohaline (MH) results because DO criteria differ according to season and salinity zone (see **Table 1**). In each graph, the inverted triangle indicates the criteria applicable to the metric on the x-axis. Points to the right of the inverted triangle are achieving that metric's criteria. **Figure 5** compares monthly means derived from the low and high frequency data. **Figure 6** delineates the threshold for failure of the instantaneous minimum criteria as a function of diel or weekly magnitude of change in DO and daily or weekly mean DO.

Findings:

- *Depending on allowable exceedances*, the 30-day mean criteria applied to the low frequency (calibration) data could be considered protective of the 7-day mean criteria. The 30-day mean criteria applied to the high frequency (CMON) data show similar results and support this finding.
- If the allowable exceedance dictates, for example, that only 1 month of the year can have failures of the 7-day mean criteria, then the 30-day mean criteria is *not* protective of the 7-day mean criteria in Piscataway Creek (2004, 2005), Piney Point (2006), St. Mary's River (2008), and Breton Bay (2008).
- The 30-day mean and 7-day mean criteria are *not* protective of the instantaneous minimum DO criteria, regardless of whether they are derived from low or high frequency data.
- Monthly means derived from low frequency (calibration) data are inaccurate estimates of the true mean, and also appear to be biased in some season-salinity zones.
- Meeting the instantaneous minimum criteria is a largely function of the daily mean DO *and* the diel magnitude of change in DO and the trajectory these parameters take over time. If the diel magnitude is large and the mean is relatively low, the probability of failing the instantaneous minimum criteria is high. If the diel magnitude is small and the mean relatively high and stable, the probability of failing the instantaneous minimum criteria is very low.
- Data points representing weeks with low frequencies (>0% - 1%) of failing the instantaneous minimum criteria provide a linear boundary that separates days or weeks achieving the instantaneous minimum criteria from those failing the criteria. This linear boundary quantitatively describes the relationship between mean DO and magnitude of change and the thresholds of instantaneous minimum criteria failure on daily and weekly scales.
- The 7-day mean DO criterion of 6 mg/liter in spring migratory and spawning reaches is only protective of the instantaneous minimum criteria when the weekly magnitude of change in DO is less than ~6 mg/liter. The 7-day mean DO criterion of 4 mg/liter is only protective of the instantaneous minimum criteria when the weekly magnitude of change

is less than ~2 mg/liter, a phenomenon that the tidal Potomac embayments and river flanks never experienced in the spring, summer or fall between 2004 and 2008.

- Daily or weekly DO means of ~10 mg/liter are protective of the instantaneous minimum DO criteria in almost all circumstances. DO means below 10 mg/liter are only protective of the criteria if their magnitudes of cyclic change in DO (diel, weekly) are proportionately smaller, i.e. below the boundary lines indicated in **Figure 5**.

Buchanan, C. 2009. An Analysis of Continuous Monitoring Data Collected in Tidal Potomac Embayments and River Flanks. ICPRB Report 09-3, 56 pgs. Available online at: http://www.potomacriver.org/cms/publicationspdf/ICPRB09-03.pdf

Table 1. Metrics, criteria, and computation guidelines.

Metric and Criteria	CMON data	Calibration data
30-day mean • ≥5.5 mg/liter, TF year-round • ≥5.0 mg/liter, OH & MH year-round	all available data averaged by month (not exactly 30 days); months with less than 20 days of uninterrupted DO recordings not included	samples from 0.5-1.5 m depths only, all available data averaged by day, then averaged by month
7-day mean • ≥6.0 mg/liter, TF&OH Feb1-May 31 • ≥4.0 mg/liter, all salzones Jun1-Jan 31 and MH Feb1-May 31	all available data between midnight on the first day and midnight on the 7th day averaged; means were calculated a) from rolling 7-day averages advanced in 1-day steps or b) from sequential 7-day periods with uninterrupted data records (method noted in figures); weeks with less than 6 days of uninterrupted DO recordings were excluded	n/a
Instantaneous minimum • ≥5 mg/liter, TF & OH Feb1-May 31 • ≥3.2 mg/liter @ ≤29°C and ≥4.3 mg/liter @ >29°C, all salzones Jun1-Jan31 and MH Feb1-May 31	the frequency of observations failing the criteria each day, week, and month; excluded: days with n<95 records, weeks with n<576 records (6 days), months with n<27 days of uninterrupted DO recordings	n/a

Figure 1. Tidal Potomac River "continuous monitoring" (CMON) stations, 2004-2008. Data for 3 of the 22 stations were not included in the analysis: the two stations in the District of Columbia and one in Neabsco Creek. Data for the two District of Columbia stations were available but had not been QA/QC'ed by the provider when the analysis was performed. Data for Neabsco Creek were only collected in the summer of 2006.

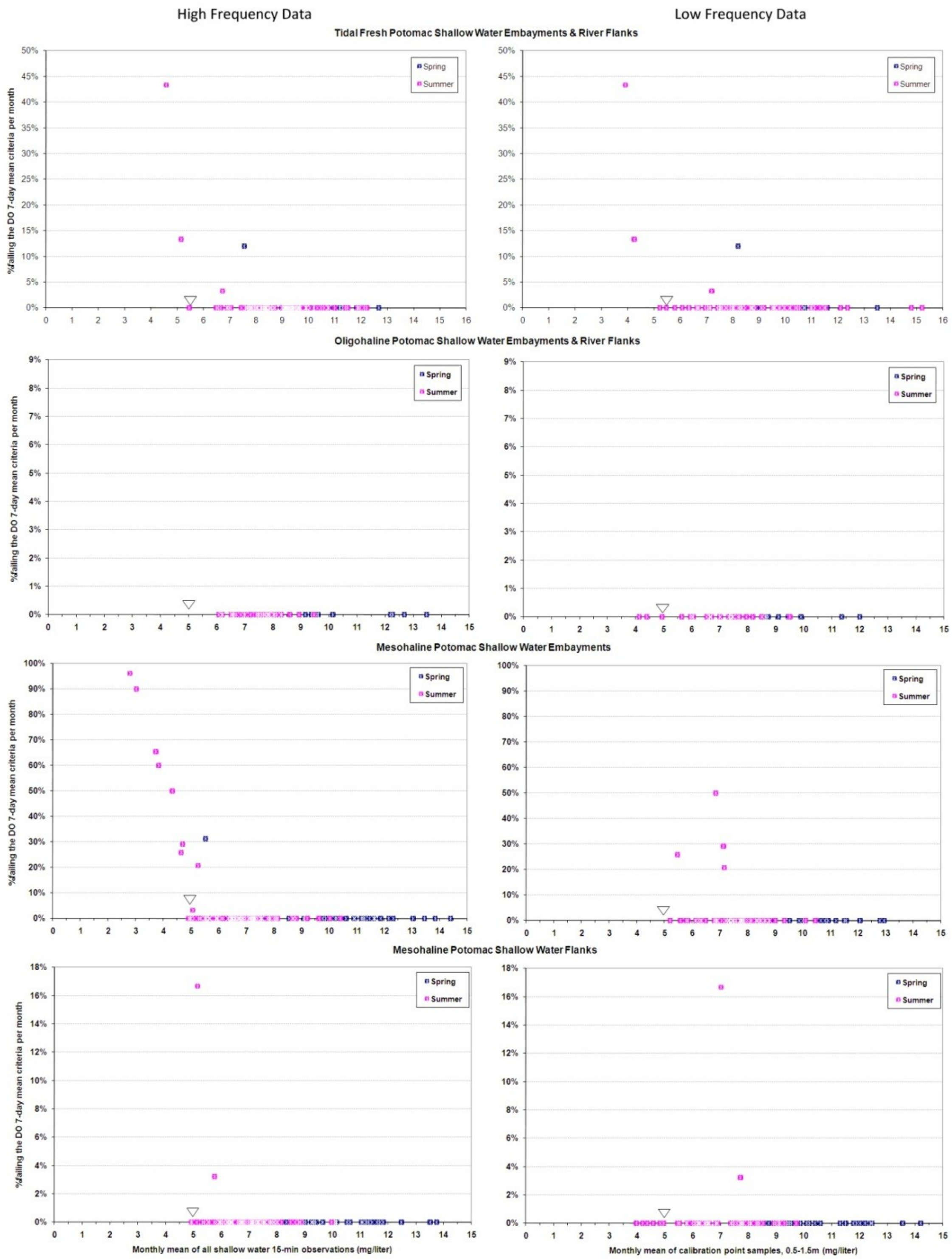


Figure 2. The frequency per month that rolling 7-day periods (1-day step) fail the 7-day mean DO criteria, plotted against the corresponding 30-day mean DO. Overall, 16 of the 415 months (3.86%) represented in the 20 tidal Potomac shallow water stations between 2004 and 2008 had one or more 7-day periods failing the 7-day mean criteria. Approximately half the failures occur in months where the 30-day mean criteria are met. Note: not all of the failing months are apparent in the low frequency data because point samples were not available for all months.

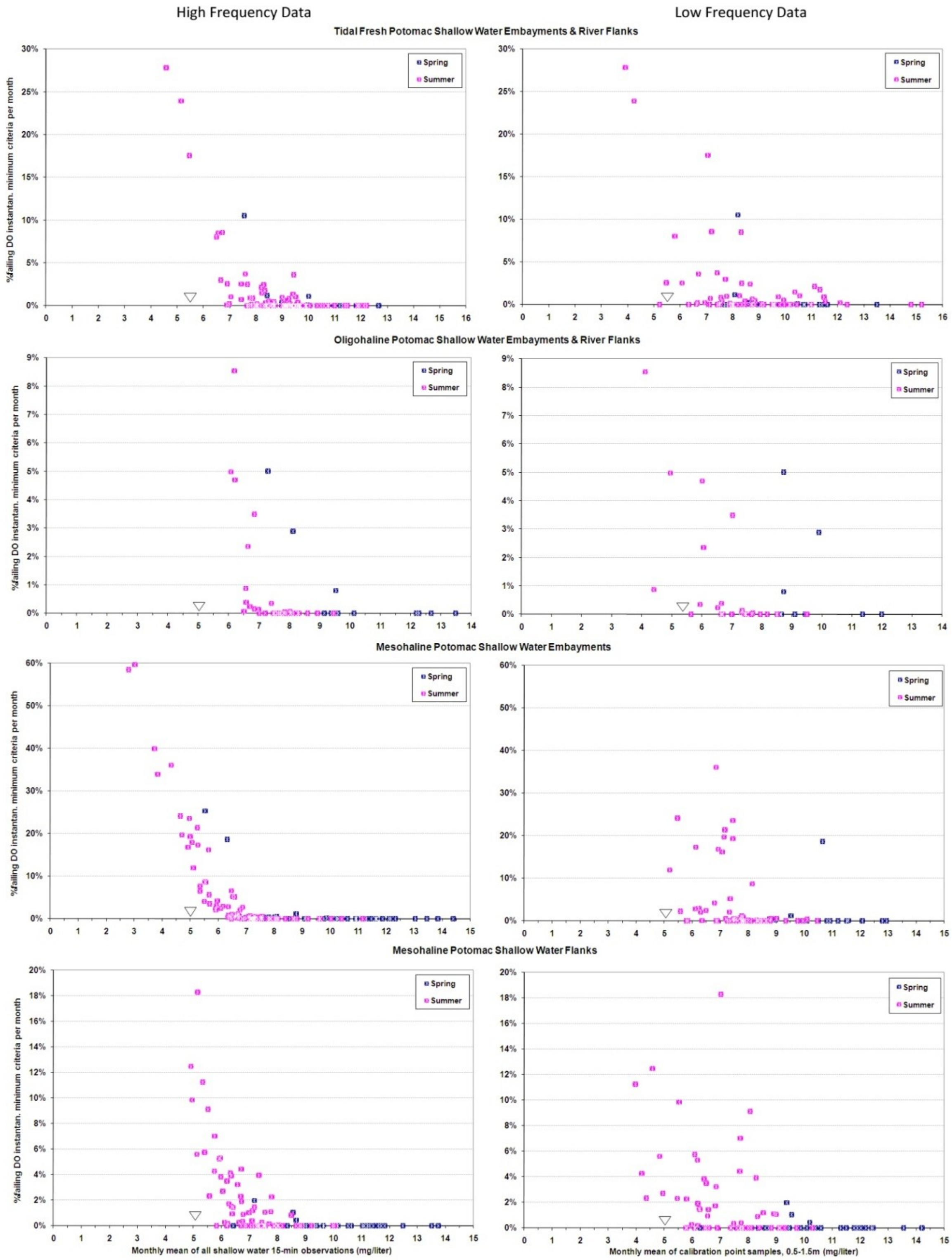


Figure 3. The frequency per month that rolling 7-day periods (1-day step) fail the 7-day mean DO criteria, plotted against the corresponding 30-day mean DO. Overall, 175 of the 415 months (42.2%) represented in the 20 tidal Potomac shallow water stations between 2004 and 2008 had failures of the instantaneous minimum DO criteria. Most instantaneous minimum criteria failures occurred in months where the 30-day mean criteria are met.

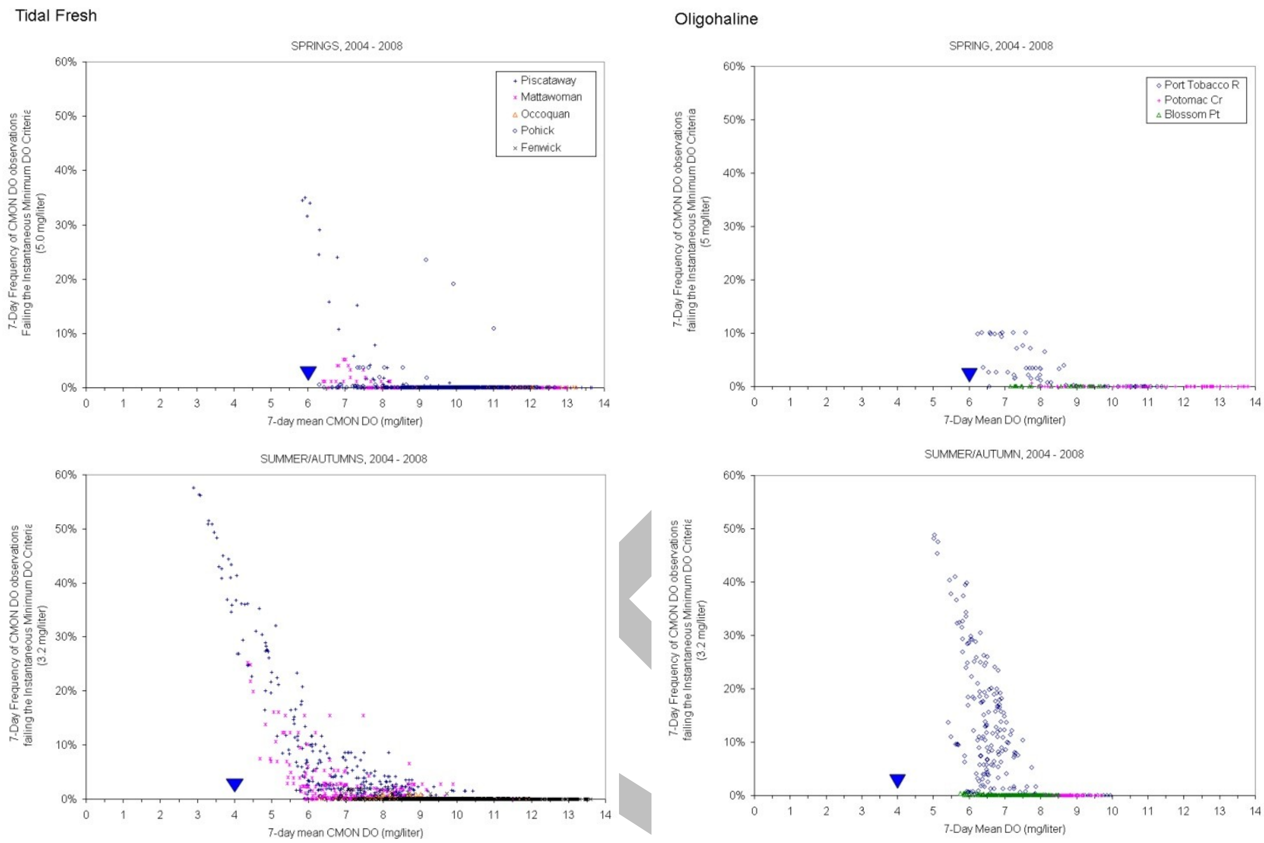


Figure 4. The frequency per 7-day period of failing the instantaneous minimum criteria, plotted against the corresponding 7-day mean in tidal fresh and oligohaline salinities. Frequencies were calculated on rolling 7-day periods (1-day step). Most instantaneous minimum criteria failures occurred in 7-day periods where the 7-day mean criteria are met.

