Water Quality Criteria Assessment Framework

chapter ii

Chesapeake Bay Program Segmentation: Western Branch Patuxent River Tidal Fresh Segment Volume Determination

For the last 30 years, the Chesapeake Bay Program partners have used various forms of a basic segmentation scheme to organize the collection, analysis and presentation of environmental data. Segmentation is the compartmentalizing of the estuary into subunits based on selected criteria. For diagnosing anthropogenic impacts segmentation is a way to group regions having similar natural characteristics so that differences in biological communities among similar segments can be identified and their sources elucidated. For management purposes segmentation is a way to group similar regions to define a range of water quality and resource objectives, target specific actions and monitoring responses. It provides a meaningful way to summarize and present information in parallel with these objectives and it is a useful geographic pointer for data management.

The Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, decisions and rationales 1983-2003 (U.S. EPA 2004b) provides documentation on the development of the spatial segmentation scheme of the Chesapeake Bay and its tidal tributaries.
A U.S. EPA (2005) addendum to U.S. EPA (2004b) was published. Finally, U.S. EPA (2008, Chapter ii) reviews the 1985, 1997, and 2003 segmentation schemes for Chesapeake Bay and documents the present (i.e., 2008) 92-segment scheme that was the foundation segmentation for the Chesapeake Bay Total Maximum Daily Load (TMDL). Currently, the Western Branch Patuxent River Tidal Fresh segment (WBRTF) is monitored for water quality in the Chesapeake Bay long term water quality monitoring program. However, this segment has not been represented in model evaluations of the TMDL due to a lack of bathymetry information nor could a water quality standards attainment assessment be conducted without a representation and measure of the water volume to support the analysis. In this chapter a bathymetric Geographic Information System (GIS) layer and volume are established for the WBRTF management segment.

Western Branch Patuxent River Tidal Fresh Segment.

The WBRTF has been a member of the Chesapeake Bay analytical segmentation schemes across years 1997/8, 2003 and 2008. All segments have at least one Chesapeake Bay long-term water quality monitoring station present where measurements are collected, data analyzed and reported. The water quality results support tracking of water quality status and trends as well as water quality standards attainment assessments. U.S. EPA (2004b) indicates two tidal water quality monitoring states are present in this segment.

Previously, no bathymetry was available for WBRTF (Table 1 in USEPA 2004b). While water quality monitoring data is available, the absence of bathymetry meant there was no volume for the segment. Without a volume measurement, no water quality standards attainment assessments could be completed. In 2013, The Chesapeake Bay Program's Scientific, Technical Assessment and Reporting Team's Criteria Assessments Protocol Workgroup and Tidal Monitoring Analysis Workgroup coordinated with U.S. EPA and Maryland Department of the Environment (MDE) staff to develop a segment bathymetry and establish a volume for WBRTF.

MDE provided the Criteria Assessment Protocol Workgroup with transect data collected 09/07/2001 to support development of a bathymetry for segment WBRTF (Appendix 1). Chesapeake Bay Program analysts first created a GIS data layer of the location points based on the latitude and longitudes for a set of ten cross sectional stream transects. Out of ten transects provided by MDE, six occurred within the boundaries of WBRTF segment (Figures 1-6, Appendix 1). Transect lines were created corresponding to the lengths of the individual transects going through the points. In five cases (Stations #1,2,4,5,6), the transects were shorter than the width of the segment. In the sixth case (Station #3), it was longer. The transects were projected to UTM Zone 18, NAD83 and transect were completed by drawing the transect length perpendicular to a shoreline through-point. In Figures 1-6, each transect is depicted in cross section, shore to shore, looking from upriver to downriver. The measurement unit is the foot.

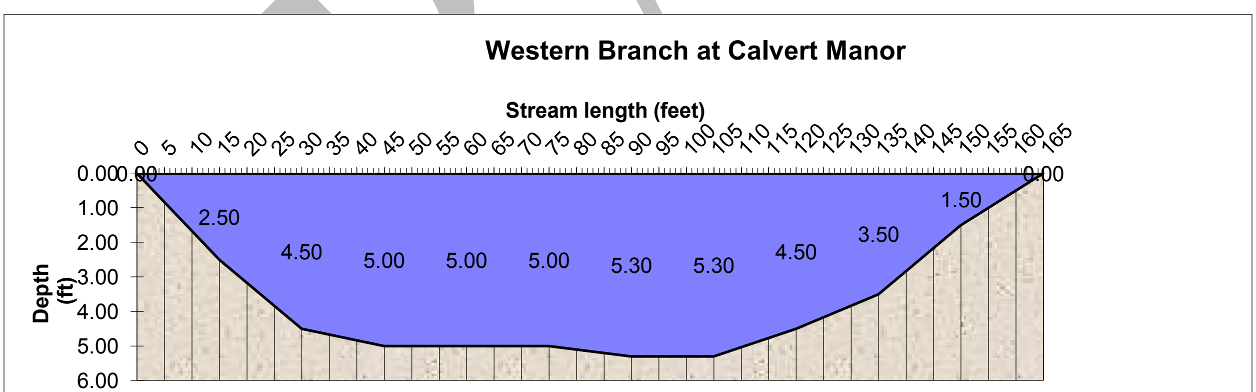

Figure 1. Station code = Station #1. Site location N 38 47.139 W 76 42.794 located 25 yards upstream of pier at Calvert Manor.

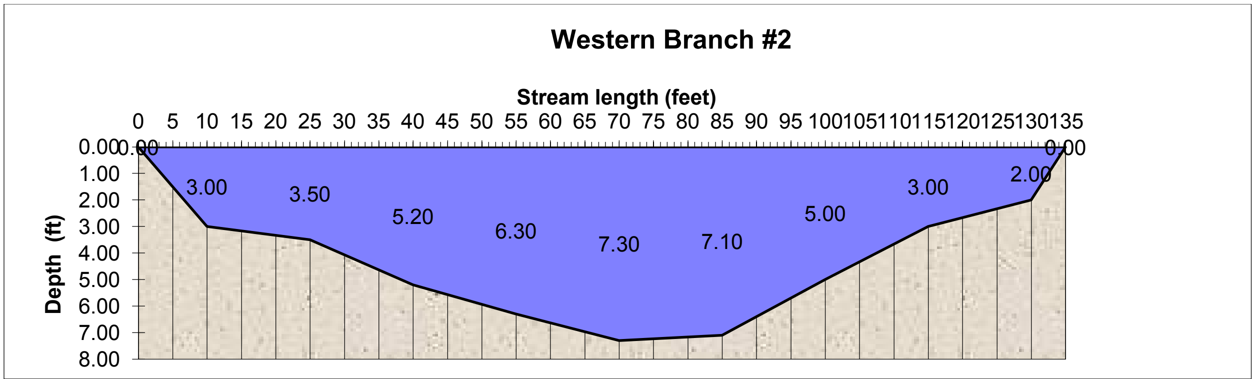

Figure 2. Station code = Station #2. Site location N 38 47.305 W 76 42.898 located 10 yards downstream of Horse Cavern Branch.

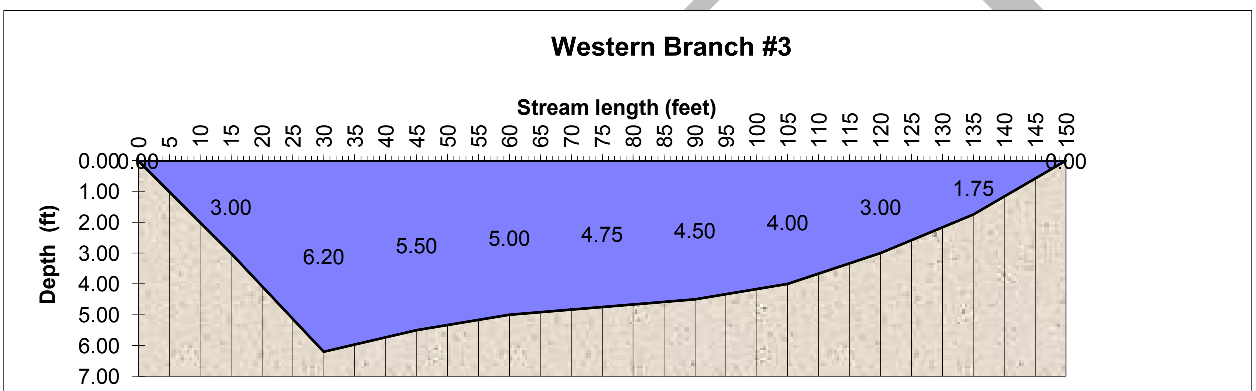

Figure 3. Station code = Station #3. Site location N 38 47.490 W 76 43.022.

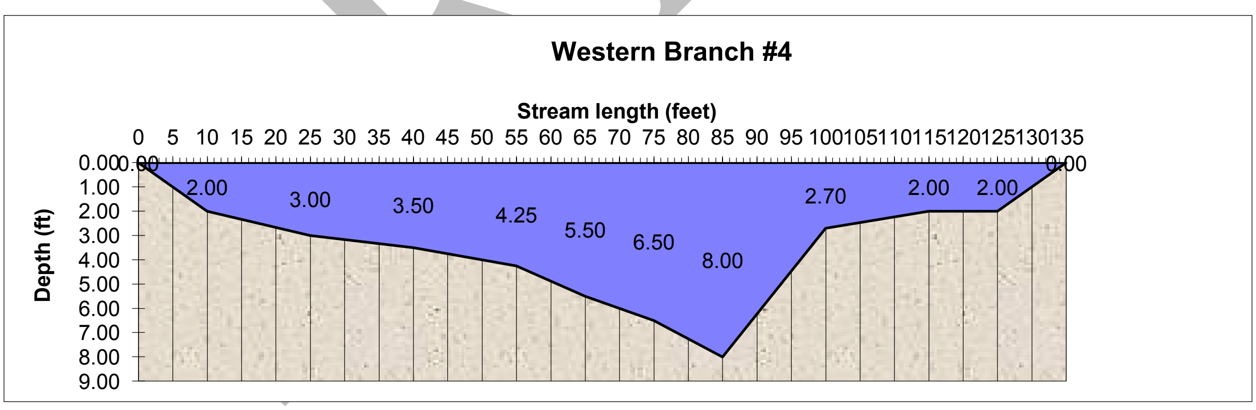

Figure 4. Station code = Station #4. Site location N 38 47.485 W 76 43.239 located downstream of a small unnamed tributary.

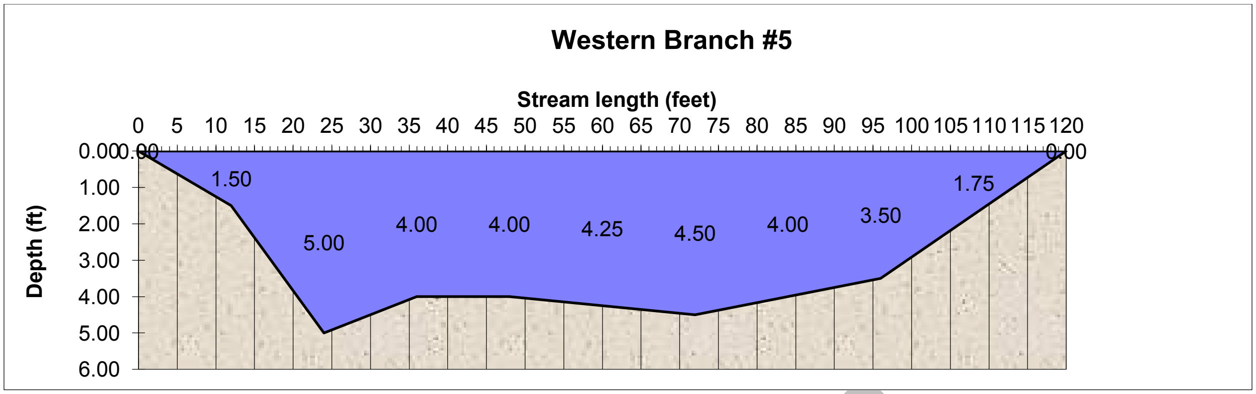

Figure 5. Station code = Station #5. Site location N 38 47.777 W 76 43.316.

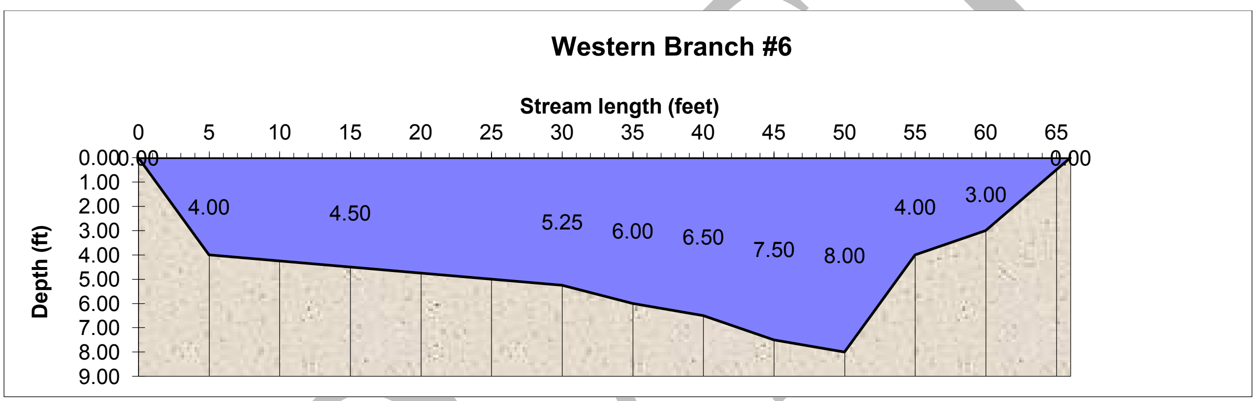

Figure 6. Station code = Station #6. Site location N 38 47.832 W 76 43.746 located 50 yards downstream of WSSC outfall.

Based on the data tables (Appendix 1), points were added along the transect line at specified distances. Points on transects were not all equidistant. A depth attribute was added to the points along the transect lines and populated with the measured depths. Depths were added at the mouth of the WBRTF segment so values there would not be zeroes. Within the current analytical segmentation representation of the Chesapeake Bay and its tidal tributaries there was no bathymetry for the adjoining segment, Patuxent River Tidal Fresh (PAXTF), that far up the river. Therefore the points for the first transect were copied and included as a transect that was placed at the mouth of the Western Branch to represent a cross section of water depth there.

Using ArcGIS, CBP analysts tried to create a triangulated irregular network and then a bathymetry grid using a variety of methods available. However, no method provided a viable bathymetry. There were insufficient data to produce a proper interpolation. An alternative approach was used to develop the segment volume.

Analysts revised their approach and took the cross-sectional areas of the transects that had already been calculated and were in the tables provided by MDE. The lengths of river segments were determined from the midpoints between two transects. Finally, the downstream cross sectional area measurement (ft^2) was multiplied by the length of stream in the section (ft) to estimate the stream section volume (ft^3) (Table 1). The sum of the stream segment volumes provided the total segment volume. Segment volume (ft^3) was then converted to cubic meters (m^3).

Table 1. Computed stream segment section lengths, cross sectional areas and the section volumes for the WBRTF segment.

	length of stream section (ft.)	cross section area	section volume (ft^3)
headwaters	1283	315.25	404,465.75
	2162	390	843,180.00
	1594	481.1	766,873.40
	1214	565.5	686,517.00
	1124	618.5	695,194.00
Mouth	861	631.5	543,721.50
Total volume (ft^3)			3,939,952
Total volume (m^3)			**111,567**

In GIS, the target grid cell volume was 2500 m^3 with dimensions 50m^2 by 1m deep. The newly computed total segment volume (111,567m^3) was divided by the volume of a single cell to get the number of cells needed to represent the WBRTF in a GIS layer (111,567m^3/ 2,500m^3 = 44.6 or 45 cells). Next, using the ArcGIS tool to create a grid, a fishnet of 50m x 50m cells was created to cover the extent of WBRTF (Figure 2). The extent of the grid was specified along with the size of the cells and the starting coordinates. The result of the work creates a block of cells over the target area. In order to for the grid to represent just the river, cells were deleted from the fishnet block of cells until there were 45 cells remaining that effectively matched the segment boundary (Figure 3). The new grid was established so that it dovetailed with the adjoining PAXTF segment of the Bay segmentation scheme used in water quality standards attainment assessments and the Chesapeake Bay water quality model used in the TMDL. X,Y coordinates were computed for the centroids of the cell polygons. Finally, a table of centroid coordinates and depths (all = 1m) was exported for use with the Bay model (Appendix 2).