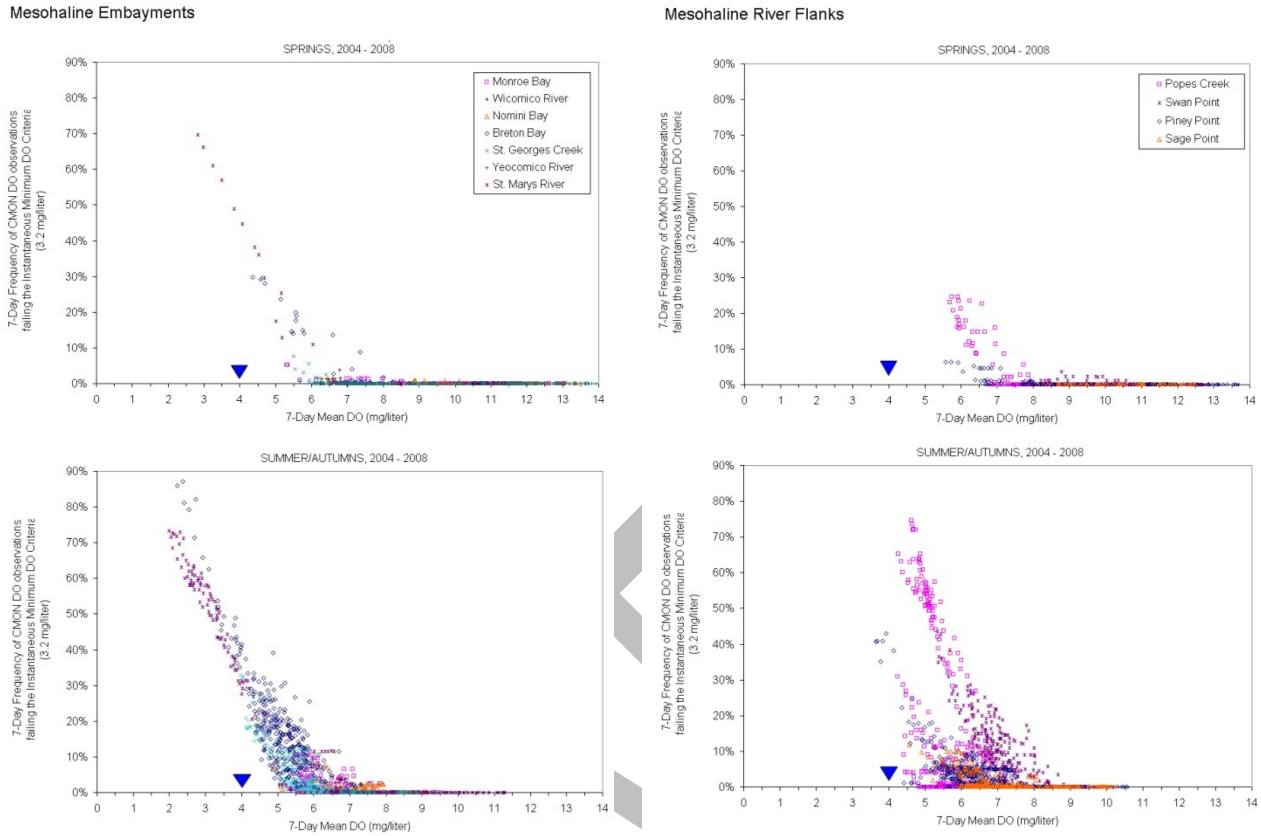


Figure 4 (cont.). The frequency per 7-day period of failing the instantaneous minimum criteria, plotted against the corresponding 7-day mean in mesohaline salinities. Frequencies were calculated on rolling 7-day periods (1-day step). Most instantaneous minimum criteria failures occurred in 7-day periods where the 7-day mean criteria are met.

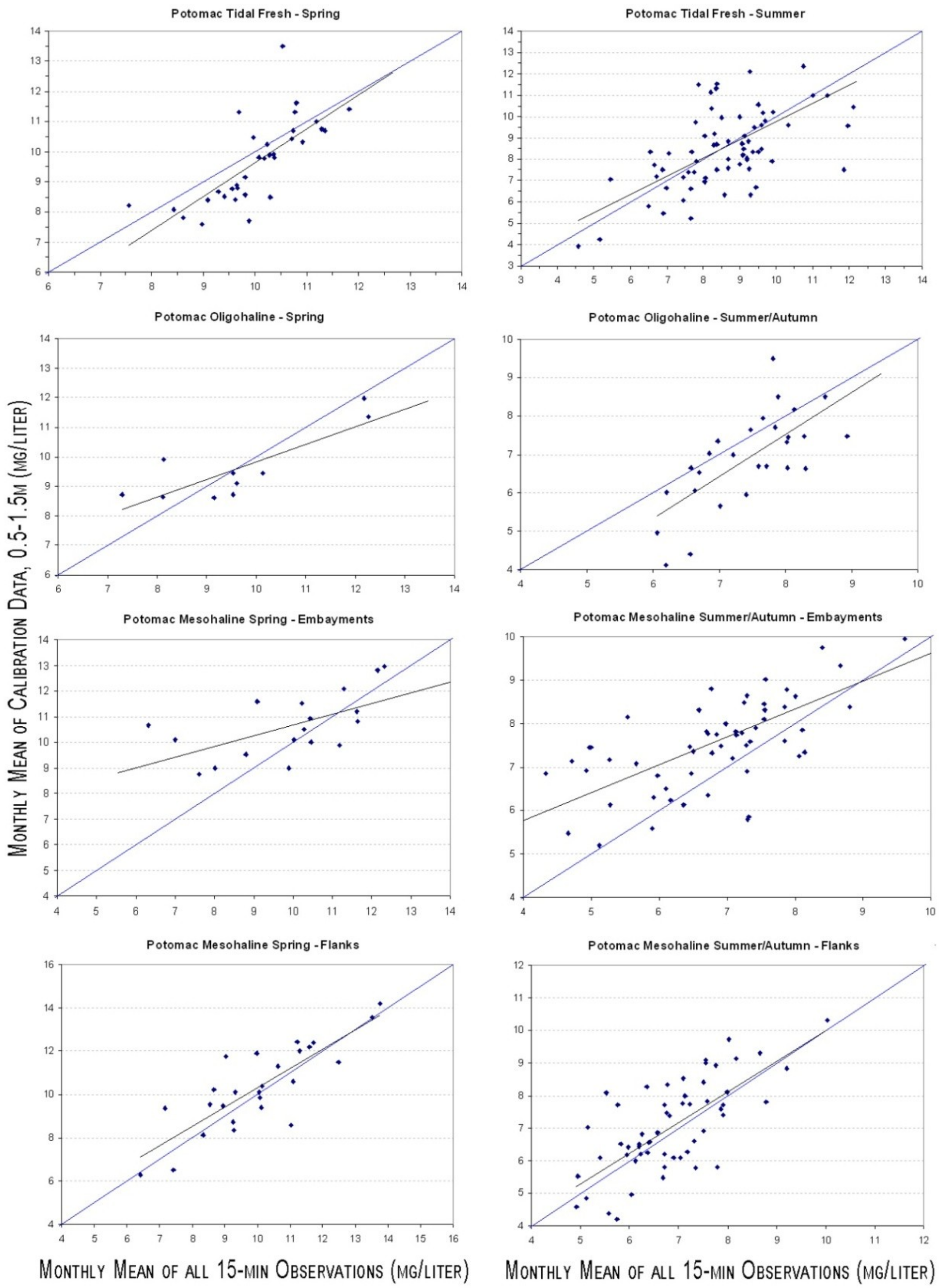


Figure 5. Paired comparison of the 30-day mean DO estimates calculated from low frequency (calibration) and high frequency (CMON) data. Blue line represents the 1:1 relationship, and it is assumed that the means derived from high frequency data (x-axis) are very close to the true mean. There are large differences between the paired 30-day means in all seasons and salinity zones, indicating inaccuracy on the part of the means derived from the low frequency data. Further, low frequency means appear to be biased downward in TF spring and OH summer/autumn, and biased upward in MH embayments.

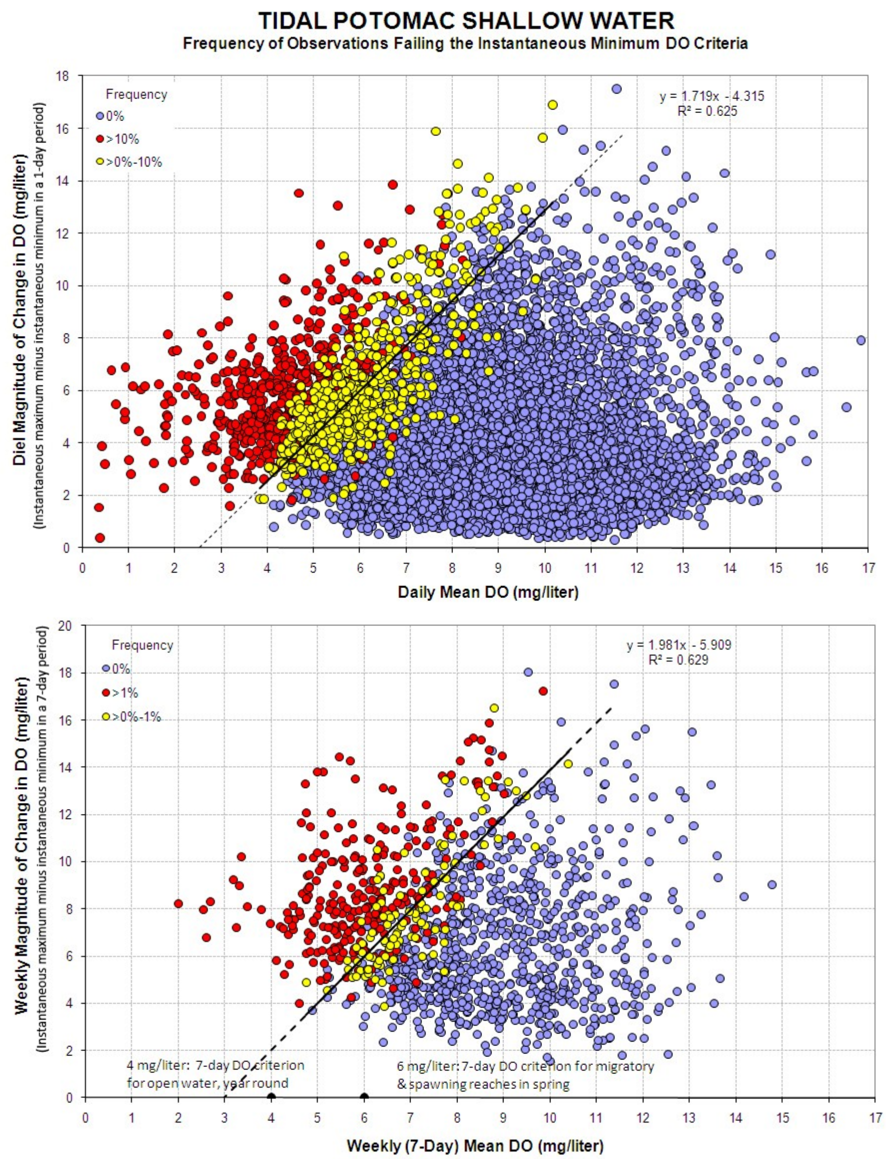


Figure 6. Attainment of the instantaneous minimum DO criteria as a function of daily (top) or weekly (bottom) mean DO and magnitude of change in DO. All tidal Potomac CMON data meeting the guidelines in Table 1 are included in each panel regardless of season or salinity zone. Top, n= 9,879 days; bottom, n= 668 weeks. The 7-day mean DO is calculated on sequential 7-day periods. The 7-day mean DO criteria presently applied to shallow waters are indicated on the x-axis in the bottom panel.

Appendix 7

Conditional Probability

30-day mean vs. 7-day mean

Elgin Perry

8-27-2010

The following work summarizes some additional analyses conducted with the Potomac Continuous Monitoring data to address the question of whether the 30-day mean criterion serves as an umbrella for the 7-day mean criterion. The results here seem to confirm that it would be a rare situation where the 30-day mean would be satisfied and the 7-day mean would be violated more than 10% of the time. However, this does not seem to be a broad umbrella in that the margin of protection is not great.

Methods:

The method employed is based on the simple-minded approach (Figure 1) that if the variability of the 7-day mean about the 30-day mean has a standard deviation less that 0.7805, then we can expect that the 7-day criterion will be violated less than ten percent of the time if the 30-day criterion is met.

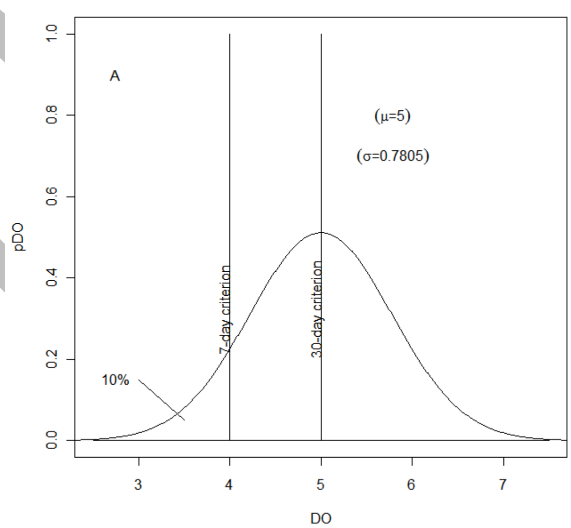


Figure 1. Illustration of the level of variability of the 7-day mean about the 30-day mean that results in up to 10 % violations of the 7-day mean criterion when the 30-day mean criterion is met.

To use this approach, an estimate of the standard deviation of the 7-day mean about the 30-day mean is needed. To estimate this quantity, I used data from the Potomac ConMon locations (Table 1, Figure 2).

Table 1. Names, locations, and years of Continuous Monitor data used.

location	Latitude	Longitude	years
Occoquan	38.64038	-77.219416	2007-2009
Pohick Creek	38.67591	-77.16641	2007-2009
Potomac Creek	38.3436	-77.30485	2007-2009
Monroe Bay	38.23197	-76.96372	2007-2009
Nomini Bay	38.1316	-76.71759	2007-2009
Yeocomico River	38.02878	-76.55184	2007-2009
Fenwick	38.66993333	-77.11513333	2004-2008
Piscataway Creek	38.70156667	-77.02593333	2004-2008
Mattawoman Creek	38.55925	-77.1887	2004-2008

Figure 2. Locations of Potomac ConMon data collection sites used for this analysis.

Beginning with the first collection day for each year at each location, blocks of 30 days were created to represent months. Partial months at the end of each collection year were counted as a month. Similarly, weeks were created by starting with the first collection day of each year and counting off blocks of 7 days. With these definitions, monthly means were computed as the arithmetic average of DO for each month. Weekly means were computed as the arithmetic average of DO for the intersection of month and week. Thus a week that bridges across two months would have it's data divided by month and a weekly mean computed for each part. Weekly means and Monthly means were merged by month and a residual computed by subtracting the monthly mean from each weekly mean computed within that month. Various analyses were conducted on these residuals to assess the variability of weekly means about the monthly mean.