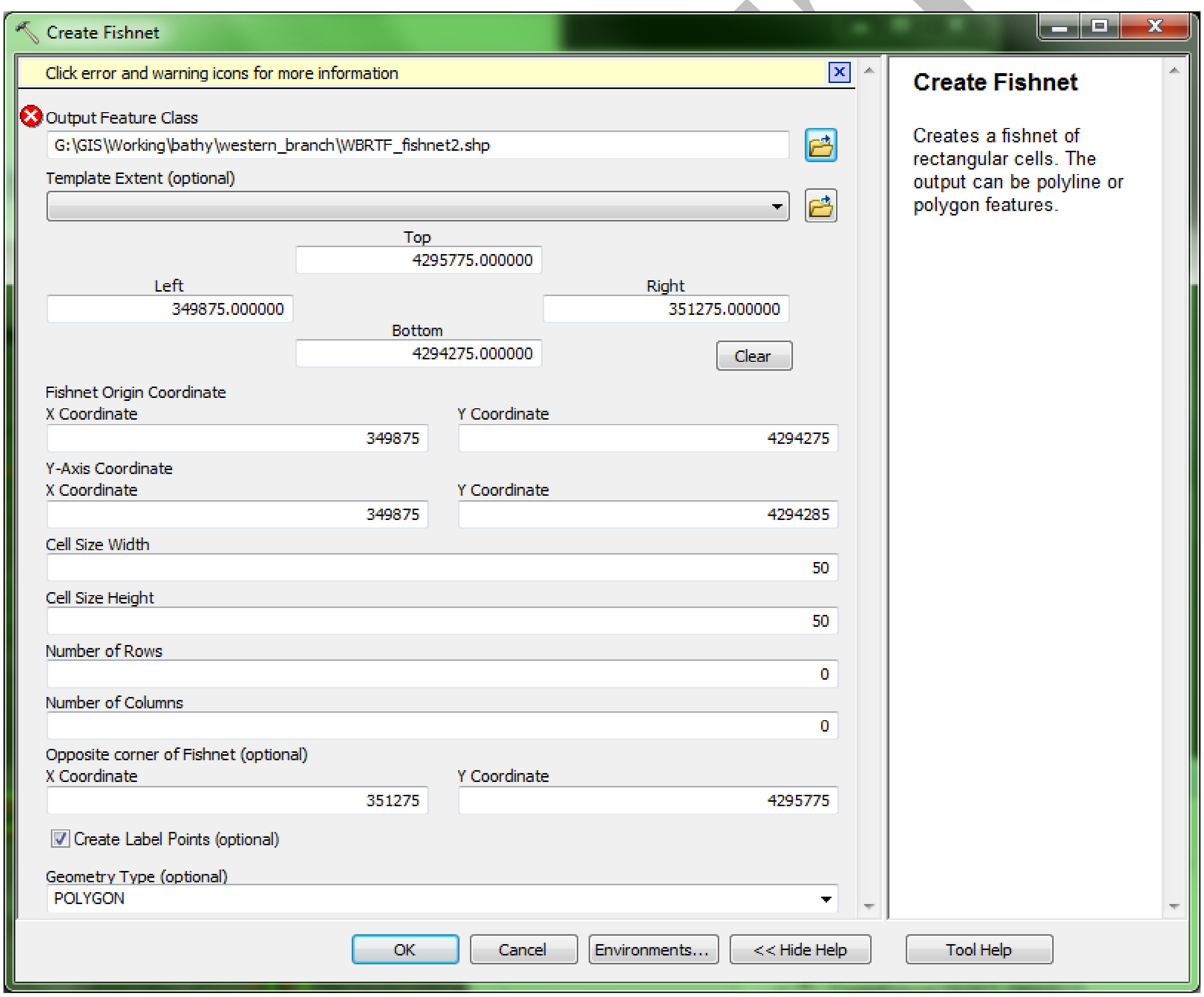

Figure 2. Screen capture of the grid tool used in ArcGIS to create the 50m x 50m cells of the WRBTF segment. Each cell was established as 1m deep.

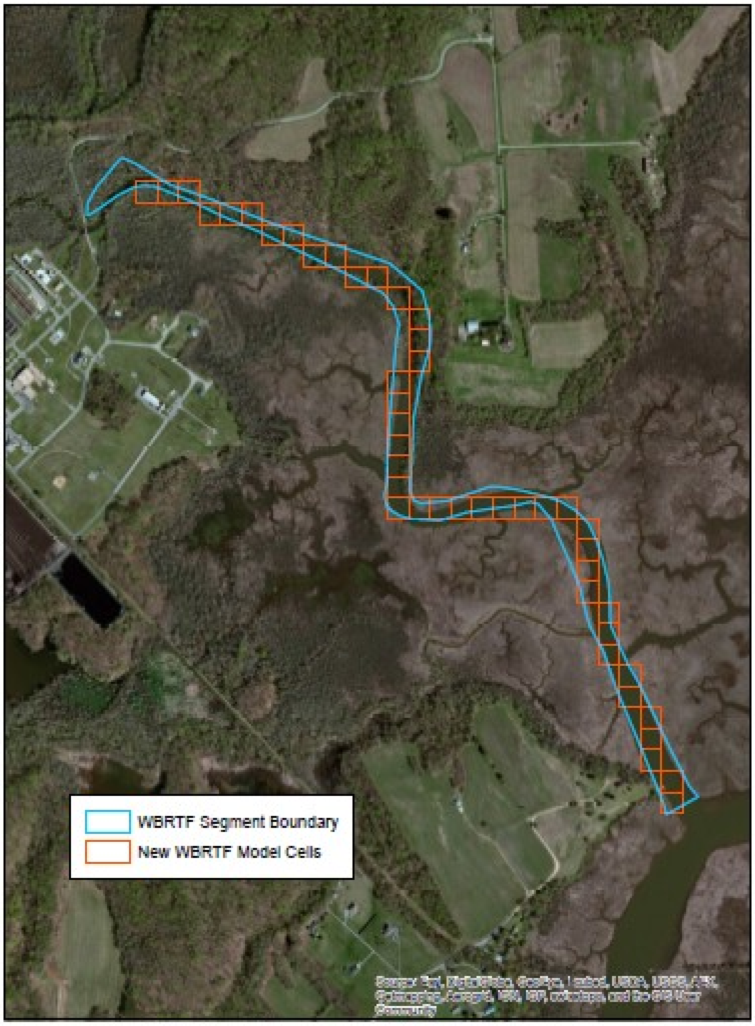

Figure 3. The new 2014 grid for Western Branch, Patuxent River (WRBTF).

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U.S. EPA. 2008. *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.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

chapter iii

Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats:

Considerations Supporting the Management Structure of the Open Water Designated Use.

BACKGROUND

The Chesapeake Bay science and management community has expressed concerns with the Chesapeake Bay dissolved oxygen criteria attainment assessment of the open water designated use (MRAT 2009, CBP-STAC 2012). The method for assessing attainment in the open water designated use combines offshore waters and shallow, nearshore waters into a single volume-based evaluation unless a state has specifically delineated a sub-segment within a Chesapeake Bay management segment (U.S. EPA 2007a). According to U.S. EPA (2007a), "Neither the need nor the requirement exists for a separate assessment of dissolved oxygen criteria attainment strictly within shallow waters (0-2 meters in depth)". However, U.S EPA (2007a) goes on to state that conditions in these shallow water areas are considered to vary greatly from the open water of the mid-channels habitats. Given significant differences in local drivers of dissolved oxygen dynamics for the two habitats, and with substantial, new Chesapeake Bay water quality monitoring data and analyses available in recent years, Bay-area scientists and managers have continued to raise concern that dissolved oxygen patterns in the two habitats may be characteristically different. Quantifying similarities and differences between the dissolved oxygen dynamics of nearshore and offshore habitats provides new insight and decision-support for any considerations being given on sub-segmenting the two habitats for dissolved oxygen criteria attainment assessment purposes.

A supplemental concern was expressed that the sheer volume of offshore water regions may overwhelm signals of distress in shallow waters for tidal Chesapeake Bay and its tributaries. In general, shallow water habitat is referenced to be a water depth of $\leq$2m (e.g. p38, U.S. EPA 2007a). The 2m depth contour was selected as the maximum depth for the lower vertical boundary of the shallow water Bay grasses designated use (U.S. EPA 2003b). Approximating the area and volume of all the shallow water habitat for the Chesapeake Bay and tidal tributaries <2m, Bay facts suggest there are at least 700,000 acres (2832.9 km^2) $\leq$ 6 feet deep (http://www.chesapeakebay.net/discover/bay101/facts). The surface area of the tidal waters of the Bay and its tributaries is estimated to be 11,601 km^2. Therefore, the shallow water habitat of the Bay is approximately 24.4% of its surface area. If we assume an average shallow water depth to be half the maximum depth of those acres, i.e. 3 feet, then an estimate for the volume of shallow water Chesapeake Bay and tidal tributary habitat is estimated at 4.56% of the total Bay volume or 2.59 km^3. For comparison regarding the importance of this habitat volume, 2.59km^3 is typically greater than the observed peak volume for estimates of late summer deep water anoxia in Chesapeake Bay between 1985 and 2010 (IAN-ECOCHECK - Figure 1) (http://ian.umces.edu/ecocheck/summer-review/chesapeake-bay/2010/indicators/anoxia/). The deep water hypoxic volume is a critical restoration target issue in the work to reduce nutrient and sediment loadings to Chesapeake Bay and restore bay habitat health for living resources. Therefore, significant differences in habitat behavior could translate to disproportionate affects on segment-specific dissolved oxygen criteria attainment assessments due to their relative and varied habitat-area contributions across the Bay.

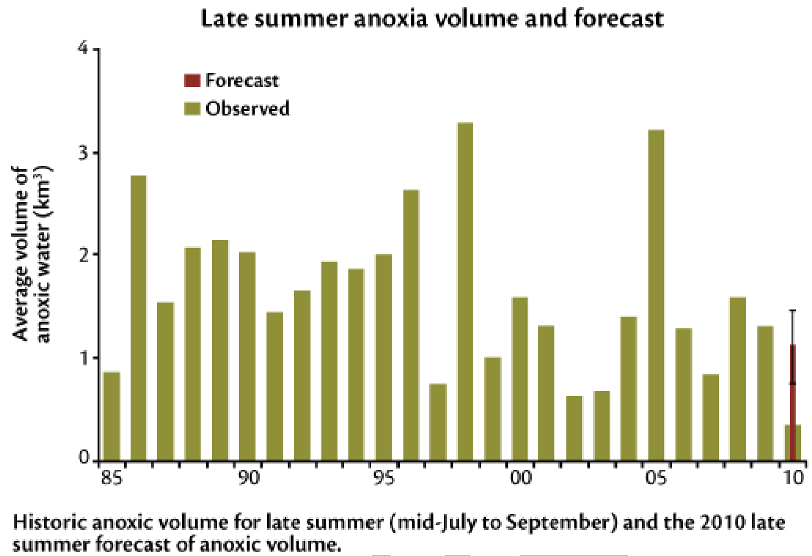

Figure 1. Historical time series of anoxic volume for late summer; also showing 2010 IAN-Ecocheck forecast.

The relationship of dissolved oxygen behavior between nearshore, shallow water habitat and offshore open water remains poorly understood. Resolving the combination of science and management concerns about this relationship for the two habitats requires a basic characterization of shallow water dissolved oxygen dynamics. Comparisons between shallow water and offshore dissolved oxygen behavior in the two habitats are especially needed to support decisions on maintaining the present open water designated use dissolved oxygen criteria attainment assessment framework or providing implications and options for delineating habitats into sub-segments. Any decision to separate the habitats into sub-segments could affect monitoring designs and programming, criteria assessment frameworks and protocols, and management considerations for the Chesapeake Bay.

The following sections of this chapter discuss 1) Chesapeake Bay open water and shallow water designated use definitions supporting the Chesapeake Bay Program partners Clean Water Act water quality standards attainment assessments, 2) recent water quality monitoring history for tidal waters of the Chesapeake Bay mainstem and tributaries relevant to understanding shallow water dissolved oxygen dynamics and high frequency patterns in dissolved oxygen behavior, 3) reviews key findings from the most recent Chesapeake Bay Program partner analyses regarding high frequency water quality dynamics and shallow water dissolved oxygen behavior conducted by the Umbrella Criteria Assessment Team (CBP STAC 2012), 4) reviews the issue of dissolved oxygen behavior comparisons between habitats contained within the open water designated use and 5) presents implications and options regarding considerations for partitioning habitats in the open water designated use for water quality monitoring, water quality standards attainment assessment and bay health management in Chesapeake Bay.

THE RELATIONSHIP BETWEEN OPEN WATER AND SHALLOW WATER DESIGNATED USE DEFINITIONS

The Chesapeake Bay ambient water quality criteria attainment assessments are habitat and season specific. Designated use definitions have been published (U.S. EPA 2003a, 2003b, 2004a) and adopted in Chesapeake Bay watershed partner water quality standards for five habitats:

- Migratory and spawning
- Open water
- Shallow water Bay grass
- Deep water
- Deep channel.

The Chesapeake Bay dissolved oxygen criteria for the open water fish and shellfish designated use were developed to fully protect the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish inhabiting open water habitats (U.S. EPA 2003a). These open water criteria were based on established dissolved oxygen concentrations to protect against losses in larval recruitment, growth effects on larvae and juveniles and the survival of juveniles and adults in tidal fresh to high salinity habitats (U.S. EPA 2003a).

The U.S. EPA designated use boundary definition for open water adopted in the Chesapeake Bay Program partner water quality standards is:

From June 1 through September 30 the open water designated use included tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline. If a pycnocline is present and, in combination with bottom bathymetry and water-column circulation patterns, presents a barrier to oxygen replenishment of deeper waters, the open water fish and shellfish designated use extends down into the water column only as far as the measured upper boundary of the pycnocline. If a pycnocline is present but other physical circulation patterns (such as influx of rich oceanic bottom waters), provide for oxygen replenishment of deeper waters, the open-water fish and shellfish designated use extends down into the water column to the bottom water-sediment interface.

From October 1 through May 31, the open-water designated us includes all tidally influenced waters extending horizontally from the shoreline to the adjacent shoreline, extending down through the water column to the bottom water-sediment interface (U.S. EPA 2003b).

The shoreline to shoreline definition of open water is based on the assumption that "the dissolved oxygen requirements for the species and communities inhabiting open- and shallow-water habitats are similar enough to ensure protection of both the open-water and shallow-water designated use with a single set of criteria". Shallow water habitats are, therefore, a subset of the open water designated use in Chesapeake Bay.

Unless a state has specifically delineated a sub-segment within a Chesapeake Bay management segment, neither the need nor the requirement exists for a separate assessment of dissolved oxygen criteria attainment strictly within shallow waters (0-2m in depth) (U.S. EPA 2007a). However, if shallow water has significantly different behavior from offshore water, the impact on dissolved oxygen criteria attainment assessments will be disproportionate with an assessment effect that is dependent on the size of the segment. More than 600,000 acres of shallow water habitat (0-2m) has been reported as the Submerged Aquatic Vegetation AV Tier III restoration goals in Chesapeake Bay which excludes no-grow zones (Baituk et al. 2000). This value is comparable to the Bay facts suggestion of 700,000 acres that is 6 feet or less which presumably did not exclude no-grow zones. It is further important to recognize is that the distribution of shallow water is proportionally unequal across Chesapeake Bay management segments. Converting acreages into estimates of shallow water volumes and comparing the results to total segment volumes (see Table IV-9, pp. 91-92, U.S. EPA 2003b) shows the proportion of shallow water habitat in a Chesapeake Bay management segment is negatively related to the size of segment (Figure 2).

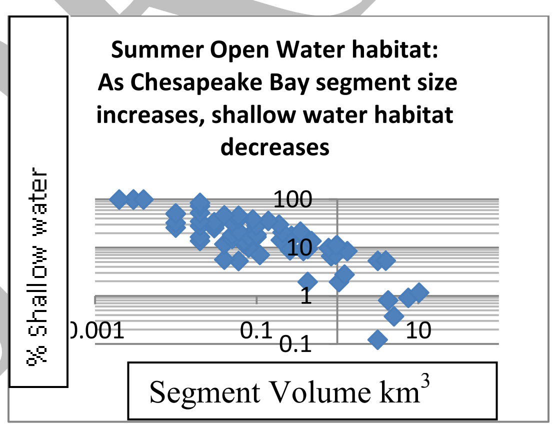

Figure 2. DRAFT FIGURE. The relationship of proportion of shallow water habitat as it relates to the size of Chesapeake Bay management segments. Total segment volumes (km3) were based on the U.S. EPA (2003b) listings; Percent shallow water volumes were calculated from SAV Tier III acres (0-2m), converted to volume by assuming a rectangular volume 3 feet deep is roughly equivalent to a triangular volume with max depth of 2m, converted to gallons, then converted to km3) and used to compare with the total segment volume for the proportion.

The science supporting decisions on delineating habitats with specific submerged aquatic vegetation application depths based on light limitation has historically been stronger than that necessary for sub-segmenting nearshore from offshore habitats based on dissolved oxygen dynamics. In Chesapeake Bay and its tidal tributaries, the shallow water designated use is a subset of all shallow-water habitat. The shallow-water bay grass designated use protects underwater bay grasses and the many fish and crab species that depend on the vegetated shallow-water habitat provided by underwater grass beds. The shallow water designated use boundary in a management segment is classified by light limitation supporting Bay grasses. This light limitation is expressed as application depths to support underwater grasses that subdivides the nearshore waters by no-grow zones (0m) or by depths out from shore to 0.5m, 1m or 2m. Similarly, with dissolved oxygen, there is an excellent understanding of vertical habitat distributions within the water column as provided for by definitions for open water, deep water and deep channel designated uses in Chesapeake Bay and its tidal tributaries. In contrast, however, no similar understanding of dissolved oxygen dynamics has been developed to support delineation of horizontal habitat boundaries like that used with light and SAV.

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

Habitat needs for species and communities in offshore and nearshore habitats were considered similar enough to combine for Chesapeake Bay dissolved oxygen attainment assessments (U.S. EPA 2003a,b 2004a). Historically, however, shallow-water water quality data and the ability to make paired-comparisons for a greater understanding about the habitats were rare for tidal waters of Chesapeake Bay. Using a wide range of data from state programs, academic institutions and citizen monitoring, comparisons of mid-channel and nearshore water quality in Chesapeake Bay were synthesized (Karrh 1999, Batiuk et al. 2000, U.S. EPA 2007a) focusing on SAV-relevant parameters (K_d, dissolved inorganic nitrogen, dissolved inorganic phosphorus, total suspended solids and chlorophyll *a*). Those analysis results suggested that the comparability of mid-channel and nearshore water quality conditions was very site specific.