Graphical analyses were used to assess the uniformity of variation over other factors. Distribution functions and quantile estimation was used to estimate the rate of violation of the 7-day criterion given that the 30-day criterion was satisfied.

Results:

First I report a number of graphical assessments:

The basic distributional assessment of the residuals (Figure 3) shows that they are reasonably symmetric and centered about zero . The distributions is heavy tailed compared to the normal distribution in the extreme tails suggesting that there are weeks that have a greater deviation (both high and low) than would be expected for a normal distribution. The central part of the distribution seems to follow the normal distribution closely.

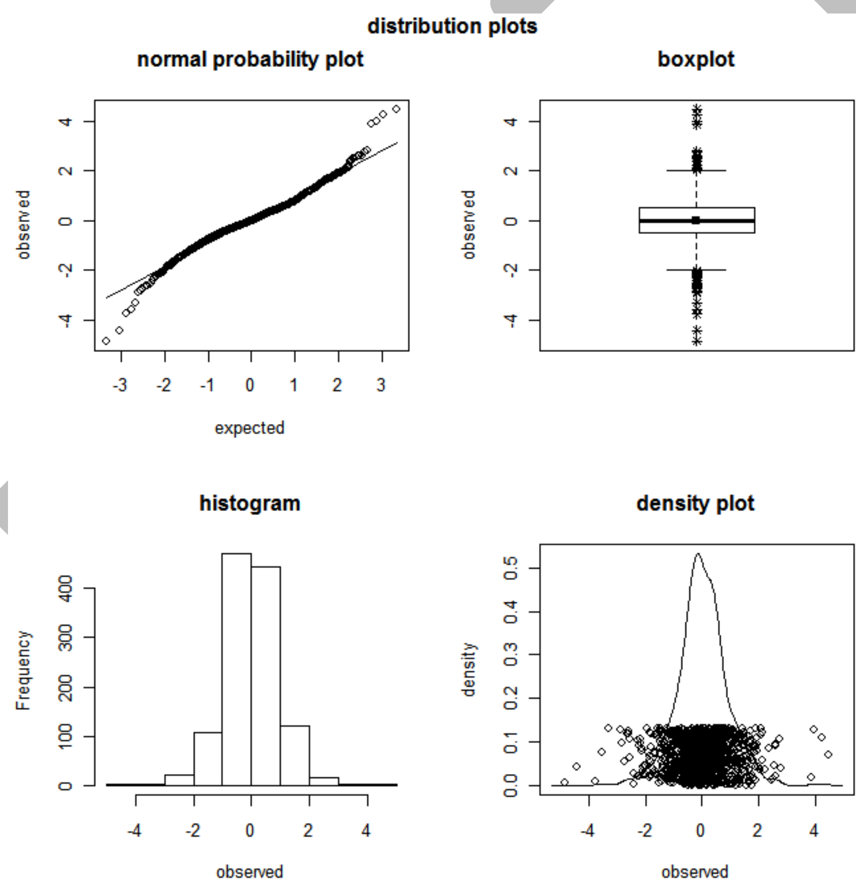


Figure 2. Basic distributional properties of the residuals.

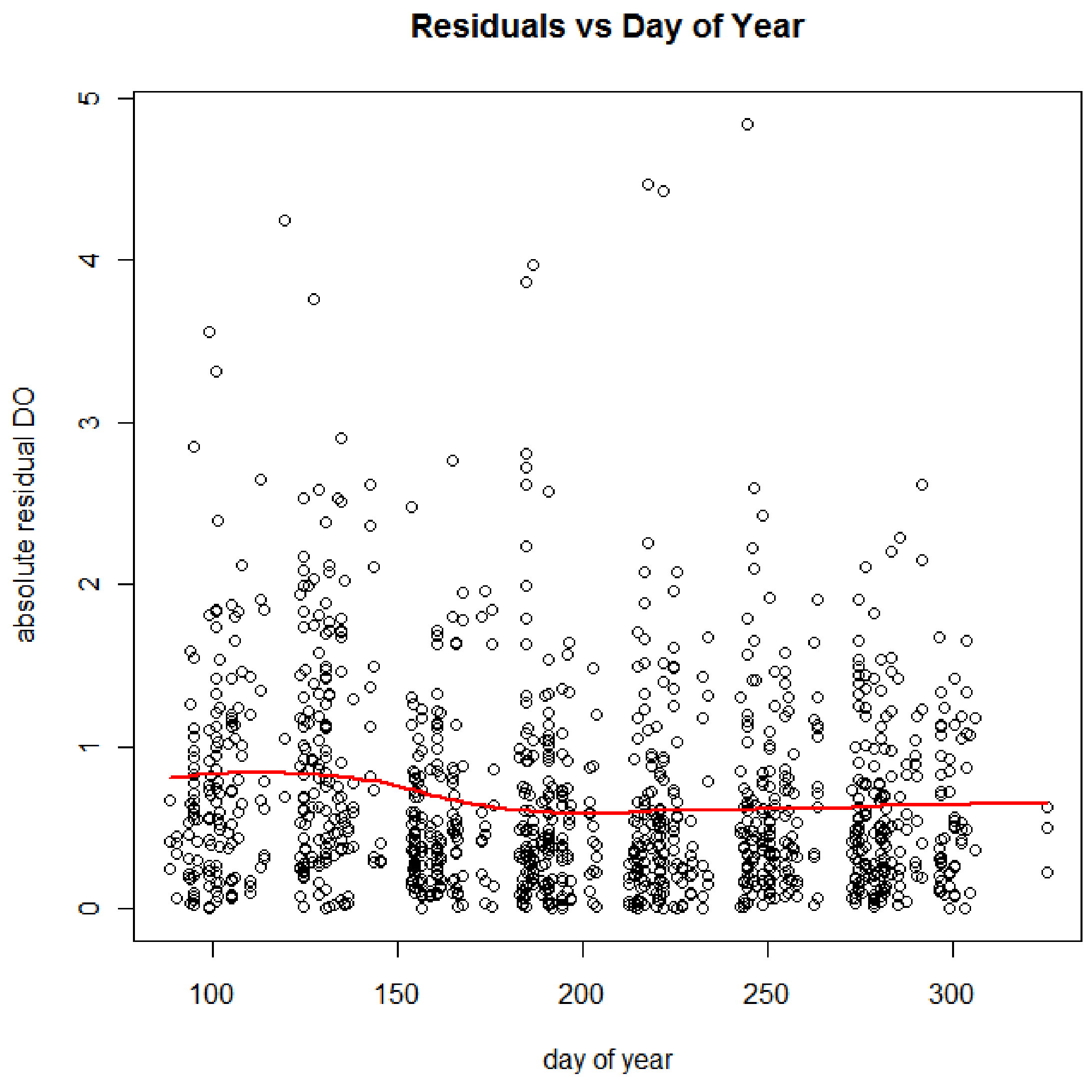


Figure 3. Assessment of seasonal trend in variability.

There is evidence of higher variability in spring than in summer and fall (Figure 4).

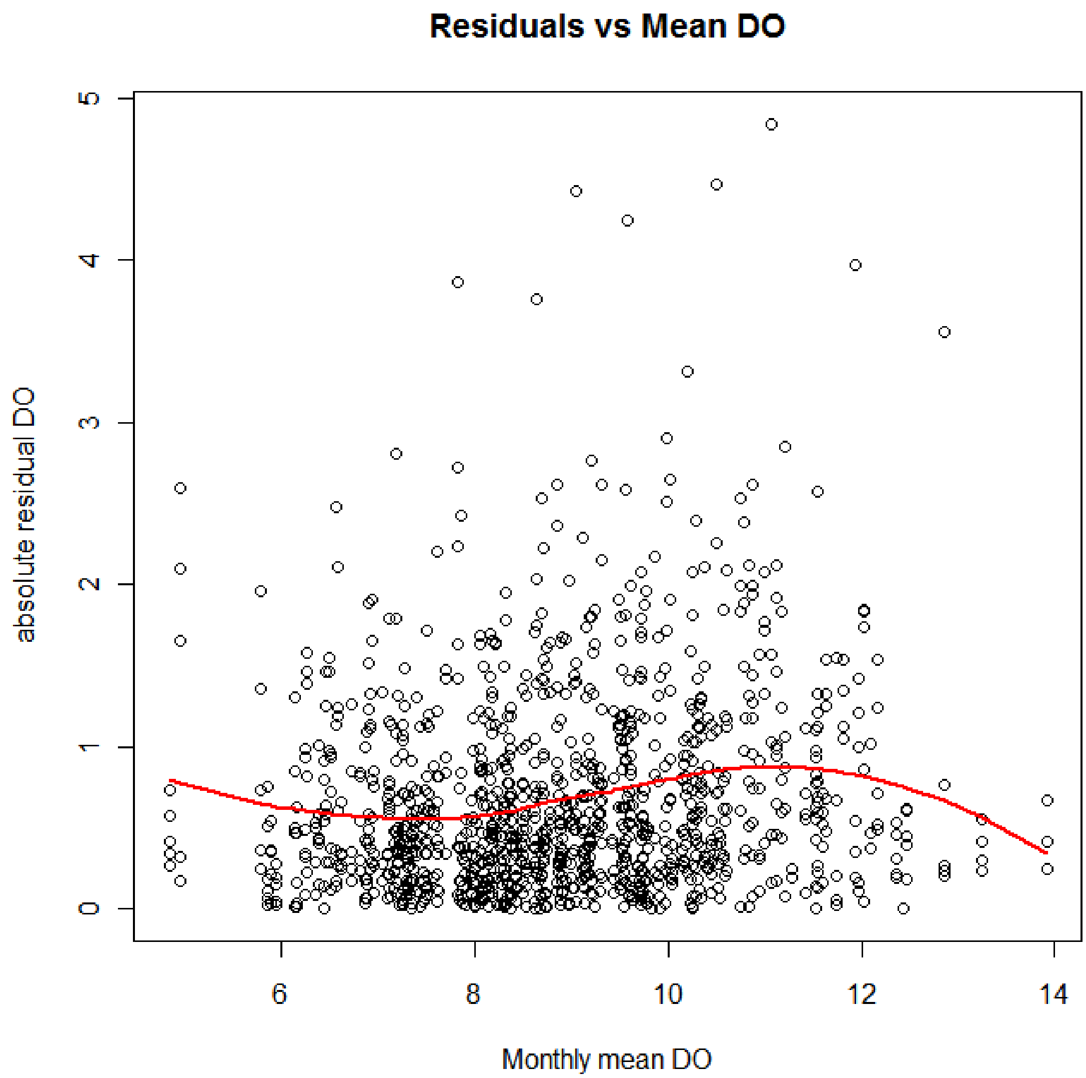


Figure 4. Trend of variability with mean DO.

There is evidence that the variability increases with increasing mean DO (Figure 5.). It is likely that the seasonal trend and the trend with the Mean DO are the same trend because there is a seasonal trend in mean DO.

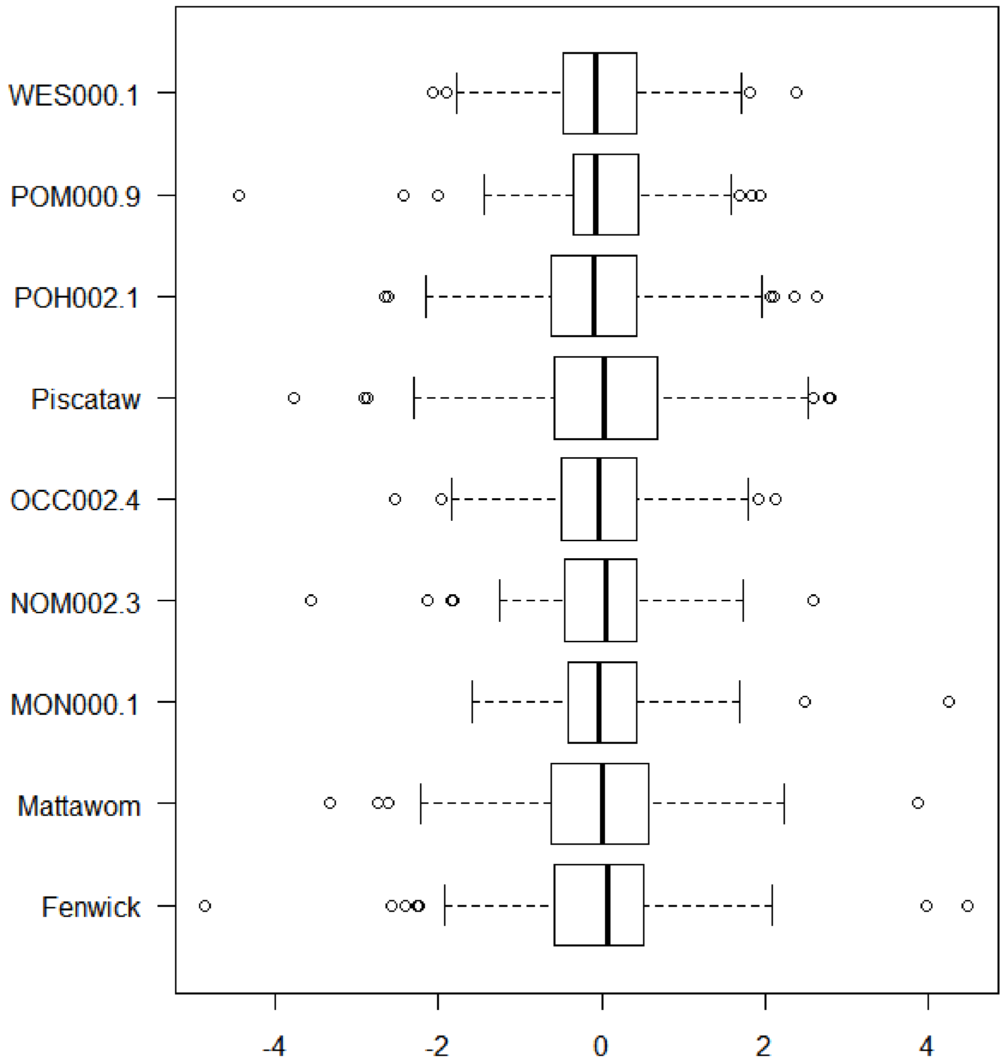


Figure 5. Box and Whisker plots of residuals by sampling location.

There is little evidence of change in variability with location except that Maryland locations appear to have greater variability than Virginia locations.

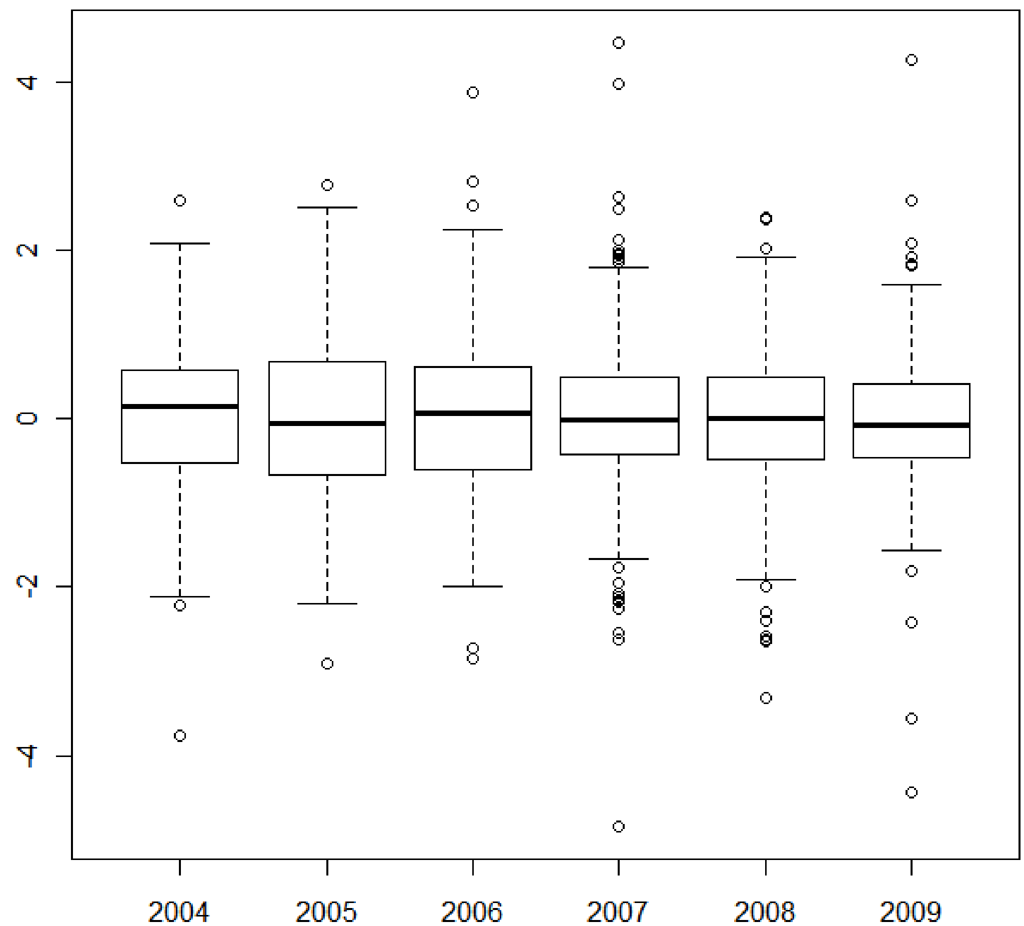


Figure 6. Box and Whisker plots of residuals by year.