Shallow water habitats with respect to dissolved oxygen dynamics further remained poorly characterized across Chesapeake Bay and its tidal tributaries (Batiuk et al. 2009). Part of this information gap is a function of how the Chesapeake Bay long-term water quality monitoring program sampling framework was designed. Since 1985, the long term water quality monitoring network has been based on fixed-location stations in mid-channel positions. Vertical profiles of water quality conditions are collected and used in evaluating status, water quality standards and tracking Bay health trends.

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.

HISTORICAL ANALYSES REGARDING COMPARABILITY OF NEARSHORE AND OFFSHORE WATER QUALITY DYNAMICS

The question concerning comparability of nearshore and offshore, midchannel water quality is a Chesapeake Bay issue with precedent. Batiuk et al. (2000) noted several such studies on the water quality comparison issue that were reported on between 1991 and 1996. The studies suggested mid-channel data can be used to describe nearshore conditions, however, not all studies were in agreement. This issue was further reviewed with long term water quality monitoring program data by Karrh (1999) and Batiuk et al. (2000). In the 1999 study, the Maryland Department of Natural Resources investigated the validity of using mid-channel data to assess water quality conditions in nearshore areas. The 13-tributary study examined water quality at 127 nearshore stations compared to 54 adjacent mid-channel stations. The study found wide variations between nearshore and mid-channel data both within and between tributaries (U.S. EPA 2007a). However, these studies focused on parameters important to underwater grass habitat (Secchi depth, dissolved organic nitrogen, dissolved inorganic phosphorus, chlorophyll a, total suspended solids and salinity) and did not evaluate dissolved oxygen behavior.

At the time of publishing the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and its Tidal Tributaries* (U.S. EPA 2003a) there remained insufficient information about the existence of different characteristic dissolved oxygen behaviors between offshore and shallow, nearshore habitat to support separating the two habitats into their own designated use assessments. More recently an evaluation targeting advances in assessing short duration dissolved oxygen criteria using offshore low frequency and nearshore high frequency monitoring data was initiated during the Chesapeake Bay Monitoring Realignment (MRAT) process (MRAT 2009). With multiple years of shallow water data collected at a wide range of site conditions from across the tidal Bay and in neighboring estuaries (e.g. the Maryland and Virginia Coastal Bays), and a foundation of analyses from the MRAT effort, an Umbrella Criteria Assessment Team (UCAT) was formed in 2010 to advance short duration dissolved oxygen criteria attainment assessments. Byproducts of the UCAT effort help inform the issue of comparability between offshore and shallow water dissolved oxygen behavior.

CHARACTERISTICS OF CHESAPEAKE BAY HIGH FREQUENCY DISSOLVED OXYGEN DYNAMICS WITH AN EMPHASIS ON SHALLOW-WATER HABITAT

The Umbrella Criteria Assessment Team used more than a decade of high frequency dissolved oxygen data from Chesapeake Bay in characterizing dissolved oxygen behavior across multiple time scales and habitats (CBP STAC 2012). The combined data sets contained more than 1 million data points. Analyses of the shallow-water water quality monitoring results has shown intersite and interannual variability. High frequency water quality data in nearshore habitats show sometime frequent diel to sub-seasonal scale hypoxic and anoxic events different from the deep water patterns of Chesapeake Bay and its lower tidal tributaries. High frequency data collected with vertical profilers provided comparative data with shallow water continuous monitoring data for offshore, deep water sites over multiple depths at seasonal scales of time.

The following section is a brief summary of the UCAT effort that expands the scientific understanding of dissolved oxygen behavior across gradients of time (i.e. instantaneous measures to interannual comparisons), space (nearshore and offshore) and habitat (tidal fresh to polyhaline salinities). The results underpin the later discussions on nearshore and offshore water quality comparisons with respect to dissolved oxygen dynamics. (Note – all Appendix references in the following sections AT THIS TIME refer to appendices of CBP-STAC 2012 *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*, August 2012, available at:
http://www.chesapeakebay.net/channel_files/19060/final_umbrellacriterion_stacpub.pdf).

Shallow water intrasite variability in dissolved oxygen behavior

Continuous monitoring data are collected to assess variability of water quality parameters throughout the day. Previous convention suggested shallow water did not experience significant low dissolved oxygen levels (U.S. EPA 2007a). Continuous monitoring data, however, often indicate a diel scale of hypoxia, some hypoxia is severe at locations (CBP-STAC 2012, Boynton et al. Appendix 4; e.g. Figure 3). Dissolved oxygen concentrations drop to low levels during the hours of darkness and sometimes reach dangerously low concentrations to most Bay life at or just after sunrise (U.S. EPA 2007a, Boynton et al. Appendix 4).

Continuous monitoring stations have detected hypoxic and anoxic events beyond the diel scale. One example illustrated a Potomac River site capturing the intrusion of anoxic deep waters into shallow water (Figure 4). Degraded dissolved oxygen conditions persisted 48-72 hours while temperature and salinities were slower to recover. A second example from the Corsica River (Figure 5) illustrated the impact of a nearly week-long event involving and algal die off; it's degradation effects reducing dissolved oxygen to anoxic conditions were followed by a multiday recovery to normoxic conditions (CBP-STAC 2012). In each case, the event data informed scientists and managers about proximate causal links to a large fish kill.

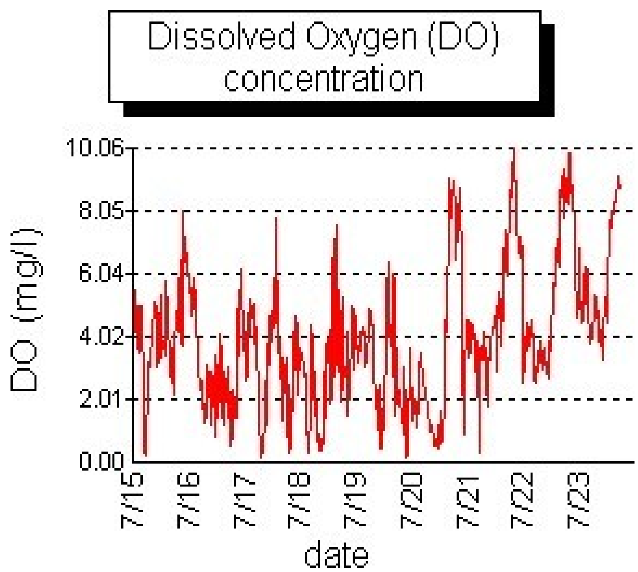

Figure 3. Ben Oaks, Severn River, MD example of diel hypoxia in shallow water. Data collected every 15   minutes. Graphic attributed to Maryland Department of Natural Resources.

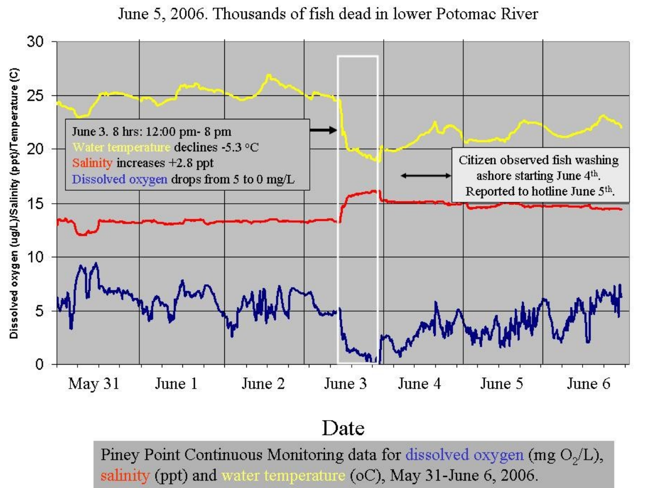

Figure 4. Lower Potomac River Piney Point ConMon data (MD DNR) from May 31- June 6, 2006 shows intrusion of anoxic waters from the Bay. Such an intrusion affecting nearshore dissolved oxygen resources was linked with climate forcing effects of wind direction changes on 6/3/06 and a resulting seiche of bottom waters of the mainstem Bay. Graphics from P. Tango.

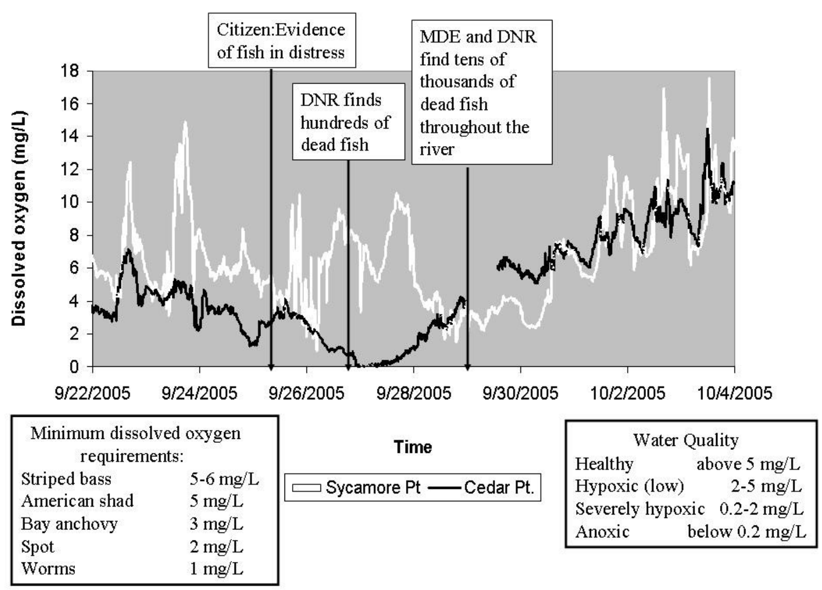

Figure 5. Corsica River, MD, 2005. Chronology of a fish kill and associated water quality. Graphic from Mark Trice, MDDNR originally released in P. Tango, 2005 Waterman's Gazette.

A 12 site assessment from the Potomac River continuous monitoring stations dissected the diel dissolved oxygen cycle by hour and shows daytime sampling results would have a positive bias and nighttime sampling would create a negative bias compared with the measured distribution for dissolved oxygen concentrations based on high frequency sampling throughout the diel cycle. (Figure 6 taken from Perry Appendix 11)

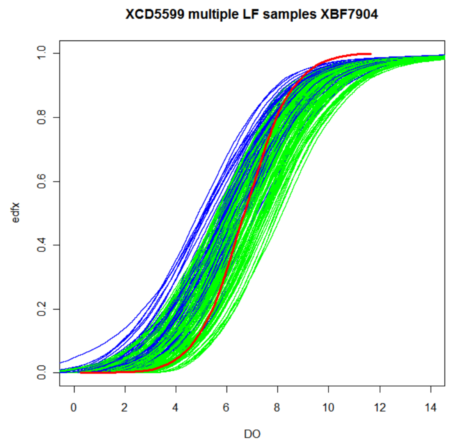

Figure 6. Empirical distribution functions illustrate variation in dissolved oxygen measurements due to multiple low-frequency samples from the receiving site using a Fourier Series interpolation. The sending site data set was held constant as a single two-week interval. Blue curves are synthetic DO data frequency distributions based on a repeated sampling of night-time data. Green curves represent DO frequency data distributions from a repeated sampling of daytime DO measurements. The red curve is the actual DO frequency distribution based on the two week-long receiving site, high-frequency time series data set. X-axis is DO values, Y axis is cumulative frequency of the DO measurements in the data.

Daily mean dissolved oxygen concentration experienced at individual shallow water sites ranged broadly over the course of a season. (Buchanan in Appendix 1B). Across all time scales assessed (instantaneous, daily, weekly, monthly, seasonally and annually), we see interannual differences in dissolved oxygen measures within a monitoring site (Buchanan Appendix 1B and Boynton et al. Appendix 3).

i. Shallow water intersite variability in dissolved oxygen behavior

Dissolved oxygen measurements were evaluated with respect to criteria thresholds. Dissolved oxygen violations of Chesapeake Bay dissolved oxygen criteria can occur even at sites of good water quality (Boyton et al. Appendix 4). Boynton noted his analysis of DO conditions in the Patuxent River estuary with data from during the 1960s, a period before this system underwent severe eutrophication, showed there were still times (though not very frequent) when surface DO criteria would have been violated. Buchanan (Appendix 1) noted that daily mean dissolved oxygen concentrations experienced at individual shallow water sites differed between neighboring sites on the Potomac River. By contrast, in a related analysis using multiple years for 9 continuous monitoring stations on the Potomac River (Appendix 11) Perry found little evidence of changing variability in dissolved oxygen concentration distributions across the Potomac River locations from tidal fresh to mesohaline sites (n=9 sites).

ii. Shallow water seasonal variation in dissolved oxygen behavior

Seasonal shifts in DO concentrations frequency distributions were shown to have lower concentrations and broader ranges in mid-summer, higher concentrations and less variation for spring/early summer and autumn (Buchanan Appendix 1, Perry Appendix 11). Perry (Appendix 11) combined data from 9 Potomac River sites and suggested spring may be more variable than summer and autumn.

Buchanan (Appendix 1B) computed daily means at the 20 tidal Potomac embayment and river flank stations from 2004-2008 showing a spring season range from 1.0 and 16.8 mg O_2/L, a summer range from 0.36-14.9 mg O_2/L and an autumn range of 3.1-14.0 mg O_2/L in autumn. The Continuous monitoring data on the Potomac River further showed that the range of diel DO variability experienced in shallow waters reached 11.0 mg O_2/L in spring, 17.52 mg O_2/L in summer and 10.8 mg O_2/L in autumn.

iii. External factors associated with dissolved oxygen variability in shallow water continuous monitoring data

River flow:

Boyton et al (Appendix 4) evaluated dissolved oxygen dynamics for the mesohaline Potomac River St. George Island Continuous Monitoring site (2006-08). All time scales of dissolved oxygen criteria-related indicators showed an increase in violation rate related to increasing winter-spring (January-May) river flow. 7-day means and 30-day means had threshold responses to increases in river flow while instantaneous and daily mean responses were more linear over a nearly 2x range of flows (Boynton et al Appendix 4 - Figure 7)

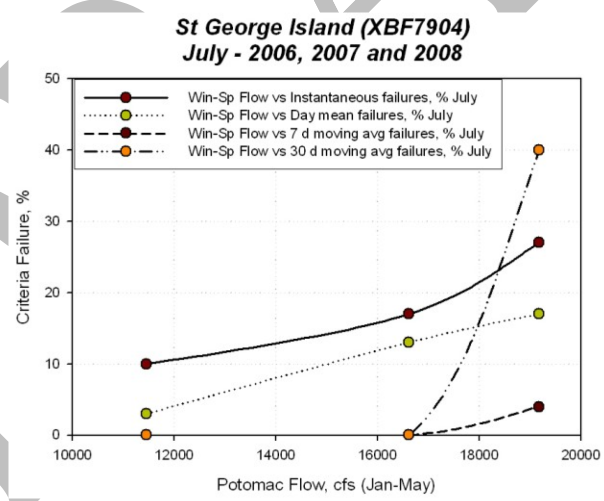

Figure 7. A multiple scatter plot of July DO % criteria non-attainment as a function of Potomac River flow (Jan-May flow period). Different DO % non-attainment calculation methods are indicated on the diagram. Boynton et al. Appendix 4 of CBP STAC 2012.

iv. Eutrophication.

Nutrient loadings are functions of river flows. Within a watershed, criterion violation rate tends to increase with increasing river flow represents a surrogate view for shallow-water dissolved oxygen patterns associated with trophic status of the waterways. Boyton et al. (Appendix 4) indicated qualitative inspection of shallow water continuous monitoring data showed that most severe diel-scale hypoxia is observed at sites experiencing severe eutrophication. By comparison, as mentioned earlier, Boynton's analysis of DO conditions in the Patuxent estuary during the 1960s, a period before this system underwent severe eutrophication, showed there were still times (not very frequent) when surface DO criteria would have been violated (Boynton Appendix 4).

Dissolved oxygen behavior among sites was compared for duration of DO criterion violations (i.e. continuous time measured below a criterion value) across a trophic condition gradient from exposures to severe eutrophication (Maryland Coastal Bays – Bishopville Prong), a tidal freshwater site in an enriched estuary (Jug Bay, Patuxent River), St. George Island in the Potomac River with reasonably good water quality, and a mesohaline site exposed to open water (Pin Oak, Patuxent River). At the Bishopville Prong site with severe eutrophication there were many criteria failures and long durations of failure (12-24 hours or longer). At less impacted sites the DO criteria failures were of shorter duration, especially for the instantaneous criteria (Boynton et al. Appendix 3,4) . The duration of dissolved oxygen concentrations below criterion issue is further characterized in a graphic showing a positive relationship between the violation rate of the 30-day mean and maximum continuous time observed below the 30-day mean criterion threshold for multiple Chesapeake Bay continuous monitoring sites. The results demonstrate again that as one indicator of dissolved oxygen status in the Bay responds, so do other scales of dissolved oxygen indicators. The slope of such relationships can suggest which indicator is more or less sensitive to change and a good direction for further analyses.