There appears to be a time trend in variability (Figure 7.) with a decrease in variability occurring in between 2006 and 2007. However, recall from the collection dates (table 1) that only Maryland collected data prior to 2007 and thus this is the state trend from a different view. The pattern of difference in variability between states persists when the data are subsetted to just 2007-2009 for Mattawoman and Fenwick, but variability at Piscataway is more comparable to Va. locations for this time period (figure not shown).

If the standard deviation of weekly mean about monthly mean is estimated for all data, the value is 0.9648719 which is slightly above the value of 0.7805 which would insure that there would be less than 10% violation of the 7 day criterion is the 30-day criterion were satisfied (Table 2., column 2). However, if the 30-day mean is increased to just 5.3, then we would expect fewer than 10% violation of the 7-day mean. Thus it seems that if the 30-day mean were hovering between 5.0 and 5.3 for an extended period, then there might be greater than 10% violation of the 7-day criterion when the 30-day criterion is satisfied. This circumstance would seem to be a rare event.

Recall that there is evidence that variability increases with the 30-day mean DO (Figure 5.). It is reasonable to exclude the variability associated with high DO because when the 30-day mean DO is high, then it is not hovering in that region close to the criterion which we would expect to also observe violations of the 7-day criterion. To exclude the variability associated with high DO, a subset of the data was created that included only weeks associated the 30-day mean DO of less than 8.0 (the minimum value for the 30-day mean is 4.848). Using this subset of the data, the standard deviation was estimated as 0.8439. This remains slightly larger than the 0.7805 which would insure that the 30-day criterion is an umbrella for the 7-day criterion, but with this, the 30-day mean DO need only be greater than 5.1 to insure fewer than 10% violation of the 7-day criterion (Table 2., column 3).

Note that in low salinity waters where the 30-day criterion is 5.5, then we would expect only 6% or 4% violations of the 7-day criterion for the two estimates of standard deviation (Table 2, row 6). Thus it seems reasonable to conclude that the 30-day mean is an effective umbrella for low salinity. These probability estimates have been made using an assumption that the weekly residuals are approximately normally distributed.

Table 2. Probability of violating 7-day mean criterion as a function of 30-day mean DO for two levels of 7-day mean variability.

30-day mean DO	Prob(|sd=0.9649)	Prob(|sd=0.8439)
5.0	0.1500	0.1180
5.1	0.1271	0.0962
5.2	0.1068	0.0775
5.3	0.0889	0.0617
5.4	0.0734	0.0486
5.5	0.0600	0.0377
5.6	0.0486	0.0290
5.7	0.0390	0.0220
5.8	0.0311	0.0165
5.9	0.0245	0.0122
6.0	0.0191	0.0089

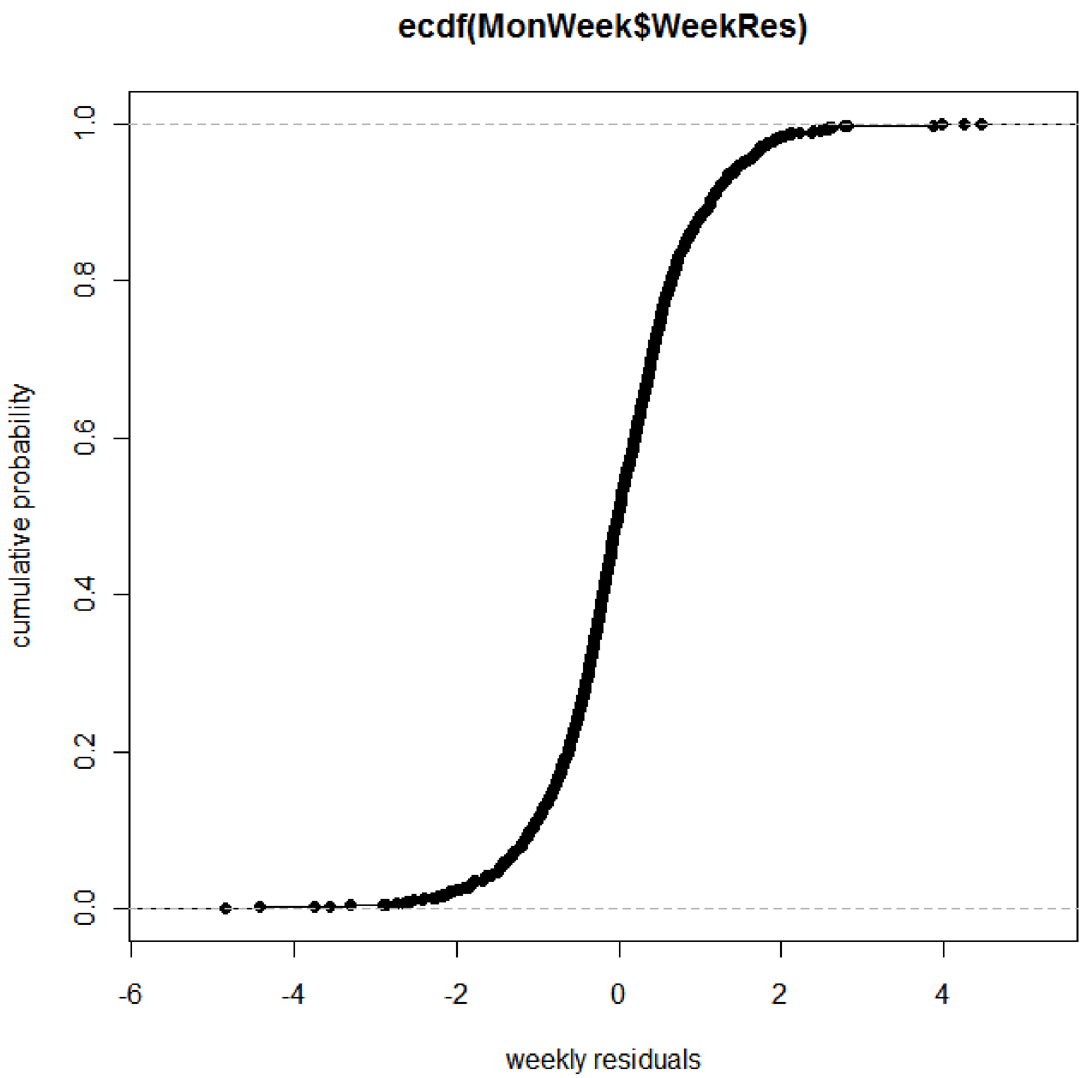


Figure 7. Empirical Cumulative Distribution Function (ECDF) of the set of weekly residuals about the monthly mean.

As a check on the reliability of the normality assumption, we compare the important quantiles of the normal distribution to those of the empirical cumulative distribution function (Figure 8.). The 10th percentile of a normal distribution with mean zero and standard deviation = **0.9649** is

-1.236533. The 10th percentile of the empirical cumulative distribution function is -1.076785. This suggest that the observed deviations at the 10th percentile are less than predicted by the normal distribution which implies that the probabilities in Table 2 are somewhat higher than might be realized. The difference between the 30-day criterion and the 7-day criterion is -1.0 and a quantile of -1.0 corresponds to between 11 and 12 percent (Table 3., column 2) based on the ECDF. This suggests that if the 30-day mean criterion were satisfied exactly, there would be on average 11-12 percent violations of the 7-day criterion. Of course typically the 30-day mean would be satisfied by some margin and if that margin were as little as 0.14 then on average there would be fewer than ten percent violations of the 7-day criterion.

Table 3. Percentiles and corresponding quantiles from the empirical cumulative distribution functions for all weekly residuals (column 2) and weekly residuals given that the 30-day mean is less than 8.0.

percentile	quantile all Weekly residuals	quantile given mean DO < 8
13%	-0.9160	-0.7321
12%	-0.9574	-0.7545
11%	-1.0329	-0.8156
10%	-1.0768	-0.8448
9%	-1.1404	-0.9186
8%	-1.2011	-0.9633
7%	-1.3006	-1.0411
6%	-1.3921	-1.1210
5%	-1.4802	-1.1903

These same calculations are done using the ECDF of weekly residuals given that the 30-day mean is less then 8.0. These results (Table 3, column 3) suggest that if the 30-day criterion is satisfied exactly, there would be on average 7-8 % violations of the 7-day criterion.

Conclusion:

These results suggest that we would only see greater than 10% violations of the 7-day criterion given that they 30-day criterion is met if the 30-day mean were hovering at or just above the 30-day criterion. Because the 30-day mean rarely exhibits this behavior, it seems safe to conclude that in most cases the 30-day criterion acts as an umbrella for the 7-day criterion. However, the umbrella does not seem to be a broad one. Slight increases in the variation of the weekly mean about the monthly mean without corresponding increases in the monthly mean could start to increase the violation rate for the 7-day criterion to above 10 percent.

APPENDIX 8

A parametric simulation approach to assessing the umbrella concept for the instantaneous minimum criteria.

Elgin Perry

3/10/2011

High frequency samples of DO at fixed locations show that there is considerable serial dependence or autocorrelation in these DO time series. This lack of independence makes it difficult to analytically compute the probability that an instantaneous criteria will be violated when an umbrella criterion (e.g. weekly or monthly mean) is satisfied. Here we develop and show results from a simulation approach to addressing this question.

The basic approach of the simulation is to generate time series that have properties similar to observed DO time series. The data used for this exercise are the open water buoy data compiled by Olson. In these data, time series that are more than 1 week in length were parsed into 1 week time series. A simple AR(2) model that included structural terms for the mean, linear trend, and diel cycle was fitted to each of these time series using Proc AutoReg in SAS. Each fitting results in a vector of 7 parameters

b_int - the intercept which reflects the mean because other covariates are centered.

b_cday - linear trend term for the week fitted as a coefficient of centered day.

b_sin, b_cos - coefficients for diel trend fitted to trig-transformed time

b_ar1,b_ar2 - autoregressive terms at lags 1 and 2

mse - residual mean square error

These parameter estimates were obtained for each 1-week time series to yield 251 sets of parameters. These 251 vector observations were analyzed by Multivariate Analysis of Variance (MANOVA) using Proc GLM in SAS. The model included terms for Month, Total Water Depth, Sensor Depth, Latitude and Longitude. Some results from this overall model are presented.

For the simulation, only data from CB4 in the surface layer (sensor < 10 m depth) were used. A MANOVA model which included terms for Month, Total Water Depth, and Sensor Depth. Coefficients from this model were used to estimate a mean predicted value for the parameter vector which seeded the parametric simulation. A multivariate normal random number generator (R-package) was used to generate 1000 realizations using this mean vector and the Variance-Covariance matrix estimate from the MANOVA. Each of these 1000 realization of the parameter vector were passed to a function which estimated a 1-week time series based on the simulated parameter vector values. The percent of violations of the instantaneous minimum criterion (3.2 ppt) were tabulated yielding 1000 estimates of this percentage. The range and frequency of these percentages are compared for various mean vectors associated with different conditions specified by different values of the independent variables in the MANOVA model.

Results:

When examining data from all buoy locations, in a multivariate sense, all of these terms are statistically significant (Table 1).

Table 1. Manova test results for dependent vector

(b_int,b_cday,b_sin,b_cos,b_AR1,b_AR2,mse).

Source	Pillai's Trace	Pr > F
month	0.2895	0.0191
TotDep	0.1018	0.0007
SampDep	0.2063	<.0001
lat	0.0592	0.0451
long	0.2102	<.0001

Table 2 shows which independent variables appeared to have an effect on which dependent variables.

Table 3. P-values for each manova term and for each dependent variable.

Source	b_int	b_cday	b_sin	b_cos	b_AR1	b_AR2	mse
month	0.0861	0.9041	0.3811	0.4845	0.0130	0.0909	0.1277
TotDep	<.0001	0.4168	0.9888	0.7560	0.1728	0.2066	0.1374
SampDep	<.0001	0.4214	0.0381	0.5415	0.1808	0.2711	0.0331

lat	0.2065	0.3651	0.2688	0.0563	0.9958	0.2387	0.1713
long	0.7956	0.0432	0.9265	0.9906	<.0001	0.2204	0.0290

Table 4. Coefficient estimates for covariates.

Source	b_int	b_cday	b_sin	b_cos	b_AR1	b_AR2	mse
TotDep	0.2224	0.0060	0.0001	-0.0031	-0.0106	0.0080	0.0148
SampDep	-0.4079	-0.0072	0.0309	-0.0074	0.0125	-0.0083	-0.0255
lat	-0.2449	0.0244	-0.0496	0.0703	0.0001	0.0271	0.0493
long	0.1058	-0.1157	0.0087	-0.0009	-0.3149	0.0595	0.1666

Notes from tables 3 and 4.

DO seems to improve as water depth increases.

DO degrades as sensor depth increases.

AR1 terms are stronger in the western bay

mse decreases with sensor depth

Table 5. Partial Correlation Coefficients from the Error SSCP Matrix / Prob > |r| DF = 239 .

	b_Int	b_cday	b_sin	b_cos	b_AR1	b_AR2	MSE
b_Int	1.000000	-.052225 0.4206	-.116969 0.0705	0.113032 0.0805	0.252967 <.0001	-.225183 0.0004	-.078779 0.2240
b_cday	-.052225 0.4206	1.000000	0.128183 0.0473	-.019640 0.7621	0.083167 0.1992	-.026105 0.6874	-.132840 0.0398
b_sin	-.116969 0.0705	0.128183 0.0473	1.000000	-.074374 0.2511	-.296165 <.0001	0.205687 0.0014	0.020856 0.7479
b_cos	0.113032 0.0805	-.019640 0.7621	-.074374 0.2511	1.000000	0.095132 0.1417	-.089933 0.1649	-.185441 0.0039
b_AR1	0.252967 <.0001	0.083167 0.1992	-.296165 <.0001	0.095132 0.1417	1.000000	-.816881 <.0001	-.297462 <.0001
b_AR2	-.225183 0.0004	-.026105 0.6874	0.205687 0.0014	-.089933 0.1649	-.816881 <.0001	1.000000	0.264092 <.0001
MSE	-.078779 0.2240	-.132840 0.0398	0.020856 0.7479	-.185441 0.0039	-.297462 <.0001	0.264092 <.0001	1.000000

Notes on Table 5.

Strongest correlation is among parameters that model the error process. The autoregressive terms b_AR1 and b_AR2 have an inverse dependence. The mse term is correlated with the AR terms and with b_cos and b_cday.

There is little correlation among terms that model the mean (i.e. b_int, b_cday, b_sin, b_cos)

add tables and notes on just CB4 MANOVA.