The Chesapeake Bay TMDL is built upon the conceptual model that reducing nutrients will improve dissolved oxygen resources. Therefore, we have large scale and local scale measures of dissolved oxygen behavior that converge on an ecosystem response behavior for improved dissolved oxygen conditions with reductions in trophic state measures. Caffrey (2004) shows dissolved oxygen patterns expressed as NEM for shallow water sites are responsive to changes in nutrient loading (Figure 8). Boyton's analyses on river flow and qualitatively for eutrophication suggest the same (Figure 7 above). Fisher and Gustafson (p. 34 in U.S. EPA 2007b) used data from four Chesapeake Bay shallow-water continuous monitoring sites and showed significant negative relationships between average dissolved oxygen compared and increases in trophic gradient indicators (e.g. chlorophyll *a*, orthophosphate, and dissolved organic nitrogen, Figure 9).

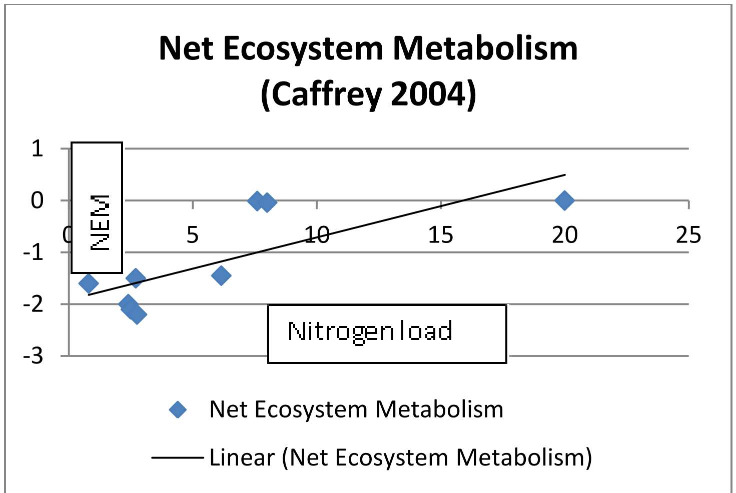

Figure 8. Net Ecosystem Metabolism (Y-axis) in relation to nitrogen loading (X-axis) based on shallow water continuous monitoring data. (Reproduced from Caffrey 2004).

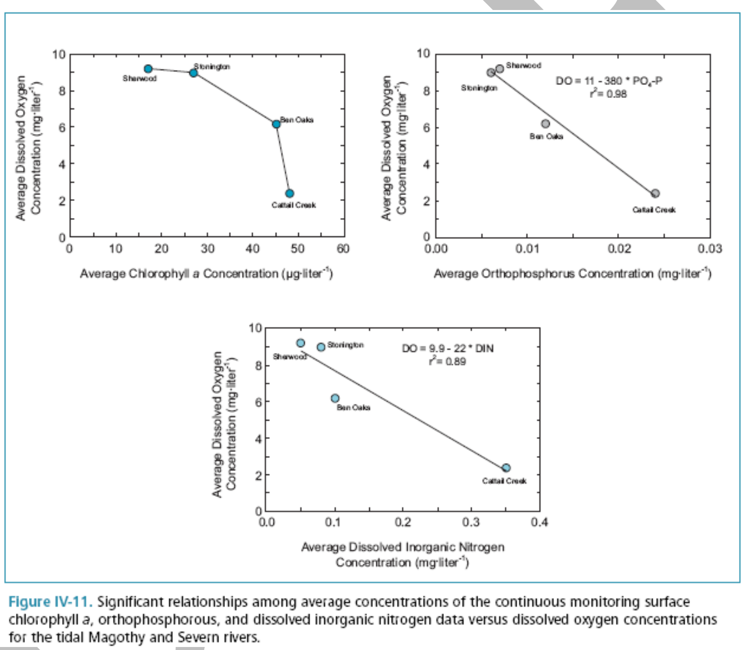

Figure 9. (NOTE: COPY RESOLUTION ISSUE - MAY NEED TO RECREATE) ConMon data from 4 monitoring sites illustrating shallow water dissolved oxygen behavior responsive to trophic state gradient shown as chlorophyll a, orthophosphate and dissolved inorganic nitrogen concentrations. (p 34, USEPA 2007b)

The patterns are repeated across many scales of indicators nearshore and offshore. Jordan et al. 1992 expected changing frequencies in low dissolved oxygen event duration to reflect improving and degrading conditions based on high frequency offshore measures (Figure 10). For nearshore habitat of the Corsica River, Boyton et al. (2009) suggest reduction of hypoxic hours with improvements in Nitrogen loading (Figure 11). Caffrey (2004) found greater autotrophic production with increasing DIN supporting again the idea of improving dissolved oxygen conditions via reductions in NEM when nutrients are reduced. Further, Hall and others in this report illustrated that as the 30-day mean violation rate at continuous monitoring stations declines, shorter-duration criteria violation rates also decline; the rate of decline between violations for different temporal criteria scales may not be 1:1 (Figure 12).

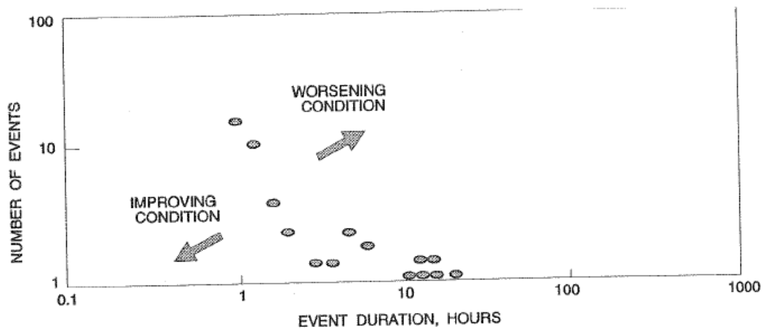

Figure 10. Jordan et al. 1992

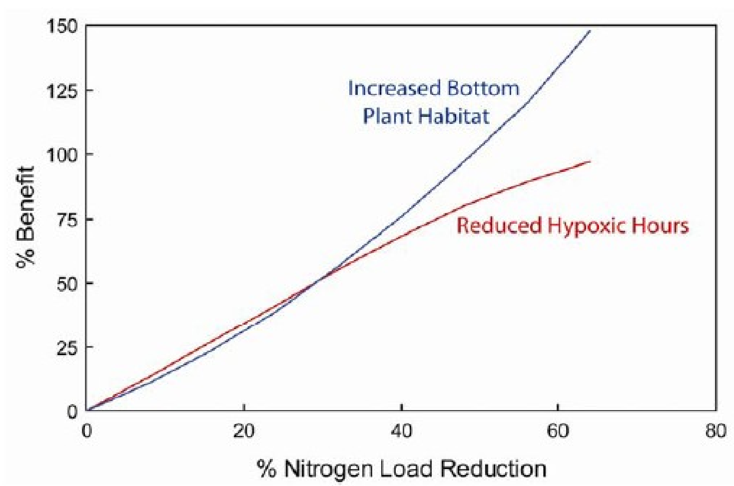

Figure 11. Boynton et al. 2009

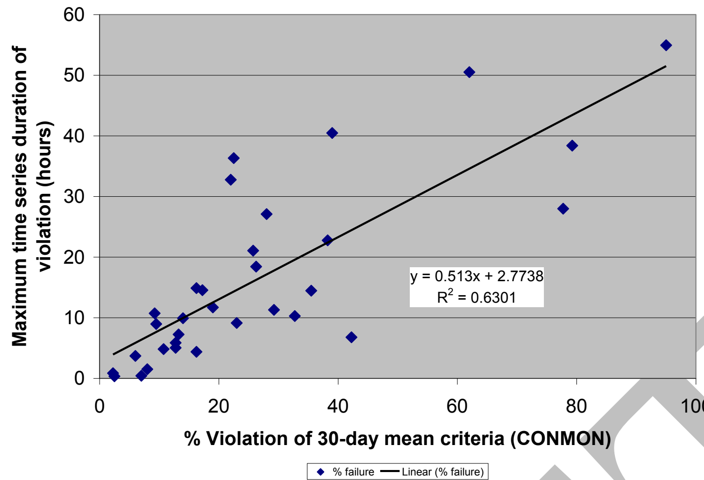

Figure 12. Maximum duration of a violation (hours) for a month compared with the violation rate of the 30 day mean for the same month assessed from shallow water continuous monitoring data.

This may be a significant point of consideration. Most every indicator of dissolved oxygen behavior is being shown to respond to gradients in water quality status.

Dissolved oxygen means and variability increased with increasing temperature and solar angle (Buchanan Appendix 1B – Figure 13 below).

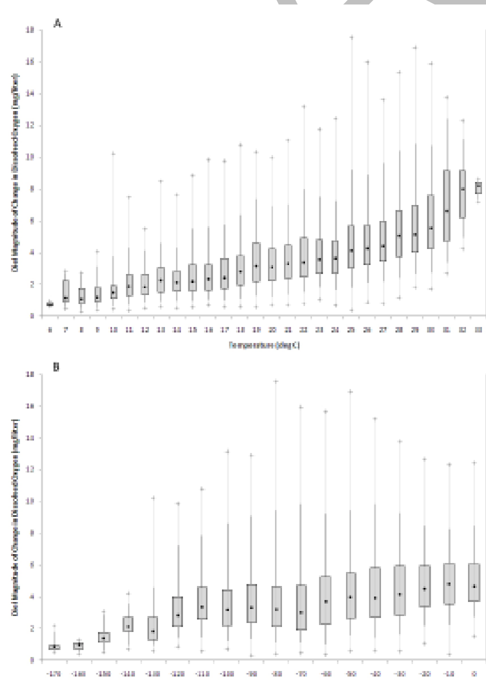

Figure 13. Dissolved oxygen means and variability related to (A) temperature and (B) solar angle for shallow water continuous monitoring data, Potomac River, Chesapeake Bay USA.

Using Chesapeake Bay dissolved oxygen criteria violation rates as indicators of water quality status, three common patterns observed in nearshore habitats:

1) As 30 day mean DO concentrations increase, variability in DO concentrations increase.
    a. Caveat. It is at least noteworthy that the Buchanan (Appendix 1a) and Perry (Appendix X) graphics exhibit a nonlinear relationship such that variability declines as you approach the very highest DO concentrations which contrast with the large scale pattern of increase over the DO gradient.
2) As the summer 30 day mean dissolved oxygen concentrations increase, the probability of violating shorter duration criteria declines (e.g. 7 day mean, instantaneous minimum, Table 1).
    a. A corollary of this appears to be that as any of the criteria means increase, there is a coincident expectation of water quality improvement at other time scale dissolved oxygen water quality indicators.
        i. Caveat: However, one author finds violation rates for the instantaneous minimum remain higher than 10% even at high 30 day mean DO concentrations (CB).
3) Criterion violation rates have a positive relationship with duration of hypoxic events. As the violation rate increases, the duration of hypoxic/anoxic events increase (Figure 9). Coincidently then as measures of violation rates decline we expect event durations to decline.

Table 1. Summary of violation rates over levels of sensor depth used as a surrogate in assessing trends related to short duration criteria response to monthly means with Bay data (from Perry Table 11 of Appendix 12 in CBP STAC 2012).

Sensor depth (m)	**6**	**5**	**4**	**3**
Monthly mean DO (ug/L)	5.0	5.7	6.3	7.0
7 day summer open water criterion failure rate	17.7	5.5	2.1	2
Rate of instantaneous criterion >10% failure for summer open water	44.9	34.3	25.4	16.6

MULTI-SCALE PATTERNS OF DISSOLVED OXYGEN BEHAVIOR: NEARSHORE AND OFFSHORE.

Umbrella Criteria Assessment Teams created synthetic data sets for offshore water quality monitoring stations based on data behaviors from nearshore water quality monitoring sites through the spectral casting technique to compare nearshore and offshore dissolved oxygen dynamics. Robertson and Lane (CBP STAC 2012) found that for long time intervals (e.g. 7-days or more), water quality conditions average out spatially, however, important differences exist at short time intervals. Robertson and Lane conducted comparisons of spectrally-derived dissolved oxygen patterns based on nearshore continuous monitoring data for an offshore long term monitoring location to compare with York River polyhaline vertical profiler data. They showed that for daily averages, spectrally-derived dissolved oxygen patterns were statistically different in variability and trend from actual measurements. However, weekly averages were statistically similar in variability to the real data. Hall (CBP-STAC 2012 Appendix 8) used two separate nearshore continuous monitoring sites on the lower, mesohaline Potomac River to generate estimates of offshore dissolved oxygen behavior. 30-day and 7 day means assessments translated well between nearshore and offshore in the summer at this lower Potomac River MH area. Like Robertson and Lane, however, there were greater discrepencies when dealing with the shortest time comparisons, i.e. instantaneous minimum assessments.

In 2013, the Scientific and Technical Assessment Team's Tidal Monitoring and Assessment Workgroup revisited the question with a paired comparison analysis of the best available high frequency, nearshore and offshore water quality monitoring data sets. Robertson (2013 TMAW) used data from their York River and Rappahannock River vertical profilers over multiple years to compare with nearshore continous monitoring data. Robertson again illustrated 30 day and 7-day mean data behaved similarly but shorter durations were different. Nearshore continuous monitoring stations found more low dissolved oxygen values than offshore. Trice (2013 TMAW) similarly supports Robertson's findings comparing 2004 and 2005 summer season hourly average data for Pin Oak (nearshore) and CBL (offshore) continuous water quality monitoring data on the lower Patuxent River showing nearshore conditions were worse 22 and 39 more days than offshore, respectively. Figure 14 provides a 2005 example of hourly average comparisons illustrating the tendency for shallow water conditions to be lower than offshore for these tow

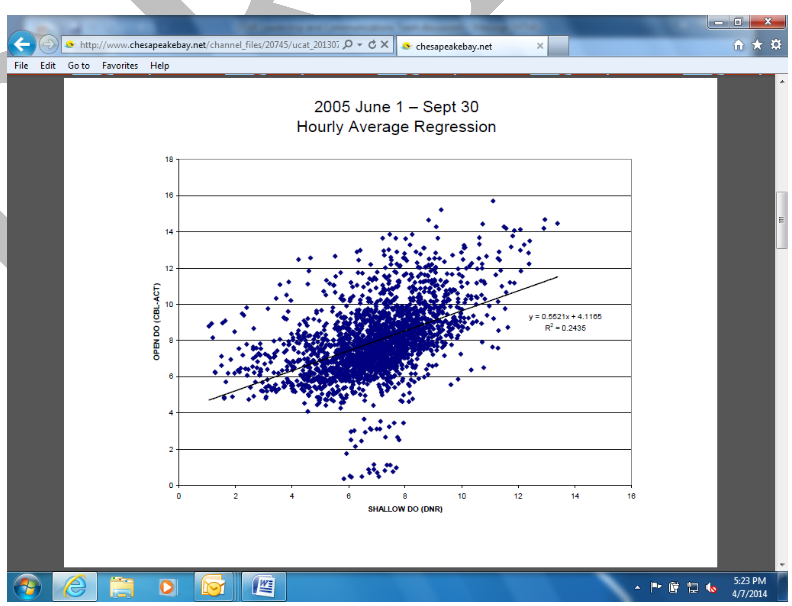

Figure 14. 2005 example of hourly average comparisons illustrating the tendency for nearshore shallow water conditions to be lower than offshore, Patuxent River. (MD DNR, Mark Trice)

PATTERNS OF ECOSYSTEM RESPONSE FROM HIGH FREQUENCY DISSOLVED OXYGEN DATA IMPORTANT TO CHESAPEAKE BAY WATER QUALITY MANAGEMENT

Nearshore dissolved oxygen dynamics show mean concentrations are similar to neighboring offshore conditions when compared for long averaging periods (i.e., 30-day, 7-day). However, paired comparisons of high temporal density (i.e. 15 minute to 1 hour) dissolved oxygen measurements between nearshore fixed station and nearby offshore vertical profiler continuous monitoring data shows nearshore dissolved oxygen measures are biased low compared to offshore waters. U.S EPA (2007a) recognized that conditions in these shallow water areas are considered to vary greatly from the open water of the mid-channels habitats. The work of the Umbrella Criteria Assessment Team, Criteria Assessment Protocol Workgroup and Tidal Monitoring and Analysis Workgroup has for the first time characterized similarities and differences in dissolved oxygen dynamics based on high temporal density data from continuous water quality monitoring sensors in both habitats.

Further, within the nearshore zone of the Bay and its tidal tributaries, distinct patterns of dissolved oxygen behavior are evident. Nearshore monitoring sites with greater exposure to mainstem Bay and mainstem tributary habitats show better water quality conditions than sites with restricted exposure (W. Boynton, Pers. Comm. 2014). Caffrey (2004) suggests careful selection of monitoring stations that are representative of the estuary as a whole could be used to estimate estuary-wide metabolic rates which are based on high frequency dissolved oxygen time series. Caffrey (2004) used high frequency dissolved oxygen data from 42 sites in 22 National Estuarine Research Reserves to assess net ecosystem metabolism (NEM). The sites were located nearshore in shallow water averaging 1.9m. Factors affecting NEM within and across monitoring sites further inform us about geomorphological and biogeochemical influences on dissolved oxygen variability. Habitat adjacent to the monitoring site explained the general trends in NEM across sites. Estuarine area was also significant in explaining patterns in NEM. Across monitoring sites, adjacent habitat, estuarine area and salinity explained 58% of the variation in NEM. Within sites, temperature was the most important environmental factor explaining within-site variation of metabolic rates; nutrient concentrations were the second most important factor. Nutrient loading explained 68% of the variation in NEM among some of the sites. Metabolic rates of the NERR sites were much larger than rates from other studies. One explanation was that small, generally shallow sites located near shore may have greater allochthonous organic inputs as well as significant benthic primary production than large deep systems represented by the literature. From the perspective of understanding shallow water versus offshore water habitats, this is additional evidence that the nearshore zone has different high frequency dissolved oxygen dynamics than the offshore zone. Factors affecting NEM within and across monitoring sites further inform us about importance of considering geomorphological and biogeochemical settings to account for variability in dissolved oxygen patterns and trends. However, of additional importance to Bay managers will be patterns of responsiveness across habitat in response to management actions.

Local and large scale measures of dissolved oxygen behavior in the Bay ecosystem are responsive to natural and anthropogenic effects. From the standpoint of detecting incremental progress we may focus on small system monitoring for water quality responses to local management actions while coincidently assessing open water at the segment and bay-wide scale to fully describe the scales of water quality changes in response to management actions. Caffrey further suggests detection of changes in the watershed such as changes in nutrient loading may be more apparent in shallow water than out in the channel. Response to nutrient loading is important as a consideration in maintaining the open water designated use as one unit or sub-segmenting the habitats for assessments. A collection of case studies on subestuaries of Chesapeake Bay illustrate positive water quality responses to local management actions (e.g. Gunston Cove on the Potomac River, Corsica River, MD - Lyerly et. al, 2014). By comparison, at the scale of Chesapeake Bay, we see improvement in dissolved oxygen conditions with fewer hypoxic volume days in response to long term management actions to manage nutrient and sediment loading while simultaneously accounting for climate factors (Murphy et al. 2011, Zhou et al. 2014). The collective science on Chesapeake Bay and its tidal tributaries provides evidence for multi-scale, parallel patterns of ecosystem response to management actions addressing nutrient loading for the range of time and space scales relevant to water quality standards assessments.

OPTIONS AND IMPLICATIONS OF REFINING THE OPEN WATER DESIGNATED USE

The Umbrella Criteria Assessment Team demonstrated that nearshore and offshore waters of Chesapeake Bay and its tributaries can behave similarly under mean conditions with long averaging periods. However, the two habitats frequently behave differently when dissolved oxygen measures are examined for the statistical distributional characteristics based on high temporal density data. Differences in dissolved oxygen dynamics between nearshore and offshore habitats have been suggested in past studies but are elucidated most clearly here in the new work of the team. Comparisons would not have been possible without the availability of nearshore and offshore high frequency water quality monitoring information provided by the application of continuous water quality monitoring sensors in the Chesapeake Bay Tidal Water Quality Monitoring Program.

While recognizing characteristic similarities and differences in dissolved oxygen dynamics of the two habitats, separating the present shallow water Bay grass designated use zone from the open water on a bay-wide basis may be limited by issues of setting a universal bay-wide boundary depth. At the same time, U.S. EPA recognizes the States rights to subsegment a management segment for CWA section 303d impairment, in part or in total, decisions.

Therefore, the Criteria Assessment Protocol Work Group, supported by the Umbrella Criteria Assessment Team, recommended to and received approval from the Water Quality Goal Implementation Team in 2013 for the following:

- The open water designated use definition remains shoreline to shoreline, keeping shallow water embodied within the open water designated use. This is supported by the similarities in dissolved oxygen dynamics for long averaging periods. However, there are sufficient results represented by data distributions from short duration time scale assessments of dissolved oxygen dynamics to justify and support States in requesting subsegmentation of a Chesapeake Bay management segment for dissolved oxygen attainment assessments on a case by case basis, applying current Open Water dissolved oxygen criteria, concurrent with U.S. EPA approval.

Recommendations on monitoring and assessment of such subsegments are discussed further in chapter v, *Assessing dissolved oxygen criteria attainment: a focus on short-duration criteria attainment assessments*, this document.

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chapter iv

INSTANTANEOUS MINIMUM DISSOLVED OXYGEN CRITERION FRAMEWORK: A SUBSEGMENTATION OPTION

BACKGROUND

Among the short-duration dissolved oxygen criteria, the Chesapeake Bay Program partnership had specific interest in revisiting the definition and assessment of instantaneous minimum dissolved oxygen criteria. Under EPA guidance, minimum criteria are acute criteria to be achieved at all times (U.S. EPA 1986). The evolution of minimum dissolved oxygen criteria specific to Chesapeake Bay, can be traced back to 1992 where progress toward developing dissolved oxygen goals for restoration of living resource habitats led to recommended target concentrations that included minimums (e.g. dissolved oxygen $\geq$ 1mg O_2/L, all times and all locations; dissolved oxygen $\geq$ 5 mg O_2/L, all times, throughout above-pycnocline waters in spawning reaches, spawning rivers and nursery areas). As national dissolved oxygen criteria were developed, a multifaceted, multidimensional exposure concept was established that has carried through into the definition of water quality standards. The definition of a water quality standard as explained in Chapter 3 of the U.S. EPA *Water Quality Standards Handbook, 2nd Edition* (U.S. EPA 1994) indicates water quality criteria definitions and assessments are not only comprised of a criterion frequency and magnitude but include duration. More recently EPA has recommended an averaging period of 1 hour as the interpretation of ‘at all times’. That is, to protect against acute effects, the 1-hour average exposure should not exceed (or, in the case of dissolved oxygen, go below) the critical concentration (U.S. EPA Standards Handbook).

In April 2003, the EPA published the guidance document *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal tributaries* (U.S. EPA 2003) with criteria and assessment procedures addressing the multiple dimensions of monitoring and assessment needed for Bay water quality standards. In the Chesapeake Bay criteria context, the standards are designed to address frequency, duration and magnitude. Instantaneous minimum dissolved oxygen criteria were developed here as elements of the suite of criteria applied to Chesapeake Bay tidal waters to support Clean Water Act section 303d water quality standards assessments (U.S. EPA 2003a, Batiuk et. al. 2009, Tango and Batiuk 2013). All of the refined Chesapeake Bay tidal water designated uses (i.e. Open Water, Deep Water, Deep Channel, Migratory and Spawning, and Shallow Water Bay Grass use) include an instantaneous minimum dissolved oxygen criterion (Table 1). Chesapeake Bay dissolved oxygen criteria and their assessment protocols accounting for magnitude, duration and frequency of conditions using a cumulative frequency distribution approach have been adopted into the water quality standards of the tidal water jurisdictions (i.e. Maryland, Delaware, Virginia and Washington, DC).

Table 1. Instantaneous minimum dissolved oxygen criteria by designated use for Chesapeake Bay ambient water quality assessments. (Derived from U.S. EPA 2003a)

Designated Use	Dissolved oxygen criterion concentration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	≥5 mg/L	Survival and growth of larval/juvenile migratory fish; protective of endangered species	February 1-May 31
	≥3.2 mg/L	Survival of threatened/endangered sturgeon species	June 1-January 31
Open water fish and shellfish use	≥3.2 mg/L	Survival of threatened/endangered sturgeon species	Year-round
Shallow water Bay grass use	≥3.2 mg/L	Survival of threatened/endangered sturgeon species	Year-round
Deep water use	≥1.7 mg/L	Survival of bay anchovy eggs and larvae.	June 1-September 30
	≥3.2 mg/L	Survival of threatened/endangered sturgeon species	October 1-May 31
Deep channel seasonal refuge use	≥1 mg/L	Survival of bottom dwelling worms and clams	June 1-September 30
	≥3.2 mg/L	Survival of threatened/endangered sturgeon species	October 1-May 31

The Chesapeake Bay Instantaneous Minimum Workshop

The Chesapeake Bay Program's Umbrella Criteria Assessment Team noted during their 2011 CBP-STAC-sponsored Workshop that the Chesapeake Bay community of managers and analysts continued to show support for the original scientific bases underlying the derivation of Chesapeake Bay instantaneous minimum dissolved oxygen criterion values (CBP STAC 2012). Minimum dissolved oxygen criteria have been developed based scientific understanding of lethal oxygen thresholds for aquatic living resources. National criteria for dissolved oxygen (U.S. EPA 1986, U.S.EPA 1988) were derived using biological impairment estimates to protect survival and growth of aquatic life below which detrimental effects are expected. The selection of target dissolved oxygen concentrations and their temporal and spatial applications followed an analysis of dissolved oxygen concentrations that would provide levels of aquatic living resource protection to achieve restoration goals. The restoration and protection goals provide for sufficient dissolved oxygen resources to support the survival, growth and reproduction of anadromous, estuarine and marine fish and invertebrates in the Chesapeake Bay and its tidal tributaries (U.S. EPA 2003).

Through the Chesapeake Bay Program's Umbrella Criteria Assessment process, representatives of the Chesapeake Bay Program partnership expressed continued concerns about assessing the instantaneous minimum criteria in Chesapeake Bay tidal waters. The Chesapeake Bay Program partnership, working through its Science, Technical Assessment and Reporting Team's Criteria Assessment Protocol Workgroup, requested an opportunity to review the existing instantaneous minimum criteria with its assessment protocols and explore potential alternative interpretations. The Criteria Assessment Protocol Work Group worked with the Tidal Monitoring and Assessment Workgroup of the Science, Technical Assessment and Reporting Team at the Chesapeake Bay Program and conducted the workshop in October 2013. The Umbrella Criteria Assessment Team used the findings of the workshop to develop recommendations on a framework to address instantaneous minimum criteria assessment.

This chapter 1) reviews the instantaneous minimum dissolved oxygen criterion assessments presently conducted by the Chesapeake Bay tidal water jurisdictions, 2) highlights findings of the Instantaneous Minimum criteria Workshop and 3) provides recommendations on a framework for sub-segment options to support requests and coordination by Chesapeake Bay tidal water jurisdictions with U.S. EPA for partial delisting decisions that track incremental progress in Chesapeake Bay recovery.

Review of the "Instantaneous Minimum" dissolved oxygen criterion assessment for the Chesapeake Bay water quality standards attainment.

Assessment of instantaneous minimum criteria in Chesapeake Bay is presently only conducted for the summer season deep channel designated use. The application of a biological reference curve to the deep channel water quality standards attainment assessment was recommended in U.S. EPA 2007 (p43). (Also see *History of EPA Guidance on the deep channel reference curve* in Appendix D, U.S. EPA 2010). The 2007 recommendation for application of a biologically-based reference curve for assessment of the deep channel dissolved oxygen criterion was based on a small number of deep-channel segment periods within which the benthic communities were categorized as "healthy" and. Therefore, appropriate to use as a biological reference (U.S. EPA 2010). U.S. EPA 2010 published a revised methodology to the developing the biological reference curve and applied it to derive a new biologically-based reference curve for the deep channel habitats. The revised method, however, yielded no segment-periods with healthy benthic communities. In the absence of a suitable reference community, a biological reference curve could not be constructed. Under these circumstances, a default reference curve such as the normal distribution curve representing approximately 10% exceedance is appropriate in this case to account for anticipated natural exceedances (U.S. EPA 2003, p173.). While States and other users must recognize that the deep-channel dissolved oxygen criterion is stated as an instantaneous minimum, and that any exceedance is assumed to have direct consequences to the survival of the bottom-dwelling community, the reference curve approach provides ultimately provides for 'allowable exceedances'.

U.S. EPA (2004) guidance on a 10% rule was intended to provide a simple "rule of thumb" in evaluating data sets of limited size for assessment purposes and is intended to account for measurement error and the potential that small data sets may not be fully representative of receiving water conditions. The EPA's criteria derivation guidelines and technical support documents do not state that the purpose of the criteria is to prevent any losses; the purpose of the criteria is to prevent "unacceptable losses". Allowable exceedances with the CFD assessment approach applied to Chesapeake Bay dissolved oxygen standards impairment decision approach accepts spatial and temporal exceedances of the criterion according to either a 10% curve or a biological reference otherwise referred to as a bio-reference curve (U.S. EPA 2003a). Thus, accounting for the definition of instantaneous minimum criterion as applied to the deep channel follows the water quality standards framework of having a magnitude, evaluated over a designated use in space for a seasonal temporal duration. Frequency of violation is accounted for by the CFD comparison. The application of 'allowable exceedances' also fits with the EPA concept of an acute criterion being evaluated as 1-hour averages since averaging implies there may be periodic exposures beyond the threshold criterion concentration of concern.

Rationale for Acceptable Exceedances of the Deep Channel Instantaneous Minimum Dissolved Oxygen Criterion (from U.S. EPA 2010)

EPA determined that there were allowable exceedances that would not adversely affect protection of the designated use. As documented on p. 168 in U.S. EPA 2003:

> *"The recommended criteria attainment assessment approach is designed to protect the living resources as defined by the designated uses. The criteria levels themselves were largely base on scientific studies performed in laboratory settings or under controlled field conditions. The criteria establish the level of a given habitat condition that living resources need for survival. They do not account for many other environmental factors that could affect survival. Reference curves were developed to provide a scientific-based, direct measure of the 'allowable' criteria exceedances. These exceedances are defined to be those that last a short enough time to have no adverse affects on the designated use. It is assumed that the designated uses can be attained even with some limited level of criteria exceedances and thus, the reference curves define those criteria exceedances deemed to be allowable—chronic in time but over small areas, or infrequent occurrences over large areas. Exceedances that occur over large areas of space and time would be expected to have significant detrimental effects on biological communities, which would imply nonattainment of designated uses."*

As reported in a recent paper on the Chesapeake Bay dissolved oxygen criteria by members of the original Chesapeake Bay Dissolved Oxygen Criteria Team, Batiuk et al. (2009):

> *"Unlike chemical contaminants or other more conventional pollutants, there we no clear, no well established guidelines for deriving criteria for DO, particularly in estuarine settings inhabited by freshwater and marine species. The goal in setting Chesapeake DO criteria was to use the best science possible to define conditions that would improve or sustain the suitability of Chesapeake Bay habitats for finfish and invertebrates, with the states ultimately factoring in consideration of attainability in adopting the criteria as water quality standards. Thus, we developed criteria that would greatly increase the spatial and temporal extent of Bay waters in which oxygen concentrations were not major limitations to growth and survival of organisms dependent on particular Bay habitats. We did not, however, derive criteria that would require oxygen concentrations high enough at all times and in all locations such that no organism would be negatively affected in any location in the Bay. The*

states and U.S. Environmental Protection Agency (EPA) determined that such conditions would not be achievable either economically nor technologically (U.S. EPA, 2003d) and may not, in fact, reflect pre-historical conditions of Chesapeake Bay, which showed that low oxygen conditions, although not nearly as severe as today, may have been a historical feature in the deep channel of the bay (Cooper and Brush,1991; Karlsen et al., 2000; Adelson et al., 2001; Zimmerman and Canuel, 2002; Bratton et al., 2003; Colman and Bratton, 2003; Cronin and Vann, 2003; Zheng et al., 2003)."

In support of the deep channel instantaneous minimum criterion of 1 mg/L U.S. EPA (2003) summarized findings of peer-reviewed literature sources indicating that keystone benthic species are resistant to dissolved oxygen concentrations as low as 0.6 mg/L. and that "extensive mortality is likely only under persistent exposure to very low dissolved oxygen concentrations at high summer temperatures" (p. 61).

In light of both (1) the recognition that low dissolved oxygen conditions are a 'pre-historical' feature of these deep channel habitats, and (2) the observation that keystone benthic species of these deep channel habitats can tolerate small scale occurrences of severe hypoxia (DO concentrations below 1 mg/L), EPA believes that an allowance for a small, limited set of exceedances in time and space is acceptable in assessment of the deep-channel designated use dissolved oxygen criterion.

EPA, therefore, recommended revision of the 2007 decision in 2010 to assess the summer season (June 1-September 30) deep channel instantaneous minimum criterion using the CFD approach with a 10% default reference curve (U.S. EPA 2010). The remainder of the designated use assessments were not addressed for assessing their respective instantaneous minimum criteria.

RECOMMENDATIONS FOR A FRAMEWORK OF SUB-SEGMENTATION TO SUPPORT PARTIAL CLEAN WATER ACT DELISTING DECISIONS

Outputs of the October 2013 Instantaneous Minimum Workshop suggested exploring a 2-zone assessment approach, nearshore and offshore, applied on a case by case basis. The recommendation was proposed based on 1) habitat differences in dissolved oxygen dynamics demonstrated by the Umbrella Criteria Assessment Team analyses showing frequent low bias for nearshore dissolved oxygen concentrations from high density time series as compared to offshore habitats (for details, refer to chapter iii - *Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats: Considerations Supporting the Management Structure of the Open Water Designated Use*, this document) and 2) the growing accumulation of data assets that are season-long, high-frequency dissolved oxygen times series in shallow water habitats that are informative of instantaneous water quality conditions but where only the calibration data collected synoptically are included in the present Chesapeake Bay water quality criteria assessments. To this second point, it was noted that most states and tribes assessing water quality standards in a variety of water bodies are making Clean Water Act 303d listing and delisting decisions regarding dissolved oxygen based on tens of data points per year; Chesapeake Bay dissolved oxygen continuous monitoring data are typically collected at 15 minute intervals. Over a 120 day summer season, there are typically over 11,500 data points per site and as many as 70 sites per year operating in the tidal waters of Chesapeake Bay.

U.S EPA (2007a) recognized that conditions in these shallow water areas are considered to vary greatly from the open water of the mid-channels habitats. The work of the Umbrella Criteria Assessment Team, Criteria Assessment Protocol Workgroup and Tidal Monitoring and Analysis Workgroup has for the first time characterized similarities and differences in dissolved oxygen dynamics based on high temporal density data from continuous water quality monitoring sensors in both habitats. Further review of available information by the Umbrella Criteria Assessment Team in winter 2014 used the habitat comparisons conducted and reviewed in evaluations of the Open Water Designated Use structure (see chapter iii *Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats: Considerations Supporting the Management Structure of the Open Water Designated Use*, this document**)** suggested a 3-zone sub-segment assessment framework, applied on a case by case basis, was better supported for assessing instantaneous minimum criteria.