CB4 - violation results-

Using the manova model for CB4 we can obtain a predicted value of the time series parameter vector as a function of month, water depth, and sensor depth. In this simuluation I have started with a choice of month, water depth, and sensor depth for which the mean DO is just greater than the 30 day mean criterion of 5.0.

The independent variable vector that yields this prediction is

May	Jun	Jul	Aug	Sep	Oct	WaterDepth	SensorDepth
0	0	1	0	0	0	10	6

for which the predicted vector of time series parameters is

b_Int	b_cday	b_sin	b_cos	b_AR1	b_AR2	mse
5.0058	-0.0493	-0.4072	-0.0527	0.9333	-0.0319	0.3164

This predicted vector and the estimated Variance-Covariance matrix is used to seed a multivariate normal random number generator that creates 1000 realizations of the time series parameter vector. A one week time series 15 minute observations is generated for each realization. The b_Int term of this predicted vector is the weekly mean of the one week time series. Based on the 15 minute observations, the percent of observations below the instantaneous minimum criterion is computed. The umbrella concept is assessed by comparing the true monthly mean (5.0058), the simulated weekly means (b_Int) in the 1000 realizations, and the violation rates of the instantaneous minimum.

By changing the SensorDepth of the independent variable vector, the longterm mean can be adjusted to assess the effect of this parameter on the relationship among the three criteria assessments. Thus by raising the sensor depth from 6m to 3m the mean DO is increased from 5.0058 to 7.0082 (Table ?). The time series parameters for diel signal and the mse term increase as well. The linear trend term and the AR terms remain fairly constant.

Sensor Depth	b_Int	b_cday	b_sin	b_cos	b_AR1	b_AR2	mse
6	5.0058	-0.0493	-0.4072	-0.0527	0.9333	-0.0319	0.3164
5	5.6733	-0.0476	-0.5114	0.0094	0.9328	-0.0294	0.4112
4	6.3408	-0.0460	-0.6156	0.0714	0.9324	-0.0268	0.5060
3	7.0082	-0.0443	-0.7198	0.1335	0.9320	-0.0243	0.6008

Results at 6.0

To compare violation rates of the 7-day criterion and instantaneous criterion I

crosstabulate cases where the 7 day mean < 4.0 against cases where the violation rate of the instantaneous minimum exceeds 10% in each 1 week time series.

Sensor Depth = 6 mean DO = 5.0058	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous minimum
failure Instantaneous minimum < 10%	520 62.35%	4 2.41%	524 52.4%
failure Instantaneous minimum > 10%	314 37.65%	162 97.59%	476 47.6%
marginal for failure of 7-day mean	834	166	1000

Sensor Depth = 5 mean DO= 5.6733	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous minimum
failure Instantaneous minimum < 10%	671 71.01%	4 7.27%	675 67.5%
failure Instantaneous minimum > 10%	274 28.99%	51 92.73%	325 32.5%
marginal for failure of 7-day mean	945	55	1000

Sensor Depth = 4 mean = 6.3408	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous

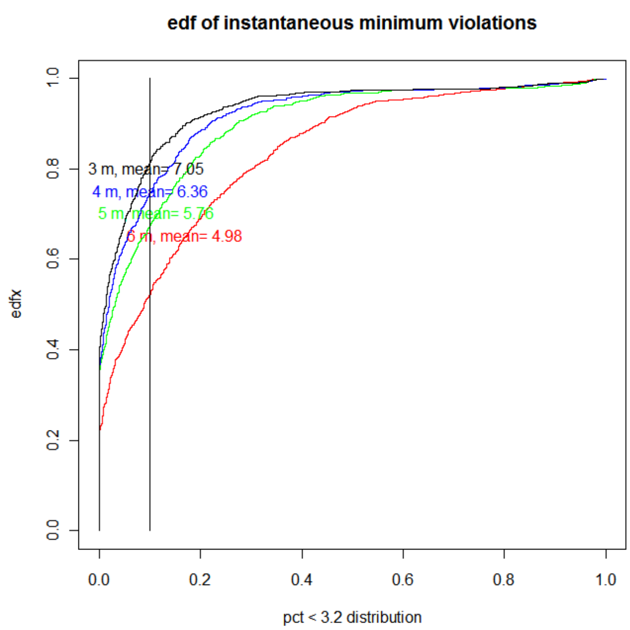
			minimum
failure Instantaneous minimum < 10%	747 75.84%	0 0%	747 74.7%
failure Instantaneous minimum > 10%	238 24.16%	15 100%	253 25.3%
marginal for failure of 7-day mean	985	15	1000

Sensor Depth = 3 mean = 7.0082	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous minimum
failure Instantaneous minimum < 10%	815 81.91%	0 0%	815 81.5%
failure Instantaneous minimum > 10%	180 18.09%	5 100%	185 18.5%
marginal for failure of 7-day mean	995	5	1000

sensor depth	6	5	4	3
Monthly Mean DO	5.0058	5.6732	6.3407	7.0082
7 day criterion failure rate	16.6%	5.5%	1.5%	0.5%
rate of instantaneous criterion > 10%	47.6%	32.5%	25.3%	18.5%

When the long term mean DO is at a 'just passing' level, the simulation predicts that the 7-day mean criterion will be violated about 16.6% of weeks . If the long term mean DO increases to 5.7 then we expected fewer than 5.5% weeks with failure of the 7-day criterion. Thus if the 30-day mean criterion is satisfied, it is quite likely that violations of the 7-day mean criterion will be satisfied unless the 30 day mean hovers in the 'just passing' zone for an extended period.

Looking the violations of the instantaneous minimum is not so encouraging. When the long term mean is 'just satisfied', the simulation predicts that the instantaneous minimum criterion exceedance rate will exceed 10% in about 47% of weeks. Even when the long term mean DO is 7, the simulation predicts 18.5% of weeks will have an instantaneous minimum criterion exceedance rate in excess of 10%.


edf of instantaneous minimum violations
3 m, mean= 7.05
4 m, mean= 6.36
5 m, mean= 5.76
6 m, mean= 4.98
edfx
pct < 3.2 distribution
0.0
0.2
0.4
0.6
0.8
1.0

APPENDIX 9 Continued

ASSESSMENT OF SAMPLING VARIABILITY ON THE ABILITY OF THE 30-DAY MEAN DO CRITERION TO SERVE AS AN UMBRELLA FOR THE 7-DAY MEAN CRITERION.

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Feb 26, 2013

Introduction

A sub-committee of TMAW reviewed the variability of the weekly mean DO about the monthly mean DO and concluded that in general, that if the 30-day DO criterion is satisfied by the monthly mean, then there is less than a 10% chance that the 7-day DO criterion will be violated by the weekly mean. This conclusion is based on having very accurate estimates of both the monthly mean and the weekly mean derived from near continuous high frequency observations of DO. However, in many parts of the bay, the monthly mean is estimated from as few as one to two point observations per month. Because the uncertainty of a monthly mean of two observations is much greater than the uncertainty of a monthly mean from near continuous data, it is reasonable to expect that effectiveness of the umbrella effect of the 30-day criterion for the 7-day criterion will diminish when the low sample size mean is employed. In this study, we examine the additional uncertainty that is created by the use of small sample size and further evaluate the consequences of this uncertainty for the umbrella concept.

Methods

This study evaluates the additional uncertainty from low sample sizes by resampling from near continuous records in a manner that simulates the twice monthly sampling of routine cruises. The near continuous DO records used are from the Potomac ConMon studies. For each calendar month in the May through September period of each record, a random day between 1 and 15 was chosen as the first sampling day of the month. To get a second sampling day, a random increment from 10 to 16 was generated and added to the first. In the event that there was no data on this second day, then the last day of the month with data was used. For each selected day, a random selection from the roughly 24 observations taken between 9:00 a.m. and 3:00 p.m. was chosen as the point estimate. These two estimates were summed and divided by 2 to obtain the monthly mean estimate. This simulation was repeated 20 times to obtain 20 monthly mean estimates for each station and month.

Months were calendar months, and weeks were designated as sequential weeks beginning January 1st of each year. Weekly means were computed for each unique combination of month and week. Thus if a month terminus divided a week, then the week was divided at this point and the resulting partial weeks were assigned to the two months. Deviations of the weekly means about the monthly mean were computed as (weekly mean DO – monthly mean DO) for weeks that occur within a month. In all cases, the weekly mean DO was computed as the mean of all high frequency observations within a week and is referred to as the near true weekly mean. The monthly mean was computed two ways. A near true estimate of the monthly mean uses all observations in the near continuous record; a small sample estimate of the monthly mean uses only two observations as described by the resampling methods above. The root mean square error (rmse) was computed across months, years, and stations for both the near true deviations and the small sample deviations. These root mean square estimates quantify the standard deviation of the weekly mean about the monthly mean for both the near true case and the small sample estimate case. The increase in the rmse for small sample case relative to the near true case illustrates the loss of precision in estimating the monthly mean by small samples.

Using these estimates of standard deviation and assuming a normal distribution for these deviations, we estimate the probability that the weekly mean is less than 4.0, the 7-day mean criterion, while the monthly mean is 5.0, the 30 day mean criterion. This probability is a measure of the efficacy of the 30-day criterion as an umbrella for the 7-day criterion.

Results:

Descriptive statistics for the true weekly deviations and the small sample deviations show a negative bias of small sample deviations relative to the true deviations (Table 1). This shows that the resampled monthly means which use daytime data only tend to be biased high, but on average this effect is not large. The range of the mean of the deviations over the resampling experiments is (-0.3428 -0.0133). The variability of the small sample deviations is much greater than that of the near true deviations. The true deviations have a rmse very close to 1.0 while the rmse from the small sample deviations always exceeds 1.6 and in one case exceeds 1.9 indicating a 60 to 90 percent increase in variability.

Summary of Monthly Mean DO vs. Weekly Mean DO resampling study results
Mon Feb 25 16:33:58 2013

Table 1.0 Summary of comparing weekly DO means to Monthly DO means for 'true' means and monthly means from 20 small sample resampling experiments.

Simu-lation	sample size	mean	rmse	minimum	q25	Median	q75	maximum
true	833	0.0017	1.005	-4.18	-0.4816	0.0125	0.4828	3.2042
1	833	-0.1344	1.6578	-5.1447	-0.9944	-0.0542	0.8052	4.9893
2	833	-0.0247	1.6903	-5.6588	-0.8519	0.0165	0.8543	4.4843
3	833	-0.2745	1.7132	-6.684	-1.1194	-0.1775	0.6852	4.4353
4	833	-0.2187	1.8037	-7.9388	-0.9968	-0.0879	0.7284	5.3265
5	833	-0.1723	1.8766	-8.2638	-0.9699	-0.0726	0.8603	4.9031
6	833	-0.0666	1.6177	-5.379	-0.8897	-0.0173	0.7745	4.6073
7	833	-0.2252	1.7196	-6.8519	-1.066	-0.2264	0.6948	5.3679
8	833	-0.0133	1.6054	-5.4517	-0.7627	0.0211	0.8046	5.1295
9	833	-0.3428	1.7471	-6.3008	-1.1947	-0.2999	0.5542	4.3745
10	833	-0.1639	1.7156	-7.3597	-1.0652	-0.1465	0.8385	4.7042
11	833	-0.0948	1.7555	-5.7288	-1.0169	-0.0054	0.8369	5.0334
12	833	-0.2193	1.9286	-7.2316	-1.0929	-0.0793	0.7621	5.5595
13	833	-0.2014	1.692	-6.5302	-1.0818	-0.0624	0.7351	5.1557
14	833	-0.1747	1.6198	-6.2597	-1.063	-0.1254	0.8021	3.9682
15	833	-0.1424	1.7216	-6.3428	-1.0468	-0.1171	0.8693	4.8051
16	833	-0.1055	1.7055	-6.114	-1.0153	0.0278	0.9094	4.3039
17	833	-0.1663	1.8126	-6.424	-1.1035	-0.107	0.7703	4.6611
18	833	-0.2157	1.8397	-6.3407	-1.1281	-0.1486	0.8262	5.2234
19	833	-0.0624	1.7048	-5.3103	-1.0217	-0.0165	0.8549	4.7011
20	833	-0.2306	1.7493	-8.2242	-1.1226	-0.1713	0.7209	4.2593

The distribution of the true weekly deviations tends to follow the normal distribution closely for the bulk of the observations (Figure 1.0). However, there is a small percentage of outliers at both the upper end and the lower end of the distribution that are more extreme than are expected for the normal distribution. Because of this heavy tailed feature of the true deviations, when the normal distribution is used to compute probabilities for this problem, these probabilities may be a slight underestimate of the true probabilities. There appear to be 10 to 15 extreme outliers in the lower tail of the distribution and thus the probability bias may be 1.2 to 1.8 percent.

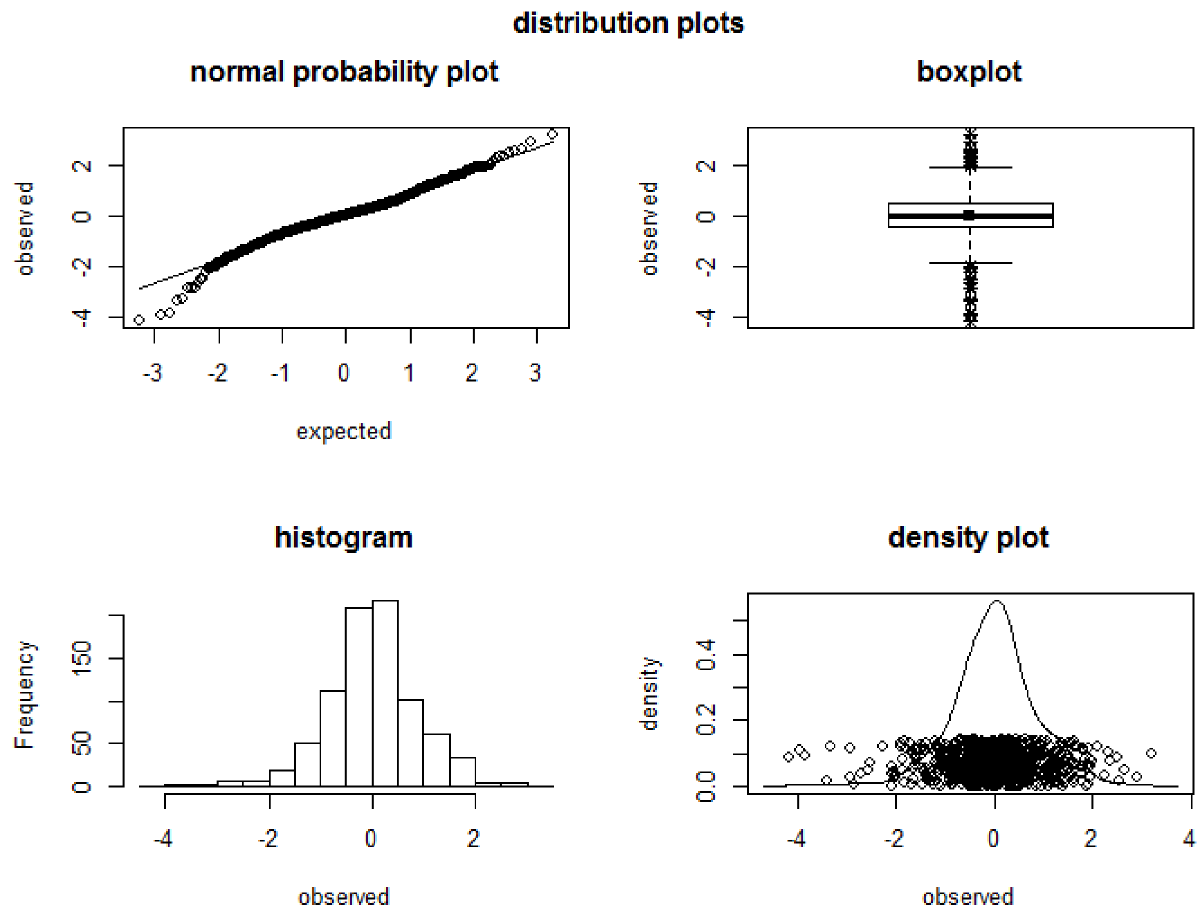

Figure 8.0 Distribution plots for the true weekly deviations.