Instantaneous minimum assessments: 3-zone approach.

Further review of available information by the Umbrella Criteria Assessment Team from the habitat comparison conducted in evaluations of the Open Water Designated Use structure (see Chapter iii, *Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats: Considerations Supporting the Management Structure of the Open Water Designated Use*, this document**)** suggested a 3-zone assessment. The three assessment zones recommended are 1) offshore, 2) nearshore of mainstem Chesapeake Bay and mainstem tributaries, and 3) subestuaries off of mainstem waters.

The basis for the recommendation is a function of geomorpholical setting influence shown to correlate with dissolved oxygen dynamics across habitats and similar habitat divisions in use for monitoring station location considerations. Within the nearshore zone of the Bay and its tidal tributaries, distinct patterns of dissolved oxygen behavior are evident. Caffrey (2004) used high frequency dissolved oxygen data from 42 sites in 22 National Estuarine Research Reserves (NERRs) to assess net ecosystem metabolism (NEM). NEM was estimated based on high temporal density dissolved oxygen concentration data collected from continuous monitoring sensors in nearshore habitats including Chesapeake Bay. As suggested by Boynton (Pers. Comm. 2014), Caffrey noted the habitat adjacent to the monitoring site explained the general trends in dissolved oxygen patterns, specifically with NEM across sites. Estuarine area was also significant in explaining patterns in NEM. Across monitoring sites, adjacent habitat, estuarine area and salinity explained 58% of the variation in NEM. (W. Boynton, Pers. Comm. 2014 (Note: **Report to MD DNR forthcoming May 2014**) nearshore monitoring sites with greater exposure to mainstem Bay and mainstem tributary habitats show better water quality conditions than sites with more restricted exposure. U.S. EPA (2003 305b guidance) highlights how Washington State Department of Ecology similarly divides estuarine habitats to define monitoring site representativeness using 3 zones: open water, sheltered bays and highly sheltered bays. Virginia Department of Environmental Quality cites U.S. EPA 2003 guidance to support the same three habitats for their existing non-Chesapeake Bay Program tidal and estuarine monitoring station location considerations (VADEQ 2014).

NEED FIGURE!

RECOMMENDATION (under review April 2014)

The Umbrella Criteria Assessment Team in conjunction with the CAP WG and TMAW provide a 3 zone alternative approach to support partial delisting decisions supported by the differential behavior of dissolved oxygen in shallow water related to their juxtaposed habitats of open water mainstem Bay or major tributary compared with subestuaries off these primary water bodies. Recommendations are:

- Zone 1: Offshore. Subject to the Open Water designated use assessment.
- Zone 2: Subsegment a nearshore zone adjacent to open water. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdication.
  - Use 3 seasons of continuous monitoring data (15 minute intervals). One or more sites can be used.
  - Assess the time series at a **1% allowable exceedance level**, substituting a 10x lower allowable exceedance rate as compensation for the reduction in spatial coverage in a Chesapeake Bay management segment.
- Zone 3: Subsegment subestuaries off the mainstem tributaries and Bay. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdication. Use discrete monitoring, minimum of 10 samples per year, for 3 years, 10% allowable exceedance. These small, shallow habitats are the least well studied and described for high frequency dissolved oxygen dynamics but have historical perspective from state monitoring programs (e.g. Virginia DEQ).

Habitat specific protocols of instantaneous minimum dissolved oxygen assessment are provided in chapter v, *Assessing Dissolved Oxygen Criteria Attainment: A Focus on Short-Duration Criteria Attainment Assessments,* this document.

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chapter v

Update of the Chesapeake Bay SAV Restoration Goal: Alignment with Chesapeake Bay Water Quality Standards.

- **Mar 2014 draft text. Final work p**ending decisions across CBP spring 2014

BACKGROUND

The submerged aquatic vegetation (SAV) acreage restoration goals were developed as a larger effort to restore Chesapeake Bay water quality. In 1993 the Chesapeake Executive Council formally adopted its first SAV restoration target as the Chesapeake Bay Program's first quantitative living resource restoration goal (Chesapeake Executive Council 1993). Subsequent revision of the goal occurred coincident with providing target goals supporting the Chesapeake 2000 Bay agreement, the development of Chesapeake Bay water quality criteria (U.S. EPA 2003a) and the adoption of the regional Chesapeake Bay water quality criteria into standards by tidal bay jurisdictions of Maryland, Virginia, Delaware and the District of Columbia.

During the Chesapeake Bay Program's Criteria Assessment Protocol Workgroup's 2012-2014 review process supporting updates to water quality standards protocol assessments in support of the 2017 TMDL mid-point assessment, Chesapeake Bay Program staff reviewed the basis for the water quality clarity standard assessment protocol. Chesapeake Bay Program staff identified a difference between the 2003 SAV goal target (185,000 acres) adopted by Chesapeake Bay Program partnership and the existing SAV target acreage goal based on the sum of Chesapeake Bay water quality standards (192,000 acres). The basis, derivation, revision and adoption of the 185,000 acre bay-wide submerged aquatic vegetation acreage goal and associated assessment protocols is provided in the U.S Environmental Protection Agency Region III's April 2003 publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries (Regional Criteria Guidance)* and accompanying volumes of technical support documentation (U.S. EPA 2003 a, b, c). Many potential goal acreages were considered in developing the 185,000 acre goal (U.S. EPA 2003 Oct.). Subsequent to this goal being developed and adopted to support the goals of the *Chesapeake 2000* agreement, water quality standards were derived for a new shallow water designated use in Chesapeake Bay. The water quality standards goals support the Total Maximum Daily Load restoration targets. The development of the water quality standards was not, however, a direct adoption of the 185,000 acre underwater bay grasses goal when the States established their water quality standards.

The Chesapeake Bay Program partnership and its Submerged Aquatic Vegetation Workgroup assisted the Criteria Assessment Protocols Workgroup in understanding the historical basis for the differences in the two underwater Bay grass acreage restoration goal totals. A review of the details of the goal derivation methodology illustrated how the State's 192,000 acre water quality standards-based goal used the underlying details forming the 185,000 acre goal as the foundation for their standards setting. The States had the benefit of the body of history used to develop the 185,000 acre goal and all the caveats with computing that target acreage. In adopting segment specific water clarity standards the Chesapeake Bay Program partners more accurately reflected segment SAV goal acreages. The 192,000 acre goal is better aligned with the method used in the annual aerial survey of SAV to assess the status of Bay grasses and track change towards attaining water clarity/SAV goals. In order to unify the goals and acknowledge a single SAV goal acreage supporting the Chesapeake Bay TMDL, we review the history of establishing Chesapeake Bay underwater bay grass goals. We provide support for updating the Chesapeake Bay Program partnership's SAV restoration goal to match the Bay jurisdictions combined water quality standards based target of 192,000 acres.

SAV RESTORATION GOAL HISTORY IN BRIEF

The original tiered SAV restoration goal acreage targets for Chesapeake Bay were first published in the 1992 SAV technical synthesis in response to commitments set forth in the *Submerged Aquatic Vegetation Policy for the Chesapeake Bay and Tidal Tributaries* (Chesapeake Executive Council 1989). Three tiers of restoration targets were developed. The tiered set of SAV distribution restoration targets was established to provide a measure of incremental progress for Chesapeake Bay in response to improvements in water quality. The Tier I SAV distribution restoration target was the restoration of SAV to areas that were currently or previously inhabited by SAV as mapped through regional and bay-wide aerial surveys from 1971 through 1990 (Batiuk et al. 1992, Dennison et al. 1993). The Tier II and Tier III distribution restoration targets were the restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat, down to the 1- and 2-meter depth contours respectively. A complete, detailed description of the original process for developing the tiered restoration goals and targets is found in Batiuk et al (1992, pages 109-119).

In 1993 the Chesapeake Executive Council formally adopted the Tier I SAV restoration target as the Chesapeake Bay Program's first quantitative living resource restoration goal (Chesapeake Executive Council 1993). Refinements were made to the Tier I restoration goal as a result of a reevaluation of the historical SAV aerial survey digital data sets, including a thorough quality assurance evaluation, which resulted in corrections to the original data. The revised Tier I goal total was 113,720 acres. The tier I goal and the coincident goal areas for each Chesapeake Bay management segment were published in SAV Technical Synthesis II, Chapter VIII, Table VIII-1 (Batiuk et al. 2000 I think).

U.S. EPA (2003 Oct pp118). The Chesapeake Bay 2000 agreement committed to revising the existing underwater bay grass restoration goals and strategies: "*.... to reflect historical abundance, measured as acreage and density from the 1930s to present"*. The basis for the goal setting acreages referred to *"*historical" underwater bay grass distribution as being assessed from aerial photographs from the 1930s to the early 1970s (U.S. EPA 2003 October). Single best year assessments were made on each Chesapeake Bay management segment and characterized as "historical" or designated a best year according year in the contemporary Chesapeake Bay underwater bay grass aerial survey monitoring data (1978-2000) (U.S. EPA 2003 Oct). Abundance was classified according to Chesapeake Bay management segments and depths that were designated for the new Chesapeake Bay shallow-water underwater-bay grass designated use (U.S. EPA 2003a + b(Oct 2003).

The new 2003 restoration goal of 185,000 acres was derived from the composited 1930s-2000 time series using the total single best year acreage summed over all the segment depths that were designated for shallow water bay grass use. U.S. EPA (2003 October, Table IV-12, pp114) describes the details of the methodology used in taking the combination of historical and contemporary information available and determining the revised 185,000 acre Chesapeake Bay-wide underwater grasses restoration goal. (See also U.S. EPA 2003 December Appendix A statement of 185,000 acre goal adoption consistent with the goals of Chesapeake 2000.) Goal options ranged 17-fold from a low for the area of the 1984 underwater Bay grass distribution (37,356 acres) to a high for the area represented by the total Bay shallow water habitat out to the 2-meter depth contour minus underwater acres from declared no-grow zones (640,926 acres). Pp119. U.S. EPA (2003 October) illustrated the array of different underwater bay grass and shallow water habitat acreages considered during the process for setting the shallow-water designated use depth and establishing the new Chesapeake Bay underwater restoration goals.

COMPARISON OF 185,000 ACRE AND WATER QUALITY STANDARDS 192,000 ACRE BAY GRASSES RESTORATION TARGET COVERAGE:

During 2013 and early 2014, the SAV Workgroup of the Habitat Goal Implement Team in the CBP partnership reviewed the restoration goal setting methodology (used to determine the single best year of SAV growth). The SAV Workgroup found there were differences between the 185,000 acre goal setting effort of 2003 and establishing the more recent 192,000 acre water quality standards goal. The 185,000 acre SAV restoration goal setting effort preceded Chesapeake Bay tidal water jurisdiction's adoption of the water quality criteria into their water quality standards. The standards setting process had the benefit of the analyses and summary information available from the development of the 185,000 acre goal and the published derivation of water quality criteria (U.S. EPA 2003a). The Chesapeake Bay Program partnership used data through 2000 for its single best year assessment and considered a 2001 underwater acreage total (U.S. EPA 2003 Oct Figure IV-31) was considered as a potential goal in setting the 185,000 acre restoration target.

The 2003 goal setting approach included many cases of undercounting SAV. The undercounting was due to estimated acres of SAV with 'clipped' SAV beds within the GIS analysis. Clipped areas represented the difference between the GIS shoreline record and actual shorelines in the aerial photographs. The process of clipping these areas produced a loss of this SAV from a segment as viewed through the lens of GIS because it would be classified as SAV being 'on land' and could not have an associated bathymetry for that area. The inaccuracy of the shoreline data layer exists for multiple reasons, i.e. either because of the scale of the data, changes in the shoreline over time not reflected in the data (e.g. erosion and sea level rise) or some other factor. At the same time there was a similar problem of undercounting involved with SAV on flats around islands due to shifting shorelines. This issue is acknowledged in U.S. EPA (2004 Oct, pp92-93).

"*The chosen solution, described in more detail in U.S. EPA 2004 Technical Support Document – 2004 Addendum, was to count all of the SAV acreage for a given segment that occurred within a single best year regardless of any shoreline, bathymetry data limitations or water clarity application depth restrictions*" (U.S. EPA 2004 Oct). Further, as described in U.S. EPA 2004 Oct, we see that EPA recognizes the officially adopted SAV restoration goals but encourages the tidal Chesapeake Bay jurisdictions to consider the new information when refining and adopting new water quality standards, setting up the CBP for different goal acreages:

"*The U.S. EPA 2004 Technical Support Document – 2004 Addendum documents the 'expanded restoration acreage' updating existing use acreage and the available shallow water habitat area for each Chesapeake Bay Program segment. As described in the 2004 addendum:* "*The expanded restoration acreage is the greatest acreage from among the updated existing use acreage (1978-2002; no shoreline clipping), the Chesapeake Bay Program adopted SAV restoration goal acreage (strictly adhering to the single best year methodology with clipping) and the goal acreage displayed without shoreline or application depth clipping and including areas from SAV still lacking bathymetry data. This 'expanded restoration acreage' is being documented here and provided to the partners as the best acreage values that can be directly compared with SAV acreages reported through the bay-wide SAV aerial survey.* ***These acreages are not the officially adopted goals of the watershed partners; they are for consideration by the jurisdictions when adopting refined and new water quality standards regulations****."*

The Chesapeake Bay Program SAV restoration goal of 185,000 acres and the segment-specific goal acreages stand as the watershed partners' cooperative restoration goal for this critical living resource community (Chesapeake Executive Council 2003). ***EPA recommends that the jurisdictions with the Chesapeake Bay tidal waters consider adopting the expanded restoration acreages…into their refined and new water quality standards regulations****.*

There were also no bathymetric data for many tidally connected ponds in the segments and SAV in these ponds was excluded. Lack of bathymetric data affected the upper portions of the Patuxent River Tidal Fresh (PAXTF) and Anacostia Tidal Fresh (ANATF) segments. The ANATF segment had no SAV, however, the lack of bathymetry in the upper Patuxent River excluded most of the known SAV acres in that area.

With respect to setting water quality standards based SAV goal acres by Chesapeake Bay management segment, U.S. EPA 2004 (Oct) further highlighted that '*Since the 2003 publication of both the Regional Criteria Guidance and the Technical Support Document, new information has become available to the watershed jurisdictions and EPA in support of state adoption of SAV restoration goal…acreages. This new information will also help the four jurisdictions with Chesapeake Bay tidal waters to adopt consistent, specific procedures for determining attainment of the shallow-water bay grass designated uses into their regulations. EPA continues to support and encourage the jurisdictions' adoption of segments-specific submerged aquatic vegetation (SAV) restoration goal acreages…necessary to support restoration of those acreages of SAV into each jurisdictions respective water quality standards regulations.*" After the 185,000 acre restoration goal was set, 2002 data for underwater bay grass aerial surveys became available to support decision making for establishing standards.

THE WATER QUALTIY STANDARDS-BASED SAV GOAL ACREAGE.

The Chesapeake Bay SAV WG, and Chesapeake Bay Program staff determined that the basis for the 185,000 acres goal formed the foundation for the 192,000 acre water quality standards based goal. As recommended by EPA, the original Chesapeake Bay underwater grasses goal acreages by segment and the expanded restoration acreages were used. With few exceptions around the Bay, the water quality standards segment goals for SAV acres are equal to or greater than the segment acreage goals supporting the 185,000 acres. The jurisdictions were consistent in their consideration for adding back previously missing acres in management segment goals due to GIS-related clipping of SAV acres. Most of these 'clipped' acres were previously considered as 'on land' even though they were clearly visible in the aerial photographs identifiable between the GIS layer land boundary and the visible shoreline of the photographs. Additional excluded acres had previously missing bathymetry or were segments without established goals (Table "X").

This table uses the split segments as individual segments. It is a comparison of WQS acres to the 2003 CBP SAV Restoration Goal Segment Acres. Segment total = 104. In 2003 the CBP recognized 104 segments according to U.S. EPA (2008). Appendix X provides a more detailed table that accounts for the decisions made in the assigning of goal acres to segments.

Table X. Summary of the decision support provided to derive the water quality standards acreages by Chesapeake Bay management segment.

Goal acreage basis for Water Quality Standards	Segment Count
Segments where WQ Standards acres were equal to or greater than the CBP 185K goal basis	93
Segments where acreages were **revised lower** than the 185K CBP goals basis	9
Missing segments acreages	2
Total	104

Final goal is the water quality standards based acreage (192K) is a function of the CBP Restoration goal, more aggressive in accounting for acres and better reflective of the measurement process than the 185,000 acre restoration goal.

"192,000" ACRE WATER QUALITY STANDARDS-BASED GOAL RECOMMENDATION

The 185,000 acre SAV restoration goal was a conservative target affected by undercounting SAV acres in a subset of Chesapeake Bay management segments. Undercounted acres were due to multiple factors included mismatches between shoreline data layers and present day shorelines that resulted in SAV 'on land' that was actually in the water or missing bathymetry (e.g., PAXTF). The 192,000 acre goal is the sum of water clarity acre standards for Bay states and DC where segment goals were developed supporting water quality standards attainment equal to or greater than the CBP restoration acreages used for each segment when creating the original 185,000 acre SAV restoration target.

Recognizing that there are still segments without goal acreages, the "192,000" acre goal should be stated as "The Water Quality Standards-Based Goal", where the acreage total remains subject to goals being set segments without goals at this time. The SAV WG could work to develop SAV acreage goals. The basis of the goal is firmly established in the underlying support developed for the 185,000 acre goal and the additional information provided to the community upon further analysis of the data. Second, the 192,000 acres goal reflects more accurately how the water quality standards attainment assessments are conducted, tracked and reported than is the 185,000 acre goal.

CONSIDERATIONS FOR FUTURE ACREAGE GOAL AND PROTOCOL ASSESSMENT CONSISTENCY

Future consideration could be given for additional consistency between states in their basis of setting their water quality standards where all jurisdictions only go out to application depth (the Maryland model) or they extend out to include the deep water acres (the Virginia model). If MD adopted the VA model, the additional deep water acres would increase the 192,000 goal by about 14,000 acres to 206,000. Further, there are additional considerations that could be given to support an even larger goal (See Table X acreages). The SAV WG has been funded in 2014-15 to produce and SAV Technical Synthesis that updates the science, management and assessment of SAV and its habitat. This publication could support a future review regarding any needs to amend the water quality criteria and subsequently standards for the four tidal Chesapeake Bay jurisdictions.

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WATER QUALITY CRITERIA ASSESSMENT

chapter vi

Assessing Dissolved Oxygen Criteria Attainment:

A Focus on Short-Duration Criteria Attainment Assessments

BACKGROUND

The development of the scientific underpinnings for Chesapeake Bay-specific criteria has been underway for decades. Dissolved oxygen dynamics of Chesapeake Bay and its tidal tributaries have been reported on since the early 1900s (Sale and Skinner 1917, Newcombe and Horne 1938 Newcombe et al. 1939, Breitburg 1990, Smith et al. 1992, D'Avanzo and Kremer 1994, U.S. EPA 2003, Kemp et al. 2004, Boynton et al. Mattawoman Crk 2012). Early in the 1990s, experts further identified DO concentrations necessary to protect the Chesapeake Bay's aquatic living resources. With the publication of the 2003 *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for Chesapeake Bay and its tributaries* (U.S. EPA 2003a), a suite of detailed dissolved oxygen criteria for Chesapeake Bay and its tidal tributaries and embayments was codified supporting living resources growth and survival protections across life stages using multiple space and time scales (Table 1). The dissolved oxygen criteria were tailored to each of five designated uses (Table 1). EPA has published and Delaware, Maryland, Virginia, and the District of Columbia have adopted into their state's water quality standards regulations the dissolved oxygen criteria protective of the published migratory spawning, open water, deep water and deep channel designated uses. These dissolved oxygen criteria include 30-day, 7-day and 1-day means along with instantaneous minima as needed to protective the variety of living resource species and their life stages within each designated use (U.S. EPA 2003). "Short-duration" as defined here will refer to a criterion with a temporal scale of less than the 30-day mean dissolved oxygen criterion used to support assessments of water quality standards in the Chesapeake Bay.

U.S. EPA (2003a) recognized that the temporal scale of the Chesapeake Bay long term, fixed station tidal water quality monitoring program was designed to capture long-term trends, as well as seasonal and interannual variation in water quality conditions. The existing program would support 30-day mean assessments, however, it was considered insufficient on its own to assess short-duration dissolved oxygen criteria (U.S. EPA 2003a, CBP-STAC 2012 Umbrella Criteria Report), i.e., it was poorly suited for supporting Clean Water Act 303d listing assessments of the new water quality criteria that included 7-day mean, 1-day mean and instantaneous minimum DO criteria (p.177, U.S. EPA 2003a). In U.S. EPA (2003a), it was suggested that assessment of short-duration criteria might be accomplished using statistical methods that estimate probable attainment (p.179). Further evaluation of water quality monitoring and assessment options to support measurements of Chesapeake Bay short-duration water quality standards attainment was needed.

The following chapter 1) overviews approaches that have been suggested to advance Chesapeake Bay water quality criteria attainment assessments to include short-duration criteria 2) documents data used in assessment methods for support of short duration criteria assessment, 3) documents approaches used to gain insights into viability of approaches and their assumptions, 4) recommends approaches toward addressing short duration dissolved oxygen criteria in Chesapeake Bay and its tidal tributaries.

Table 1. Chesapeake Bay Water Quality Criteria (from USEPA 2003a).

Designated Use	**Criteria Concentration/Duration**	**Protection Provided**	**Temporal Application**
Migratory fish spawning and nursery use	7-day mean ≥ 6 mg/L (tidal habitats with 0-0.5 salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species	February 1-May 31
	Instantaneous minimum ≥ 5 mg/L	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species	
	Open-water fish and shellfish designated use criteria apply		June 1 – January 31
Shallow-water bay grass use	Open–water fish and shellfish designated criteria apply		Year-round
Open-water fish and shellfish use[1]	30-day mean ≥ 5.5 mg/L (tidal habitats with ≤0.5 salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species	Year-round
	30-day mean ≥ 5 mg/L (tidal habitats with >0.5 salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species	
	7-day mean ≥ 4 mg/L	Survival of open-water fish larvae.	
	Instantaneous minimum ≥ 3.2 mg/L	Survival of threatened/endangered sturgeon species[1]	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg/L	Survival and recruitment of bay anchovy eggs and larvae.	June 1 – September 30
	1-day mean ≥ 2.3 mg/L	Survival of open-water juvenile and adult fish	
	Instantaneous minimum ≥ 1.7 mg/L	Survival of bay anchovy eggs and larvae	
	Open-water fish and shellfish designated-use criteria apply		October 1 – May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥ 1 mg/L	Survival of bottom-dwelling worms and clams	June 1 – September 30
	Open-water fish and shellfish designated use criteria apply		October 1 – May 31

AN EXPLORATION OF SHORT-DURATION DISSOLVED OXYGEN CRITERIA ASSESSMENT APPROACHES TO INFORM CHESAPEAKE BAY WATER QUALITY MONITORING AND ASSESSMENT STRATEGY OPTIONS

Spectral analysis and logistic regression were statistical methods previously highlighted for consideration in supporting Chesapeake Bay short-duration dissolved oxygen criteria attainment assessments (U.S. EPA 2004, 2007a). An alternative decision framework was developed called **the "Umbrella Criterion" approach**. The "Umbrella" approach suggested that measuring and attaining a single criterion could be used to ensure protection for one or more other scales of the associated criteria. In practice then, the application of an Umbrella Criterion assessment for protecting short-duration dissolved oxygen criteria in Chesapeake Bay tidal waters could be based on one measured criterion such as the 30-day mean. The two statistical methods and the Umbrella Criterion approach have been explored by Chesapeake Bay community analysts evaluating 1) the technical capacity to apply the techniques with available Bay monitoring data and 2) the appropriateness of the method to fulfill dissolved oxygen criteria assessment needs.

The **logistic regression approach** utilizes a well established statistical procedure and has previously been applied to Chesapeake Bay data (U.S. EPA 2007). Results were used to analyze relationships of mutual protections for water quality targets across multiple time scales (Jordan et al. 1992). Jordan et al. concluded that knowing the seasonal mean DO concentration for a given region of the Bay permitted "a good estimate of what proportion of actual DO observations are likely to meet, or fail to meet," target dissolved oxygen concentrations such as the instantaneous minimum. This approach conceptually reflected an umbrella criterion-style assessment method; attaining a criterion for one time scale provided an additional, implicit protection against violating a criterion assessed at one or more other time scales. U.S. EPA (2007a Appendix E) detailed advances and limitations in applying the logistic regression approach for Chesapeake Bay water quality standards assessments. Additional support was expressed for the continued development and eventual application of statistical approaches to assess short-duration dissolved oxygen criteria. The work of the Chesapeake Bay Program's Scientific and Technical Reporting Teams' Umbrella Criteria Assessment Team focused on advancing the use of spectral analysis to address the gaps in short-duration criteria attainment assessments . No further advances were made in applying logistic regression solutions to this issue.

Spectral analysis is a time series approach that was considered an alternative to logistic regression for potentially filling gaps in short-term DO criteria attainment assessments supporting Chesapeake Bay 303d water quality standards listing and delisting decisions (U.S. EPA 2007). The foundation for using spectral analysis to estimate DO concentration behavior at short time scales was published by Neerchal et al. (1992). The approach provided an analytical method for developing an estimate the behavior of high temporal density DO concentrations at a location where only low temporal density measurements were available. Spectral analysis, therefore, provided a potential option to effectively combine two types of water quality monitoring data: high frequency (temporally dense, e.g. sub-hourly to sub-daily) and low frequency (temporally sparse, e.g. biweekly to monthly) DO measurements. The resulting time series was considered to leverage the power of the two types of DO behavior information that are available through the Chesapeake Bay water quality monitoring program and enhance the power of the monitoring network for supporting DO criteria attainment assessments.

An early caveat to thoroughly testing the Neerchal et al. (1992) spectral analysis method for Bay water quality criteria attainment assessment applications was a lack of season long, temporally dense water quality monitoring data sets. With the advent of the Chesapeake Bay Program Shallow-water monitoring network in 2004, dozens of shallow-water sensors have now been used throughout Chesapeake Bay and its tidal tributaries to generate many season-long data records. Well over a million data points are now available. Measurements are derived from mostly nearshore and some offshore monitoring sites located across tidal fresh to polyhaline Bay and tidal tributary habitats.

Bay analysts demonstrated the technical feasibility of conducting spectral analysis to create temporally dense 'synthetic' DO concentration time series for a full summer season using the Chesapeake Bay Program DO data (U.S. EPA 2003a, 2007a, MRAT 2009). The method was modified for use by Bay analysts and termed "**Spectral casting**" (CBP-STAC 2012). With the new, robust data sets available, a more complete evaluation of the spectral casting application to dissolved oxygen criteria assessments was pursued by Chesapeake Bay Program partner analysts during the Umbrella Criteria Assessment (CBP-STAC 2012).

The **Umbrella Criteria Concept** was explored as an alternative to, or a complement of, adopting the statistical approaches to overcome gaps in assessing short-duration DO criteria in Chesapeake Bay. The idea of an umbrella criterion was borrowed from conservation biology's use of the term "umbrella species", first used by Wilcox (1984) and with additional applications over recent decades (Launer and Murphy 1994, Roberge and Per Angelstam 2004). Some scientists have found that the umbrella effect provides a simpler way to manage ecological communities (e.g., Dunk et al. 2006). Specific to Chesapeake Bay water quality criteria assessments for Clean Water Act water quality standards evaluations then, the single most protective DO criterion being measured was termed an "Umbrella Criterion". The condition of mutual criteria protection for multiple criteria by a single measured criterion meeting its standards threshold then was termed the "Umbrella Criterion Assumption". The Umbrella Criterion Assumption surmises that attainment of one dissolved oxygen criterion can serve as an "umbrella" assessment protective of the remaining dissolved oxygen criteria in a designated use. Demonstrating support for the application of the Umbrella Criterion Assumption using Chesapeake Bay water quality data could simplify assessment of multi-tiered dissolved oxygen water quality standards in Chesapeake Bay. Supporting evidence was needed to show that applying an umbrella approach can be used to effectively and simultaneously assess multiple criteria protections with a single DO assessment result.

U.S. EPA (2004) showed an initial assessment of multi-scale DO criteria protections by single criterion for Chesapeake Bay DO criterion attainment using multiple lines of evidence. The assessment demonstrated a strong but not exclusive relationship between achieving or not achieving criteria for the 30-day DO mean and 7-day DO mean (U.S. EPA 2004). U.S. EPA (2004) findings further recommended that for a majority of Chesapeake Bay Program management segments, dissolved oxygen concentration data collected through the monthly to biweekly sampling across the Chesapeake Bay long-term water quality monitoring program fixed-station network could be used to assess attainment of all higher frequency (i.e. short-duration) dissolved oxygen criteria. However, the Chesapeake Bay Program tidal Bay partners did not adopt this umbrella criterion approach into their water quality standards for addressing assessment of the short-duration dissolved oxygen criteria. Further demonstration and quantification of the umbrella approach to fully support the Clean Water Act Chesapeake Bay dissolved oxygen criteria assessments would be needed.

In the course of developing the Chesapeake Bay Total Maximum Daily Loads (TMDL), analysts at the USEPA's Chesapeake Bay Program Office (CBPO) conducted an assessment of how well DO criteria that are already measured with the current Chesapeake Bay Partnership's long term water quality monitoring program mutually protected the unmeasured, short-duration criteria (Shenk and Batiuk 2010). Using hourly output from a calibration run of the Chesapeake Bay Water Quality Sediment Transport Model (WQSTM), the CBPO analysts produced a summer season evaluation of the Umbrella Criterion Assumption. Note that for the purposes of developing the Chesapeake Bay TMDL, the summer season (June – September) is assumed to be the limiting season in all designated uses being assessed for DO impairment (i.e. Open Water, Deep Water and Deep Channel). CBPO analysts determined that evaluation of the 30-day mean DO criteria was sufficient to determine attainment of the open-water and deep-water designated uses of the Bay (Shenk and Batiuk 2010). Furthermore, in segments containing a Summer Deep Channel designated use (8 of the 92 segments in Chesapeake Bay), non-attainment rates of the summer instantaneous minimum DO criterion for the Deep Channel were higher than for any other criterion in the Open Water and Deep Water designated uses of the same segment. *Thus, the criteria currently being assessed by the Chesapeake Bay long term water quality monitoring program appear to be "**umbrella criteria**" – the most restrictive of all available criteria protective of the full range of criteria by designated use*.

These findings can have significant implications for monitoring and assessment of the full suite of dissolved oxygen water quality standards applicable to the Chesapeake Bay's tidal waters. Chesapeake Bay Program partners further requested additional testing of the umbrella criterion concept using Chesapeake Bay Program water quality monitoring data to validate the model-based results. The request led to the 2010-2012 "Umbrella Criteria Assessment" process. The Umbrella Criteria Assessment Team, a group of Chesapeake Bay community analysts under the Chesapeake Bay Program's Scientific, Technical Assessment and Reporting Team, was charged with providing further tests of the umbrella concept as well as any of the previously mentioned statistical approaches, and providing options and recommendations toward supporting assessments of short-duration dissolved oxygen standards attainment (CBP-STAC 2012).

CHESAPEAKE BAY WATER QUALITY DATA SUPPORTING DEVELOPMENT AND TESTING OF SHORT-DURATION DISSOLVED OXYGEN CRITERIA ASSESSMENTS

Quality assured, quality controlled water quality data sets were targeted by the Umbrella Criteria Assessment Team to conduct their method evaluations (Table 3). The nearly three decades-long Chesapeake Bay Program long-term water quality monitoring network data set formed the foundation of the low frequency monitoring data needs. During the U.S. EPA (2004) analyses evaluating umbrella-like DO criteria protection, the temporally dense, high frequency monitoring data sets were largely limited to U.S. EPA EMAP short-term buoy deployments (Table 2). At that time, season-long continuous dissolved oxygen monitoring data sets from tidal waters of Chesapeake Bay were not widely available. The focus on high frequency dissolved oxygen data collection was on the threshold of being incorporated into the new, shallow-water focused station network in an expanded Chesapeake Bay Program tidal Bay monitoring framework. In 2004, the Chesapeake Bay Program formalized this monitoring network expansion and invested in what is now known as the Shallow-water Monitoring Program. During the 2000s, Federal, State and local agencies along with academic institutions further made investments into nearshore and offshore water quality monitoring technologies. Application of the new technologies produced water quality time series with temporally dense dissolved oxygen measurements at fixed depth and in vertical profile. Alternative technologies were also attached to a boat at fixed depth or pulled behind a boat to get multiple depths over space with high resolution, underway monitoring efforts.

Table 3. Data sources serving the Umbrella Criterion Assumption analyses.

Program Description	Data Collection and Availability	Sampling Locations and Habitats
CBP long-term water quality monitoring program: Low temporal frequency and spatial spatial resolution, good vertical profile resolution of the data.	1985-present. Biweekly to monthly sampling. Water column profiles taken with grab samples and sensors. Web accessible data: *CBP CIMS* accessible.	Fixed site, mid-channel, Bay and tidal tributaries, approximately 150 stations. Covers tidal fresh to polyhaline habitat conditions.
USEPA EMAP: Historical short-term buoy deployments with high temporal frequency at a station. Single depth sensor evaluations.	Mix of short term (days to weeks) time series with high temporal frequencies by sensor. See USEPA (2004).	Fixed site, off shore locations, varied depths. Tidal fresh to polyhaline habitat conditions.

CBP Shallow Water Monitoring Program, **Con**tinuous **Mon**itoring (CONMON): High temporal frequency at moored locations.	Approximately 2000-present. Mostly seasonally, near continuous (15 min interval) time series April-October. Fixed depth sensor, usually 1m off bottom. Web accessible data: *Eyes on the Bay* in MD, *VECOS* in Virginia.	Fixed site, shallow water, nearshore locations, approximately 70 sites Baywide with 1-9 yrs of data. Tidal fresh to mesohaline conditions.
VIMS, MD DNR Vertical Profilers: High temporal frequency in 2 dimensions. **VIMS**: Bottom sonde .	Approximately 2006-present. Limited seasons. Sensors provide water column profiles at sub-daily scales. Bottom sonde. Web accessible data: MD DNR and VADEQ.	Fixed sites (n<5), offshore locations in MD (Potomac River) and VA (York and Rappahannock Rivers). Dominantly mesohaline lower tidal tributary data.
CBP Shallow Water Monitoring Program, surface water quality mapping with DATAFLOW: High Spatial resolution along temporally dense collection track.	Approximately 2000-present. Biweekly to monthly mapping assessments within April-October season. Multi-year assessments (3 yr sets). Sensor 0.5m below surface Web accessible data: *Eyes on the Bay* in MD, *VECOS* in Virginia.	Chesapeake Bay Program management segments. Approximately 40 of 92 segments assessed to date. Tidal fresh to polyhaline habitats.
VIMS Volumetric Assessment with ACROBAT (towed sensor underwater at variable depths). High spatial resolution -	Approximately 2003-present Limited seasons. 3-dimensional sensor assessment of water column water quality. *VIMS data*, Brush et al.	York and Rappahannock Rivers (VA) study sites, deep water reaches. Dominantly mesohaline habitat.