The weekly deviations computed using the small sample monthly mean estimates appear to fit the normal distribution better than the true week deviations (Figure 2.0). The variability of deviations in the small sample experiment is clearly greater than variability for the true deviations. Compare for example the frequency of observation where the weekly mean is greater than 2 units below the monthly mean between Figures 1 and 2.

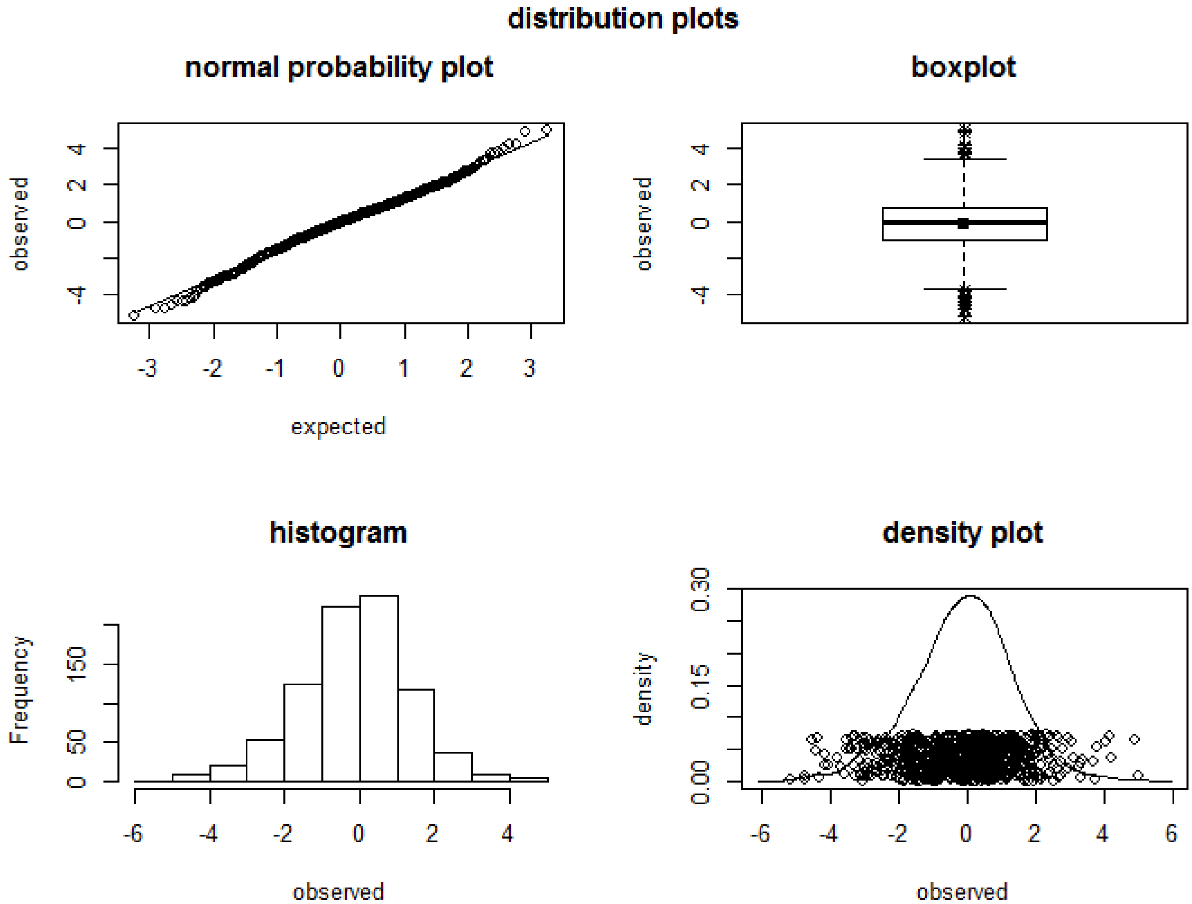

Figure 9. Distribution plots for weekly deviations computed for the first resampling experiment.

Discussion

If the 30-day criterion is to serve as an umbrella for the 7-day criterion, we would like to show that if the 30-day criterion is satisfied, there is a small probability that the 7-day criterion is violated. If we accept less than 10% as an acceptable risk of wrongly concluding that the 7-day criterion is satisfied when it is in fact violated, then this is satisfied when the standard deviation of the weekly mean from the monthly mean is .7805 or smaller. At this level of variability in the weekly deviations, excursions of the weekly mean below the 7-day criterion of 4.0 while the monthly mean is at the 30-day criterion of 5.0 would be about 10% (Figure 3). This scenario would be strong evidence that the 30-day criterion is an effective umbrella for the 7-day criterion.

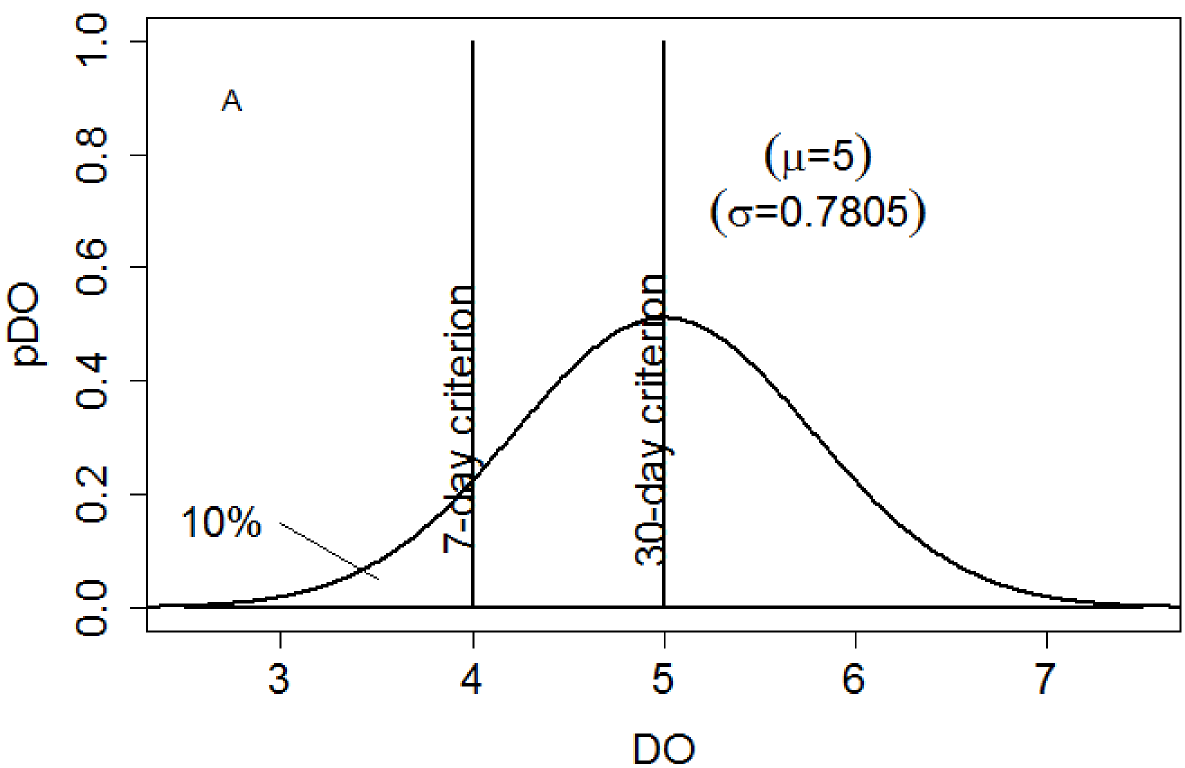

Figure 10. Illustration of the 30-day criterion as an umbrella for the 7-day criterion.

In the Potomac ConMon data, the standard deviation of the weekly mean from the monthly mean exceeds this ideal 0.7805 value and is estimated to be 1.005 or very close to 1.0. At this level of variability, the risk of violating the 7-day criterion when the 30-day criterion is satisfied exactly is about 16% (table 2., Figure 4.) However, increasing the monthly mean to 5.285 again brings the risk of violations of the 7-day criterion to an acceptable level of 10%. Because it is unlikely that the monthly mean will hover in this narrow window of (5.0, 5.285) for an extended time then it seems reasonable to consider that the 7-day criterion is satisfied if the 30-day criterion is satisfied. This evidence is one supporting fact for the TMAW conclusion that the 30-day criterion is an effective umbrella for the 7-day criterion. It is important to recognize that this conclusion assumes that both the true monthly mean and the true weekly mean can be estimated with great precision. This high level of precision is obtained here by using a near continuous record of DO.

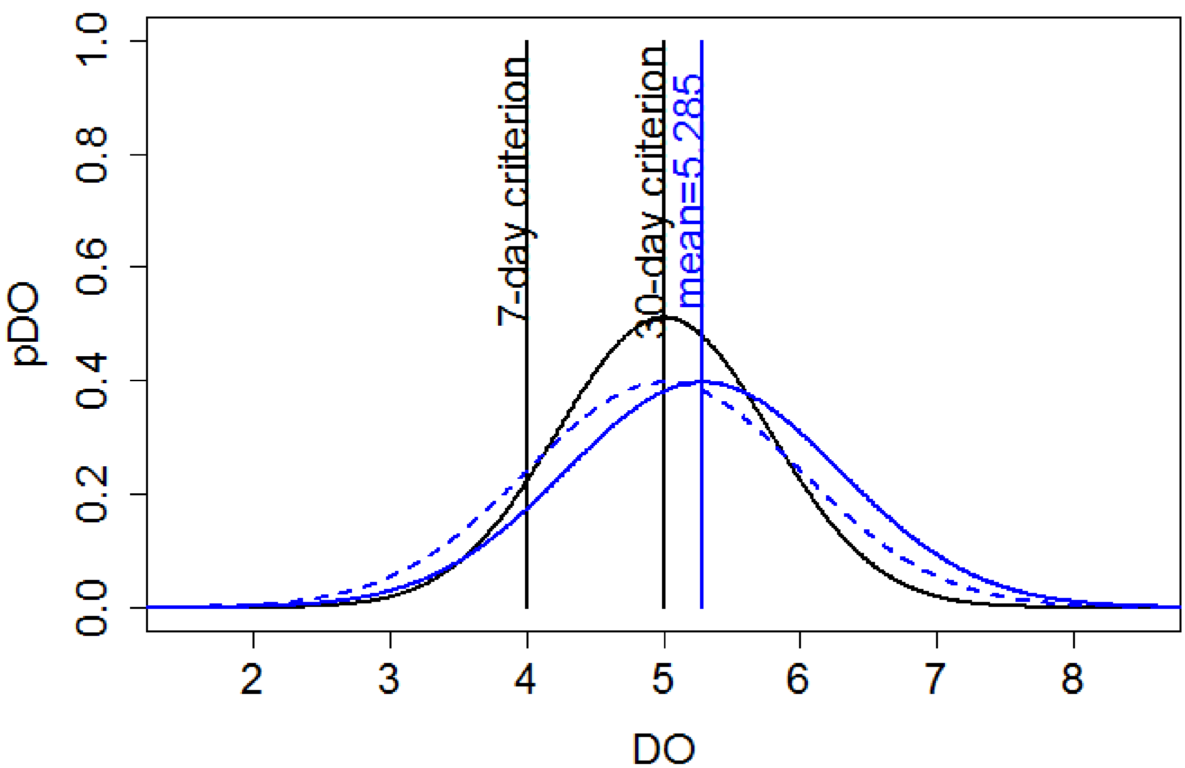

Figure 11. Illustration of the shift in the monthly mean required to meet 10% risk tolerance for the 7-day criterion when the weekly mean deviation is 1.005.

When the monthly mean is estimated by a sample size of two observations, then the variability of the deviations between the monthly mean estimate and the weekly means increases by 60 to 90 percent (table 3.0, Figure 5). At this higher level of variability, satisfying the 30-day criterion exactly results in a 28% risk of violating the 7-day criterion. Estimates of the monthly mean would have to exceed a threshold of 6.22 to insure that the risk of violating the 7-day criterion is 10% or less.

Table 2.0 Estimates of risk of violating the 7-day criterion given the monthly mean estimate (column 1) and four levels of sampling variation (columns 2-5). Column 1 assumes near true weekly deviations, column 2 assumes variation the average of 20 small sample estimates, column 3 assumes variation at the minimum of 20 small sample estimates and column 4 assumes variation at the maximum of 20 small sample estimtes.

	Risk of violating 7-day criterion			
Monthly Mean DO		SD=1.7358[2]	SD=1.6054[3]	SD=1.9287[4]
5.0	0.1598	0.2822	0.2666	0.3020
5.1	0.1368	0.2631	0.2466	0.2842
5.2	0.1162	0.2446	0.2273	0.2669
5.3	0.0979	0.2269	0.2090	0.2501
5.4	0.0818	0.2099	0.1915	0.2339
5.5	0.0677	0.1937	0.1750	0.2183
5.6	0.0556	0.1783	0.1594	0.2033
5.7	0.0453	0.1636	0.1448	0.1890
5.8	0.0366	0.1498	0.1311	0.1753
5.9	0.0293	0.1368	0.1183	0.1622
6.0	0.0232	0.1246	0.1064	0.1498
6.1	0.0183	0.1131	0.0954	0.1381
6.2	0.0142	0.1024	0.0852	0.1269
6.3	0.0110	0.0925	0.0759	0.1165
6.4	0.0084	0.0833	0.0674	0.1066
6.5	0.0064	0.0748	0.0597	0.0974

1 standard deviation of true weekly mean from true monthly mean
2 standard deviation base on pooling 20 resampling estimates
3 standard deviation based on minimum of 20 resampling estimates
4 standard deviation based on maximum of 20 resampling estimates

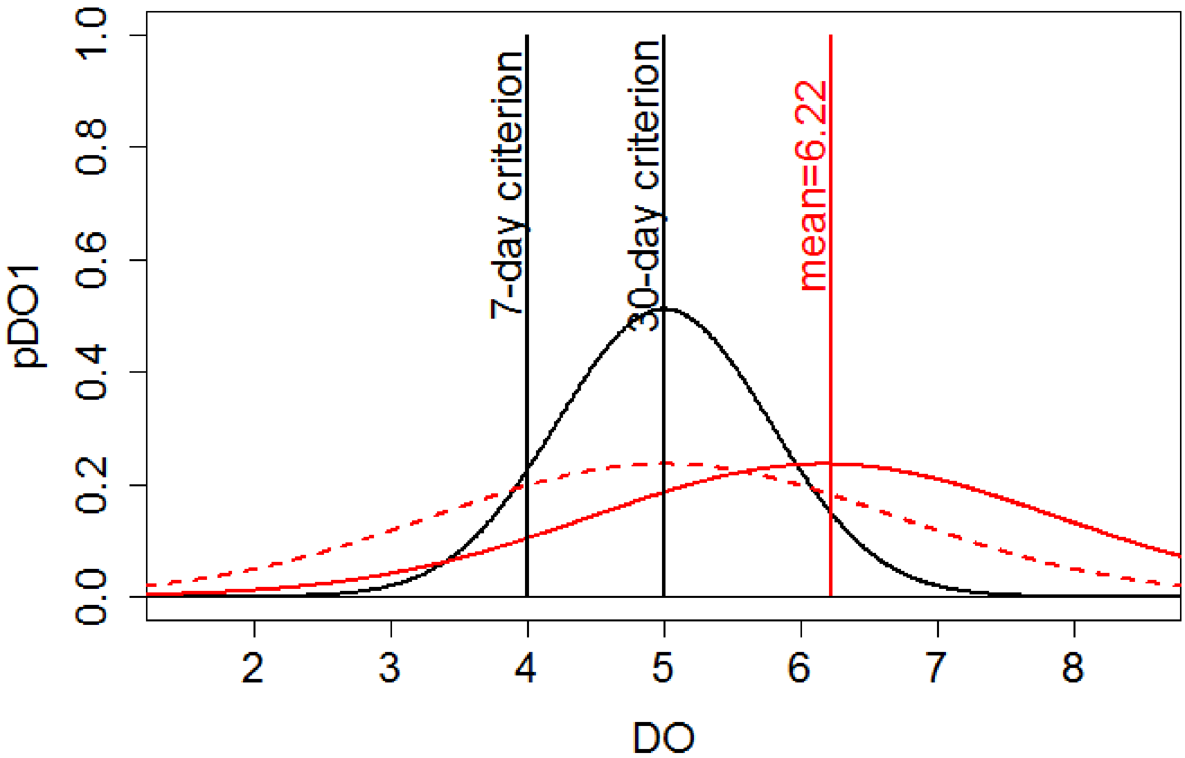

Figure 12. Illustration of the shift (from red dashed line to red solid line) in the monthly mean required to meet 10% risk tolerance for the 7-day criterion when the weekly mean deviation is at the small sample level of 1.74.

Conclusion:

Based on the evidence that the monthly mean threshold of 6.22 which insures that violations of the 7-day criterion is less than 10% is far above the 30-day criterion of 5.0, the 30-day criterion is not an umbrella for the 7-day criterion when the monthly mean is estimated by a sample size as small as two.

APPENDIX 10

Development of a Multimetric Chesapeake Bay Water Quality Indicator for Tracking Progress toward Bay Water Quality Standards Achievement

A. Category/Name/Source/Contact

(1) Category of Indicator

___ Factors Impacting Bay and Watershed Health

___ Restoration and Protection Efforts

___ Watershed Health

_x_ Bay Health

(2) Name of Indicator: Water Quality Standards Achievement

(3) Description of Dataset used:

Dissolved oxygen (DO), secchi depth, submerged aquatic vegetation (SAV) acreage, and chlorophyll *a* measurements are used to calculate standards attainment.

- For what purpose(s) were the data collected? (e.g., tracking, research, or long-term monitoring.)
  Tracking, research, and long-term monitoring

- Which parameters were measured directly?
  - DO concentrations are measured in-situ at surface and depth profiles across the entire Bay.
  - Secchi depths are measured directly during Bay transect cruises.
  - SAV area and percent coverage is measured from photographs during the aerial surveys (after photo-interpretation).

- Chlorophyll-a concentrations were measured in a lab using bio-matter collected from filtered water samples at fixed stations.

- Which were obtained by calculation?
    - Aggregations of photo-interpreted SAV area data to segment, zone and bay-wide levels.
    - Standards attainment for DO, water clarity, and chlorophyll *a* are calculated according to the April 2003 USEPA publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (http://www.chesapeakebay.net/content/publications/cbp_13142.pdf) Refinements to these procedures are described in subsequent technical addenda, all of which can be downloaded from http://www.chesapeakebay.net/publications.

(4) Source(s) of Data:

DO, secchi depth and chlorophyll *a* are measured by the MD Department of Natural Resources (MD mainstem and tributary data), the VA Department of Environmental Quality (VA tributary data and benthic monitoring data), Old Dominion University (VA mainstem data), Virginia Institute of Marine Sciences (VA trib data), and submitted citizen/volunteer monitoring data (VA trib data). SAV area is measured by Virginia Institute of Marine Science (VIMS).

DO and chlorophyll *a* assessments are conducted at CBPO by the tidal monitoring analyst (Liza Hernandez, UMCES-CBPO) and modeling research scientist (Richard Tian, UMCES-CBPO). Water clarity/SAV assessments are conducted by the Maryland Department of Natural Resources (Mark Trice) and Virginia Institute of Marine Science (Dave Parrish).

Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions?

Yes.

If yes, please indicate where complete dataset can be obtained.

DO, secchi depth, and chlorophyll *a* data are located on the Chesapeake Information Management System (CIMS) data hub and can be downloaded from the CBP Water Quality Database (1984-present) webpage (http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present). Additional data submitted by the states from citizen science monitoring programs can be obtained by contacting Chesapeake Bay Program's, Water Quality Database Manager (Mike Mallonee, ICPRB-CBPO).

SAV area data can be downloaded from http://web.vims.edu/bio/sav/StateSegmentAreaTable.htm.

DO and chlorophyll *a* assessment results can be obtain by contacting Liza Hernandez, CBPO's Tidal Monitoring Analyst (lhernandez@chesapeakebay.net). Water clarity attainment results may be obtained by contacting Dave Parrish (parrishd@vims.edu) at VIMS or Tish Robertson (tlrobertson@deq.virginia.gov) at VADEQ for the VA results and Mark Trice (MTrice@dnr.state.md.us) at MDDNR for the MD results.

(5) Custodian of Source Data (and Indicator, if different):

- For raw data: Mike Mallonee (ICPRB-CBPO)
- For DO and chlorophyll *a* assessments: Liza Hernandez (UMCES-CBPO) and/or Richard Tian (UMCES-CBPO)
- For SAV acreage data: Bob Orth (VIMS) or David Wilcox (VIMS)
- For Water Clarity assessments: Dave Parrish (VIMS) (VA) or Tish Robertson (VADEQ) (VA) and Mark Trice (MDDNR) (MD)

(6) CBPO Contact:

Liza Hernandez (UMCES-CBPO)

B. Communication Questions *(complete either part 1, 2, or 3 AND part 4)*

2. Bay Health or Watershed Health indicators only

(7b) What is the long-term trend? (since start of data collection)

A linear trend analysis suggests a gradually increasing (i.e., improving) trend since 1985 for every 3-year assessment period.

(8b) What is the short-term trend? (10-year trend)

A linear 10-year trend analysis suggests no significant trend since 2002 for every 3-year assessment period.

(9b) What is the current status in relation to a goal? N/A

(10b) What does this indicator tell us?

This combined indicator measures baywide attainment of water quality standards for DO, water clarity/SAV and chlorophyll *a* for each 3-year assessment period beginning in 1985.

The best available data, not including water clarity assessment results from Maryland, indicate that water quality conditions from 2010-2012 indicate that about 31% of the Bay's tidal waters met DO, water clarity/underwater bay grasses and chlorophyll *a* standards. This number is subject to change once Maryland's water clarity assessment data may be incorporated into the calculations.

Nutrients, along with sediments, are the primary causes of impairments to the Chesapeake Bay and its tidal tributaries. To meet the objectives of the Clean Water Act, the EPA's implementing regulations specify that states must adopt criteria that contain sufficient parameters to protect existing and designated uses. In 2003, EPA Region III developed *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (http://www.chesapeakebay.net/content/publications/cbp_13142.pdf). This was developed in order to achieve and maintain water quality conditions necessary to protect the aquatic living resources of the Chesapeake Bay and its tidal tributaries from the effects of nutrient and sediment pollution. Within the publication, five designated uses were identified and described, that when adequately protected, will ensure the protection of the living resources therein.

For each of the 92 Chesapeake Bay tidal management segments, a variety of unique combinations of Chesapeake Bay water quality criteria are applied, where appropriate, to each of the five tidal water designated uses. Each segment can have between one (e.g., Eastern Branch of the Elizabeth River which has only the open-water designated use) and all five designated uses (e.g., Lower Rappahannock River which has migratory fish and spawning nursery, open-water, deep-water, deep-channel, and shallow-water bay grass designated uses). Furthermore, the mainstem James River segments and the District of Columbia's Upper Potomac River and Anacostia River segments have applicable numeric chlorophyll *a* criteria in addition to the designated use application. For a detailed outline of which designated uses and criteria apply to each of the 92 segment, refer to Table 1 of Attachment vii.b downloadable from http://www.chesapeakebay.net/S=0/calendar/event/18751/.

The methodology used for the calculation of the indicator considers the achievement or non-achievement of the dissolved oxygen, water clarity/underwater bay grasses, and chlorophyll a water quality standards applicable to a designated use within a segment. Rather than reporting progress only when all designated uses are met within a segment, this methodology reports when a water quality standard is met for each of the designated uses in that segment; therefore, rather than reporting on the 92 Chesapeake Bay segments used for the establishment and management of the Chesapeake Bay Total Maximum Daily Load (TMDL), this methodology reports on 291 designated-use segments contained within.

This indicator uses a surface area-weighted approach, which multiplies the surface area of each of the 92 segments times the number of applicable designated uses and criteria for that segment. This approach factors in the relative size of each segment, ensuring we report the best available measure of how much of the Bay tidal waters were achieving water quality standards. At the same time, this approach gives equal weight to achievement of the criteria protective of each designated use and segment, preventing any need to weigh differently the importance of restoring dissolved oxygen versus bringing back underwater bay grasses. Restoration of a fully functioning Chesapeake Bay ecosystem requires attainment of all five designated uses and their applicable criteria. This indicator consolidates the baywide results in the final calculations and reports percent of Bay water quality standards meeting attainment.

(11b) Why is it important to report this information?

The Chesapeake Bay Program (CBP) Partnership approved the development of this combined indicator to measure progress towards the achievement of the four jurisdictions' Chesapeake Bay water quality standards. The indicator is fully consistent with how Delaware, the District of Columbia, Maryland, and Virginia currently list their portion of the Bay's tidal waters and provide a means for illustrating improvements through time. Additionally, this indicator is being used to measure progress toward the Chesapeake Bay Executive Order Strategy's water quality outcome.

(12b) What detail and/or diagnostic indicators are related to this reporting level indicator?

The dissolved oxygen indicator featured at http://www.chesapeakebay.net/indicators/indicator/dissolved_oxygen provides information on the percent of the combined volume of open-water, deep-water and deep-channel water of the Bay and its tidal tributaries having met dissolved oxygen standards during summer months for each 3-year assessment period.

The SAV indicator featured at http://www.chesapeakebay.net/indicators/indicator/bay_grass_abundance_baywide provides information on progress towards the SAV restoration goal, which is to have 185,000 acres of underwater grasses in the Chesapeake Bay.

The individual component pieces (i.e., the individual surface-area assessments of standards attainment for each designated use) that, in combination, result in the baywide percentage of water quality standards meeting attainment are features at

- Dissolved Oxygen: http://www.chesapeakebay.net/indicators/indicator/water_quality_standards_achievement_for_dissolved_oxygen_surface_area_asses
- Chlorophyll *a*: http://www.chesapeakebay.net/indicators/indicator/chlorophyll_a
- Water Clarity/Underwater Bay Grasses: http://www.chesapeakebay.net/indicators/indicator/mid_channel_water_clarity

.4. All indicators

(7d) What did the most recent data show compared to the previous year?

Results for 2010-2012 indicated that 31% of the Bay was attaining water quality standards. With the availability and subsequent incorporation of Maryland's 2010-2012 water clarity assessment data into the calculations, this percentage may change. In the meantime, these results are not significantly different from those of the previous assessment year (2009-2011) in which 30% of the Bay was attaining water quality standards.

(8d) If this was a significant increase/decrease: No.

- To what do you attribute it? N/A

- Is this educated speculation or actual cause? N/A

(9d) What is the goal, target, threshold or expected outcome for this indicator? N/A

(10d) Was a new goal, target, threshold or expected outcome established since last reporting? N/A Why? N/A

(11d) Did the methodology of data collection or analysis change from previous year(s)?

Yes, but only the case for the attainment determination of the shallow-water bay grasses designated use.

Why and how?

Water clarity assessments are only conducted on a biennial basis since the 2006-2008 listing cycle. Furthermore, water clarity assessments are only conducted for a given set of segments throughout the Bay, which rotate every three years. When water clarity assessments are not available for any segment, the attainment of the shallow water bay grasses designated use is assessed using the measured SAV acres meeting the segment-specific restoration acre goals *only*. When water clarity assessment data is available the shallow-water bay grasses designated use is considered in attainment if:

1. sufficient acres of SAV are observed within the segment; or

2. enough acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired SAV acreage for that segment.

Assessment of either measure, or a combination of both, serves as the basis for determining attainment or impairment of the shallow-water bay grasses designated use.

- If so, how will this improve your/our future work?

  The availability of high frequency water clarity data in shallow-water that can be used in assessments provide a more comprehensive look at the water clarity conditions within a segment. Aerial SAV photography data is only indicative of existing SAV beds. Water clarity data provides an additional means of assessing in areas where the SAV restoration goal may not be met, but not as a result of insufficient water clarity conditions.

C. Temporal Considerations

(13) Data Collection **D**ate(s): 1985-2012

(14) Planned Update Frequency (e.g. - annual, bi-annual):

(a) Source Data:

Annual (except for water clarity assessment results which are only updated biennially beginning with the 2006-2008 listing cycle)

(b) Indicator:

Annual

(15) For annual reporting, month spatial data is available for reporting:

- Raw data is available in the spring of the following year.
- DO and chlorophyll *a* assessments are available in the spring of the following year.
- SAV data is available in the spring of the following year.
- Water Clarity assessments, when conducted, are available in the fall of the following year.

D. Spatial Considerations

(16) Type of Geography of Source Data (point, line polygon, other):

- DO, chlorophyll *a*, and secchi depth are all point data.

- USGS 7.5 minute quadrangle maps are used to organize the SAV mapping process; 258 quadrangles in the study area include all regions with potential for SAV growth.

(17) Acceptable Level of Spatial Aggregation (e.g. - county, state, major basin, tributary basin, HUC):

- DO and SAV data are aggregated to 92 tidal water segments for the Chesapeake Bay (2008 revised Chesapeake Bay Program segmentation scheme: http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).
- Chlorophyll a data are aggregated to the 7 tidal water segments for which numeric criteria apply.
- Water clarity data are aggregated to each tidal water segment where the shallow-water monitoring (i.e., continuous monitoring) is active.

(18) Are there geographic areas with missing data? Yes

If so, where?

POTOH2_MD and POTOH3_MD were not assessed for attainment of dissolved oxygen criteria due to insufficient data.

POTMH_VA was not assessed for attainment of the deep-water and deep-channel designated uses for dissolved oxygen criteria due to insufficient data.

In areas that cannot be assessed due to lack of bathymetry data or insufficient data (i.e., “NoData”), the designated use for that segments is treated as out of attainment.

(19) The spatial extent of this indicator best described as:

(a) Chesapeake Bay (estuary) _x_

(b) Chesapeake Bay Watershed ___

(c) Other (please describe): _______________________

Please submit any appropriate examples of how this information has been mapped or otherwise portrayed geographically in the past.

Throughout the development of this indicator, attainment status for each of the designated uses was mapped. These maps are contained within Attachments vii.a and vii.b, which were presented to the Management Board. These attachments may be downloaded from http://www.chesapeakebay.net/S=0/calendar/event/18751/.

(20) Can appropriate diagnostic indicators be represented geographically? Yes.

E. Data Analysis and Interpretation: (Please provide appropriate references and location of documentation if hard to find.)

(21) Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates? (i.e., how well do the data represent the phenomenon?)

Yes. An extensive technical review of the assumptions drawn, the data selected to be used, data interpretation, the methods employed and all supporting information and conclusions was conducted by state, federal and non-government organization partners through the development of this indicator.

Specifically, the Chesapeake Bay Program Office, working with EPA Region 3's Water Protection Division and Office of Regional Counsel, as well as the CBP Partnership's Scientific, Technical Assessment and Reporting Team's (STAR) Criteria Assessment Protocols (CAP) Workgroup, explored a series of options for analysis. Final recommendations were reviewed and approved by members of the Criteria Assessment Protocols Workgroup (CAP), the Tidal

Monitoring and Analysis Workgroup (TMAW), the Water Quality Goal Implementation Team (WQGIT), and the Management Board.

Materials presented to the Management Board, including a brief write-up of methods may be found at http://www.chesapeakebay.net/S=0/calendar/event/18753/. Further development of the indicator as recommended by the Management Board led to the derivation of all final assumptions being used in the calculation of the water quality standards indicator. These are stated in the presentation which can be found at http://www.chesapeakebay.net/S=0/calendar/event/18754/.

(22) What is the process by which the raw data is summarized for development and presentation of the indicator?

The published dissolved oxygen criteria assessment methodology currently used for assessing Chesapeake Bay water quality criteria attainment involves the use of cumulative frequency distribution (CFD) curves in a 2D space of percent time and percent space to determine the volumetric extent of compliance. The procedure for assessing dissolved oxygen criteria attainment is described in detail in Appendix A of the September 2008 water quality criteria addendum: *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries 2008 Technical Support for Criteria Assessment Protocols Addendum* (http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).

In 2004, Virginia and the District of Columbia adopted numerical chlorophyll *a* criteria for application in the tidal James River and across the District's jurisdictional tidal waters. In 2007, EPA provided states guidance for the assessment of chlorophyll *a* criteria through the publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2007 Chlorophyll Criteria Addendum* (http://www.chesapeakebay.net/content/publications/cbp_20138.pdf). The published chlorophyll *a* criteria assessment methodology currently used for assessing Chesapeake Bay water quality criteria attainment involves the use of cumulative frequency distribution (CFD) curves in a 2D space of percent time and percent space to determine the volumetric extent of compliance.

Water clarity acres are calculated from the most recent consecutive three-year period of available shallow-water monitoring water clarity data. The general methodology is described in Appendix E of the September 2008 water quality criteria addendum: *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries 2008 Technical Support for Criteria Assessment Protocols Addendum* (http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).

ArcGIS geodatabase in a Universal Transverse Mercator (UTM) Zone 18 projection was used to calculate area in square meters for all SAV beds. These areas are summarized in tables by USGS 7.5 minute quadrangle, Chesapeake Bay Program and Delmarva Peninsula coastal bay segments, zone, and by state. Segment and zone totals were calculated using an overlay operation of segment and zone regions on the SAV beds.

For the presentation of this indicator, we assumed that attainment of the open-water dissolved oxygen criterion can serve as an “umbrella” assessment protective of the remaining dissolved oxygen criteria in each designated use. In this way, we are able to fully assess attainment across all segments, uses and criteria using the following criteria for making impairment status determinations:

- Migratory Fish and Spawning Nursery Habitat: applied the 6 mg/L 7-day mean DO criterion as a 30-day mean
- Open-Water Fish and Shellfish Habitat: 5 mg/L 30-day mean DO criteria,
- Deep-Water Seasonal Fish and Shellfish Habitat: 3 mg/L 30-day mean DO criteria,
- Deep-Channel Seasonal Refuge Habitat: 1 mg/L instantaneous minimum DO criteria
- Shallow-Water Bay Grasses Habitat:
  When water clarity assessment data is available the shallow-water bay grasses designated use is considered in attainment if:
  1. sufficient acres of SAV are observed within the segment; or
  2. enough acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired SAV acreage for that segment.
  - Assessment of either measure, or a combination of both, serves as the basis for determining attainment or impairment of the shallow-water bay grasses designated use.
- Chlorophyll *a* numeric criteria as it applied to the open-water designated use for the mainstem James River segments and the District of Columbia’s Upper Potomac River and Anacostia River segments:
  - James River segments:
    1. Criteria attainment assessed during spring (Mar1-May31) and summer (Jun1-Sep30) seasons; both seasons must be meeting the standards for the segment to be in attainment.
  - District of Columbia’s Upper Potomac River and Anacostia River segments:
    1. Criteria attainment only assessed during the summer (Jun1-Sep30) season.

Impairment determinations were then summarized for every applicable designated use and criteria contained within each of the 92 segments. Using a surface area-weighted approach, which multiplies the surface area of each of the 92 segments times the number of applicable designated uses and criteria for that segment, this indicator factors in the relative size of each segment, ensuring we report the best available measure of how much of the Bay tidal waters were achieving water quality standards. At the same time, this approach gives equal weight to achievement of the criteria protective of each designated use and segment, preventing any need to weigh differently the importance of restoring dissolved oxygen versus bringing back underwater bay grasses. Final calculations represent the baywide percent of Bay water quality standards meeting attainment.

(23) Are any tools required to generate the indicator data (e.g. - Interpolator, watershed model)

- Interpolator and FORTRAN programs to determine the volumetric extent of compliance of DO and chlorophyll *a* standards.
- ArcGIS used to calculate area in square meters for all SAV beds.
- ArcGIS used to calculate water clarity acres for segments containing shallow-water monitoring data.

(24) *Are the computations* widely accepted as scientifically sound? Yes.

(25) Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

Yes, the Chesapeake Bay Program's interpolator (Vol3D461) was used to interpolate DO and chlorophyll *a* the data within each segment; ArcGIS was used to interpolate water clarity data.

(26) Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the desired state of the environment? (health/stressors only)

Yes. Water quality criteria for the Chesapeake Bay and its tidal tributaries used for the assessment of water quality standards have been developed and are available at http://www.chesapeakebay.net/content/publications/cbp_13142.pdf.

F. Data Quality: (Please provide appropriate references and location of documentation if hard to find.)

(27) Were the data collected according to an EPA-approved Quality Assurance Plan?

Yes, methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA grant. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

If no, complete questions 28a – 28d:

(28a) Is the sampling design and/or monitoring plan and/or tracking system used to collect the data over time and space based on sound scientific principles? N/A

(28b) What documentation clearly and completely describes the underlying sampling and analytical procedures used? N/A

(28c) Are the sampling and analytical procedures widely accepted as scientifically and technically valid? N/A

(28d) To what extent are the procedures for quality assurance and quality control of the data documented and accessible? N/A

(29) Are the descriptions of the study or survey design clear, complete, and sufficient to enable the study or survey to be reproduced?

Yes, methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA grant. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

(30) Were the sampling and analysis methods performed consistently throughout the data record?

Beginning with the 2005-2007 3-year assessment period, ancillary data provided by the states are included for the assessment of DO criteria. Ancillary data did not exist prior to 2007, therefore is not included for analyses going back to 1985. Furthermore, since 2003, improvements in the development of the underlying biological reference curves used for the assessment of DO criteria have resulted in modified reference curves. In addition, the logic of pycnocline application for determination of designated uses was corrected, in order to allow for episodic occurrence of deep-water and deep-channel designated uses. These refinements are described in the Technical Addendum published in May 2010 and are available at http://www.chesapeakebay.net/content/publications/cbp_51366.pdf.

Some technical improvements (e.g., photo-interpretation tools) were made over the 26 years of the annual SAV survey in Chesapeake Bay. Surveyors and analysts have carefully evaluated the effect of methodological changes along the way and made corrections to adjust for any known effects. The quality assurance project plan for the EPA grant to the Virginia Institute of Marine Sciences describes data collection, analysis, and management methods. This is on file at the U. S. Environmental Protection Agency Chesapeake Bay Program Office (contact: EPA grant project officer, Mike Fritz (fritz.mike@epa.gov). The VIMS web site at http://www.vims.edu/bio/sav/ provides this information as well. Metadata are included with the data set posted at the VIMS web site (http://www.vims.edu/bio/sav/metadata/beds11.html).

Revisions to the water clarity acres assessment methodology were implemented in 2008 and are outlined in Chapter 4 of the September 2008 water quality criteria addendum: *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries 2008 Technical Support for Criteria Assessment Protocols Addendum* (http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).

(31) If datasets from two or more agencies are merged, are their sampling designs and methods comparable?

Yes, methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA grant. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

(32) Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

Uncertainty measurements/estimates are available for the underlying data. Methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA grant. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

(33) Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

Yes. DO, chlorophyll *a* and water clarity are variable both spatially and temporally. The interpolation method used for each of these parameters to determine the spatial variability has inherent errors that add to the uncertainty of estimating measurements in large areas of the Bay. Moreover, the interpolations have inherent errors in that they are a composite of monthly data and the sampling of different parts of the Bay occurs over different times of the month. Therefore, there are limitations to how the data can be applied and interpreted both spatially and temporally

(34) Are there noteworthy limitations or gaps in the data record? Please explain.

Noteworthy gaps only apply to the underlying SAV acreage data– due to funding constraints, no SAV survey was conducted in 1988. For further detail on SAV spatial gaps since 1988, refer to the analysis and methods documentation for SAV available for download at http://www.chesapeakebay.net/indicators/indicator/bay_grass_abundance_baywide.

G. Additional Information (optional)

(35) Please provide any other information about this indicator you believe is necessary to aid communication and any prevent potential misrepresentation. N/A

APPENDIX 11

Tidal water designated uses by Chesapeake Bay segment

Table 1. Tidal water designated uses by Chesapeake Bay segment

Waterbody	CBP Segments & Split Segments	Jurisdiction	Migratory Spawning & Nursery	Open Water	Deep Water	Deep Channel	Shallow Water Bay grasses	Chlorophyll-a (applies to open water)
Anacostia River	ANATF_DC	DC	X	X			X	X
Anacostia River	ANATF_MD	MD	X	X			X	
Appomattox River	APPTF	VA	X	X			X	
Back River	BACOH	MD	X	X			X	
Big Annemessex River, Lower	BIGMH1	MD	X	X			X	
Big Annemessex River, Upper	BIGMH2	MD					X	
Bohemia River	BOHOH	MD	X	X			X	
Bush River	BSHOH	MD	X	X			X	
C&D Canal	C&DOH_DE	DE	X	X				
C&D Canal	C&DOH_MD	MD	X	X			X	
Northern Chesapeake Bay, Turkey Pt. South	CB1TF1	MD	X	X			X	
Northern Chesapeake Bay, Susquehanna River and Flats	CB1TF2	MD					X	
Upper Chesapeake Bay	CB2OH	MD	X	X			X	
Upper Central Chesapeake Bay	CB3MH	MD	X	X	X	X	X	
Middle Central Chesapeake Bay	CB4MH	MD	X	X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_MD	MD		X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_VA	VA		X	X	X	X	

Western Lower Chesapeake Bay	CB6PH	VA		X	X		X	
Eastern Lower Chesapeake Bay	CB7PH	VA		X	X		X	
Mouth of the Chesapeake Bay	CB8PH	VA		X			X	
Chickahominy River	CHKOH	VA	X	X			X	
Mouth of the Choptank River	CHOMH1	MD	X	X			X	
Lower Choptank River	CHOMH2	MD	X	X			X	
Middle Choptank River	CHOOH	MD	X	X			X	
Upper Choptank River	CHOTF	MD	X	X				
Lower Chester River	CHSMH	MD	X	X	X	X	X	
Middle Chester River	CHSOH	MD	X	X			X	
Upper Chester River	CHSTF	MD	X	X			X	
Corrotoman River	CRRMH	VA	X	X			X	
Eastern Bay	EASMH	MD		X	X	X	X	
Eastern Branch Elizabeth River	EBEMH	VA		X				
Mouth of the Elizabeth River	ELIPH	VA		X				
Elk River, Upper	ELKOH1	MD	X	X			X	
Elk River, Lower	ELKOH2	MD					X	
Fishing Bay	FSBMH	MD	X	X			X	
Gunpowder River, Upper	GUNOH1	MD	X	X			X	
Gunpowder River, Lower	GUNOH2	MD					X	
Honga River	HNGMH	MD		X			X	
Lower James River	JMSMH	VA	X	X			X	X
Middle James River	JMSOH	VA	X	X			X	X
Mouth of the James River	JMSPH	VA		X			X	X
Upper James River	JMSTF1	VA	X	X			X	X
Upper James River	JMSTF2	VA	X	X			X	X

Lafayette River	LAFMH	VA		X				
Little Choptank River	LCHMH	MD		X			X	
Lynnhaven River	LYNPH	VA		X			X	
Magothy River	MAGMH	MD	X	X	X		X	
Manokin River, Lower	MANMH1	MD	X	X			X	
Manokin River, Upper	MANMH2	MD					X	
Mattawoman Creek	MATTF	MD	X	X			X	
Middle River	MIDOH	MD	X	X			X	
Mobjack Bay	MOBPH	VA		X			X	
Lower Mattaponi River	MPNOH	VA	X	X				
Upper Mattaponi River	MPNTF	VA	X	X			X	
Lower Nanticoke River	NANMH	MD	X	X			X	
Middle Nanticoke River	NANOH	MD	X	X			X	
Upper Nanticoke River	NANTF_DE	DE	X	X				
Upper Nanticoke River	NANTF_MD	MD	X	X				
Northeast River	NORTF	MD	X	X			X	
Patapsco River	PATMH	MD	X	X	X	X	X	
Lower Patuxent River, Lower	PAXMH1	MD	X	X	X		X	
Lower Patuxent River, Upper	PAXMH2	MD					X	
Lower Patuxent River, Mill Creek	PAXMH3	MD					X	
Lower Patuxent River, Cuckold Creek	PAXMH4	MD					X	
Lower Patuxent River, St. Leonard Creek	PAXMH5	MD					X	
Lower Patuxent River, Island Creek	PAXMH6	MD					X	
Middle Patuxent River	PAXOH	MD	X	X			X	
Upper Patuxent River	PAXTF	MD	X	X			X	

Piankatank River	PIAMH	VA		X			X	
Piscataway Creek	PISTF	MD	X	X			X	
Lower Pamunkey River	PMKOH	VA	X	X				
Upper Pamunkey River	PMKTF	VA	X	X			X	
Lower Pocomoke River	POCMH_MD	MD	X	X			X	
Lower Pocomoke River	POCMH_VA	VA	X	X			X	
Middle Pocomoke River	POCOH_MD	MD	X	X				
Middle Pocomoke River	POCOH_VA	VA	X	X				
Upper Pocomoke River	POCTF	MD	X	X				
Lower Potomac River	POTMH_MD	MD	X	X	X	X	X	
Lower Potomac River	POTMH_VA	VA	X	X	X	X	X	
Middle Potomac River, MD Mainstem	POTOH_VA	VA	X	X			X	
Middle Potomac River, MD Port Tobacco River	POTOH1_MD	MD	X	X			X	
Middle Potomac River, MD Nanjemoy Creek	POTOH2_MD	MD	X	X			X	
Middle Potomac River	POTOH3_MD	MD	X	X			X	
Upper Potomac River	POTTF_DC	DC	X	X			X	X
Upper Potomac River	POTTF_MD	MD	X	X			X	
Upper Potomac River	POTTF_VA	VA	X	X			X	
Rhode River	RHDMH	MD	X	X			X	
Lower Rappahannock River	RPPMH	VA	X	X	X	X	X	
Middle Rappahannock River	RPPOH	VA	X	X			X	
Upper Rappahannock River	RPPTF	VA	X	X			X	
Sassafras River, Lower	SASOH1	MD	X	X			X	
Sassafras River, Upper	SASOH2	MD					X	
Southern Branch Elizabeth River	SBEMH	VA		X	X			

Severn River	SEVMH	MD	X	X	X		X	
South River	SOUMH	MD	X	X	X		X	
Tangier Sound	TAHMH_VA	VA		X			X	
Tangier Sound, MD Main Body	TANMH1_MD	MD		X			X	
Tangier Sound, MD Deal Island to Mouth of Nanticoke River	TANMH2_MD	MD					X	
Western Branch Elizabeth River	WBEMH	VA		X				
Western Branch Patuxent River	WBRTF	MD	X	X			X	
Wicomico River	WICMH	MD	X	X			X	
West River	WSTMH	MD	X	X			X	
Middle York River	YRKMH	VA	X	X			X	
Lower York River	YRKPH	VA		X	X		X	
TOTAL Number of Segments by Designated Use & Applicable Criteria			**72**	**92**	**18**	**10**	**90**	**7**

Note: This table contains additional split segments (in grey) beyond the 92 Chesapeake Bay segments strictly for purposes of applying separate water clarity criteria application depths (0.5, 1, or 2 meters) within the same Bay segment for assessing water clarity/SAV criteria attainment only (USEPA 2004).

Sources: USEPA 2003b, 2004, 2010; Code of Maryland Title 26 Subtitle 08, Chapter 2, Section 3; Code of Virginia 9 62.1-44.13 3a; Delaware Administrative Code 7401; District of Columbia Municipal Regulations Title 21, Chapter 11.