METHODS

ANALYSES SUPPORTING THE EVALUATION OF OPTIONS FOR ASSESSING CHESAPEAKE BAY SHORT-DURATION CRITERIA.

Multiple analytical methods were used to assess the validity of the umbrella criterion concept as a means of protect habitats with short-duration criteria using Chesapeake Bay Program water quality monitoring data. Several methods were evaluated for their utility in multi-scale DO concentration criteria assessment.

APPROACHES ASSESSING MUTUAL PROTECTIVENESS OF THE 30-DAY MEAN CRITERION FOR SHORT-DURATION (7-DAY MEAN, 1-DAY MEAN, INSTANTANEOUS MINIMUM) CRITERIA.

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

STATISTICAL ASSESSMENT OF HIGH FREQUENCY SHALLOW-WATER CONTINUOUS MONITORING DATA TO INFORM CRITERIA PROTECTION ACROSS TIME SCALES

Water quality standards nonattainment rates were computed directly from nearshore shallow water monitoring continuous monitoring data records or high frequency offshore vertical water quality profiler data using the range of Chesapeake Bay dissolved oxygen criteria attainment thresholds. Results were provided in table or graph formats (Appendix 2, 3)

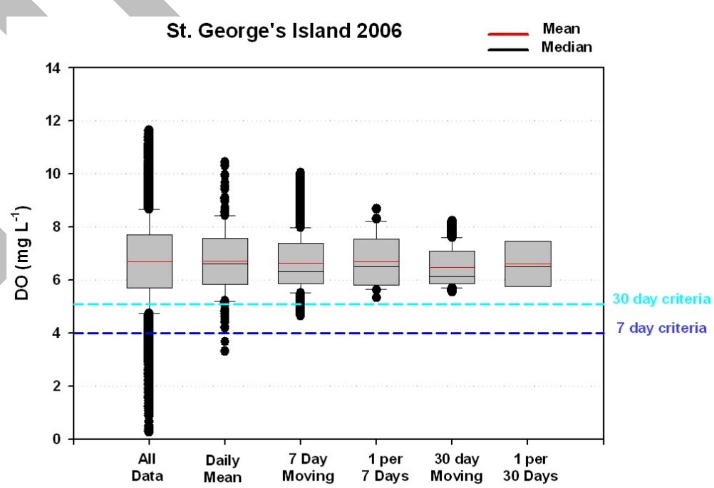

Figure X1,X2 examples.

BIPLOT ASSESSMENT OF COMPARATIVE PROTECTION FOR DIFFERENT TIME SCALES OF THE DISSOLVED OXYGEN CRITERIA

Plots were created that compared 30-day mean measurements on the X-axis with violation rates of a shorter duration criteria such as the 7-day mean on the Y-axis. The resulting graphics illustrated the coincident behavior of DO conditions at two temporal scales and allowed for an assessment of violation rate thresholds between those scales (Figure X1, X2). Sequential 30-day means and coincident short duration (e.g. 7-day) criteria means were computed from Chesapeake Bay water quality monitoring data for the summer season period (June-September). Sequential means are used under the current protocols of criteria attainment assessment. The use of rolling means within the context of the current Chesapeake Bay CFD criteria assessment procedures was examined by the Umbrella Criteria Assessment Team. However, the Team evaluation of both approaches supported continued use of sequential means and found rolling means to be inappropriate for use with the present CFD criteria assessment methodology. (Appendix 4).

Data used to generate the nonattainment rates were derived from high frequency near-continuous (i.e. every 15 minutes) data records of water quality sensors located in offshore (U.S. EPA 2004) and shallow water (CBP-STAC 2012) habitats. Open water designated use criterion thresholds were applied to the data to calculate the percent non-attainment. Means were computed based on the full record data set for a criterion period (e.g. 30-day, 7-day, 1-day). Unless otherwise noted, it is important to note that data were not sub-sampled to mimic the low frequency, biweekly to monthly, Chesapeake Bay long term water quality monitoring program sampling scheme.

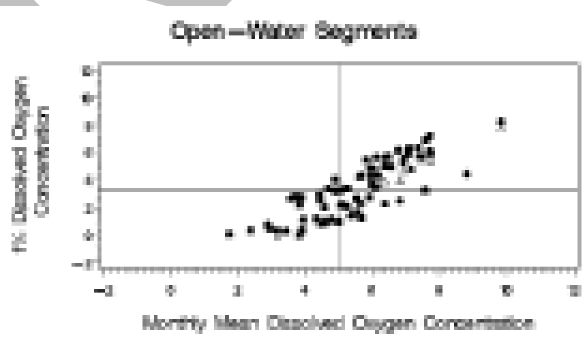

Fig X1. DRAFT! Example biplot examining mutual criteria protections between monthly mean measures and the 1% dissolved oxygen concentration as an estimate of instantaneous minimum. Graphic from U.S. EPA (2004), p53.

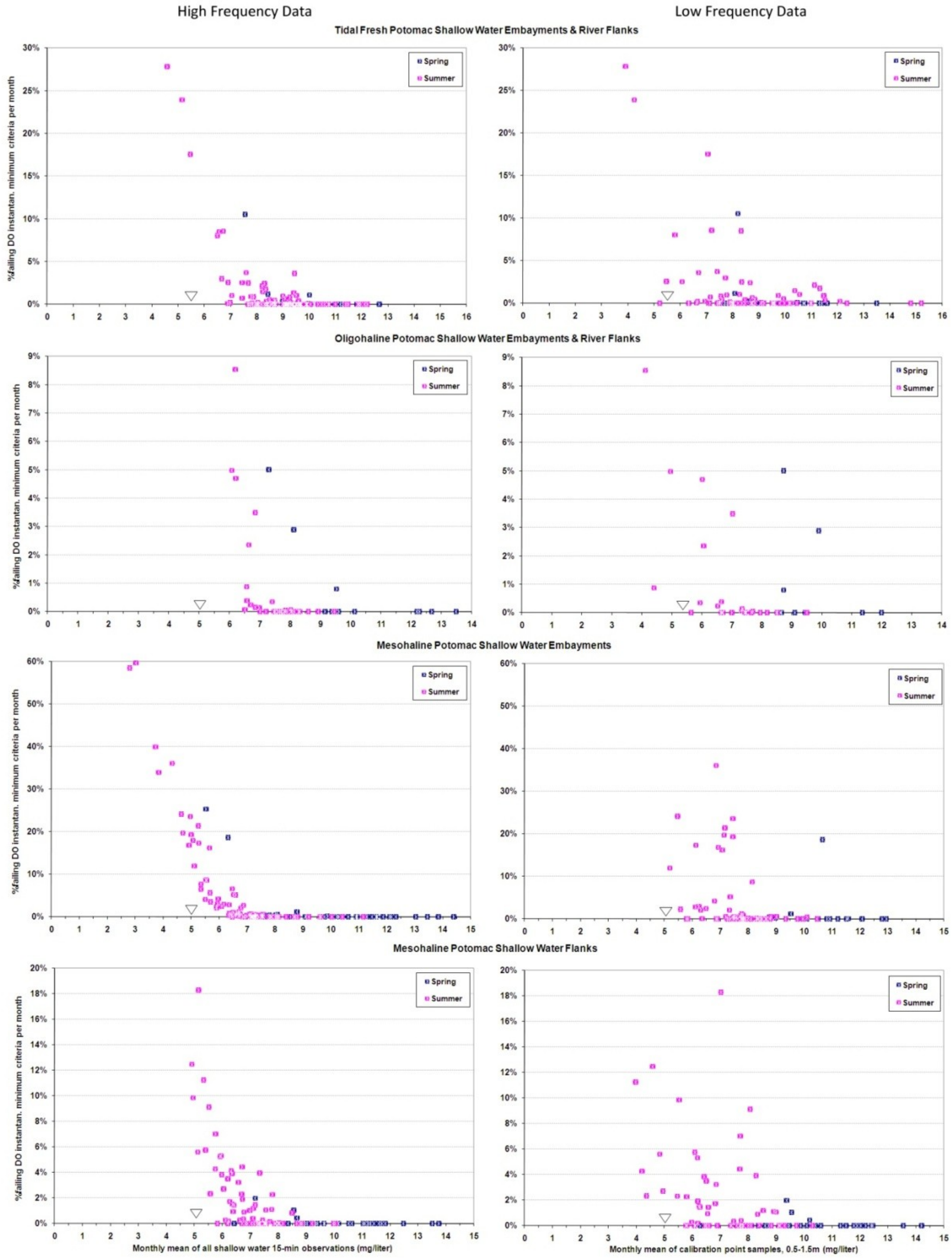

Figure X2. Example of biplots with frequency per month using rolling 7-day periods (1-day step) fail the 7-day mean DO criteria, plotted against the corresponding 30-day mean DO. Overall, 175 of the 415 months (42.2%) represented in the 20 tidal Potomac shallow water stations between 2004 and 2008 had failures of the instantaneous minimum DO criteria. Most instantaneous minimum criteria failures occurred in months where the 30-day mean criteria are met. (Appendix 4)

CONDITIONAL PROBABILITY ANALYSIS: PROTECTION OF THE 30-DAY MEAN FOR THE 7-DAY MEAN.

The method employed is based on the basic approach that if the variability of the 7-day mean dissolved oxygen concentration 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. To use this approach, an estimate of the standard deviation of the 7-day mean for dissolved oxygen about the 30-day mean is needed. To estimate this quantity, Potomac River Shallow water Continuous Monitoring data was used. Further details of methods are provided in Appendix 5.

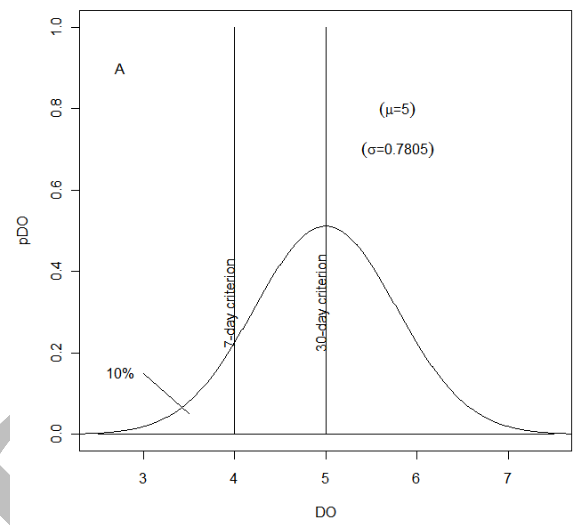

Figure 1. Illustration of the level of variability of the 7-day mean about the 30-day mean that results in up to 10 % violations of the 7-day mean criterion when the 30-day mean criterion is met.

A PARAMETRIC SIMILATION APPROACH TO ASSESSING THE UMBRELLA CONCEPT WHEN ASSESSING THE 30-DAY MEAN AND ITS ABILITY TO PROTECT THE OPEN WATER 7-DAY MEAN AND INSTANTANEOUS MINIMUM CRITERIA.

The basic approach of the simulation is to generate time series that have properties similar to observed DO concentration time series. Autoregressive (AR) modeling is a statistical technique that has been used to describe certain time-varying processes in nature. Perry (CBP STAC 2012) used a specific case of autoregressive models, an AR(2) model, for simulating Chesapeake Bay dissolved oxygen dynamics The data used for this exercise are the open water buoy data compiled by Olson (Chapter X in U.S. EPA 2004). To illustrate the level of protectiveness for short-duration criteria provided by a 30-day mean based on Bay specific data, the results were presented to show a gradient of monthly mean dissolved oxygen concentrations and the estimated level of criteria non-attainment for related 7-day mean and instantaneous minimums dissolved oxygen levels associated with a 30-day mean dissolved oxygen concentration. For details of the autoregressive modeling approach, refer to Appendix 6 in this document.

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

The Umbrella Criteria Assessment Team examined the additional uncertainty that is created by the use of small sample size to estimate DO 30-day means and further evaluated the consequences of this uncertainty for the application of the umbrella criterion concept. In many parts of the bay, the monthly mean is estimated from as few as one to two point observations per month by the Chesapeake Bay Partnership's long term water quality monitoring program. 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 protecting other criteria will diminish when the low sample size mean is employed. Appendix 7 provides details of the analysis approach.

METHOD TO ADDRESS HIGH FREQUENCY DATA NEEDS IN TEMPORALLY SPARSE DATA LOCATIONS

SPECTRAL CASTING AS A METHOD FOR GENERATING HIGH FREQUENCY DATA AT MONITORING STATIONS WITH LOW FREQUENCY WATER QUALITY MONITORING.

The synthesis of a temporally dense, high frequency dissolved oxygen data set (e.g., every 15 minutes to 1 hour time step) for a low frequency, fixed station monitoring location (e.g., tidal water, mid-channel Chesapeake Bay Program monitoring network sites, generally biweekly sampling in the summer season) is one potentially new step in the Chesapeake Bay dissolved oxygen criteria assessment process to support short-duration criteria assessments. Season-long, high frequency vertical profiles of water quality in offshore habitats of Chesapeake Bay are rare (e.g. VIMS York and Rappahannock River locations, MD DNR Potomac River). In lieu of not having high frequency vertical profile measurements of water quality conditions for most regions of the Bay and its tributaries, an estimated time series could potentially help fill the gap in short time-scale dissolved oxygen assessment needs. Mid-channel locations without high frequency monitoring profiling technology could now be linked in the spatial assessments of water quality using temporally dense measurements of nearshore water quality conditions, a complement to these coincidently available continuous monitoring data records. The resulting data sets could be used to interpolate the dissolved oxygen patterns from shoreline to shoreline or shoreline to management segment boundary. Enhanced temporal resolution would provide decreased uncertainty in time and improve spatial resolution for estimating patterns in dissolved oxygen concentrations giving the Chesapeake Bay partnership the capacity to better assesses short-duration criteria. The approach was recommended for further evaluation (U.S. EPA 2003a, 2007a).

Between 2010 and 2012, the Umbrella Criteria Assessment Team conducted analyses validating a modified use of spectral analysis, i.e. spectral casting, for developing high frequency dissolved oxygen time series at monitoring sites where only low frequency (biweekly to monthly) monitoring data exists in Chesapeake Bay and its tidal tributaries (Appendix 1). The approach provides a method to statistically transfer information about the variation in dissolved oxygen behavior at short time scales from a location with high frequency measurements (e.g. nearshore, continuous monitoring stations) to fill in or estimate dissolved oxygen behavior at a different location where measurements are more temporally sparse.

Three elements of the spectral casting method were evaluated and validated: 1) statistical methods to pass information about water quality behavior between monitoring sites, 2) assessing the ability of the new, estimated dissolved oxygen data to match actual, dissolved oxygen patterns measured in high frequency at one depth offshore locations, and 3) assessing the results of spectral casting outputs to match details of measured, high frequency vertical water column patterns in dissolved oxygen concentrations at offshore locations. Addressing the first element involved evaluating multiple statistical approaches for passing information about dissolved oxygen behavior from a temporally dense, high frequency data location (e.g. a continuous monitoring sensor) over to a temporally sparse data location (e.g., Chesapeake Bay tidal monitoring network mid-channel monitoring stations). Applying the processes create the new, estimated high frequency dissolved oxygen records at the temporally sparse data locations (U.S. EPA 2003a, 2007, Appendix 1). The temporal interpolation methods evaluated for this potentially new step in the criterion attainment assessment process were Fast Fourier Transformation (FFT), cubic spline and linear approaches. Benefits of FFT interpolation is that it is computationally fast, allows cycle trimming, deals with cyclical prediction and preserves autocorrelation structure in the data. Limitations to FFT include meeting assumptions of cyclical behavior, a need for equally spaced inputs in time and equally spaced outputs. By comparison the cubic spline and linear interpolation approaches had fewer implementation constraints.

The second and third elements of spectral casting evaluations by the Umbrella Criteria Assessment Team used the new, estimated (i.e. ‘synthesized’) high frequency dissolved oxygen concentrations time series to compare with the actual time series of the offshore

Chesapeake Bay monitoring locations. A small number of highly valuable, high frequency vertical profiler stations collecting continuous water quality measurements provided the support needed to inform the results (e.g York River, Rappahannock River, Potomac River). Comparisons of dissolved oxygen violation rates were made between synthesized and measured time series, and sources of uncertainty in estimating the offshore time series for dissolved oxygen concentrations were assessed.

APPLYING ANALYSIS OUTCOMES TO INFORM OPTIONS FOR SUPPORTING MONITORING AND ASSESSMENT OF CHESAPEAKE BAY SHORT DURATION DISSOLVED OXYGEN CRITERIA.

Umbrella Criteria Approach: 30-DAY mean criterion protection of short-duration (7-day mean, 1-day mean and instantaneous minimum) dissolved oxygen criteria

An Umbrella Effect exists between the 30-day mean criterion and shorter-duration criteria in Chesapeake Bay. To apply the Umbrella Criterion Approach:

- *the sampling effort (e.g., 2x month, weekly, daily, hourly) used to estimate the mean for comparison with the dissolved oxygen criterion being used as the Umbrella Criterion (e.g., 30-day mean summer open water criterion) must be accounted for, and*
- *analyses showed that means need to be greater than the stated dissolved oxygen criteria in order to fully express the level of protection, i.e. level of risk for nonattainment, provided for an unmeasured, shorter-duration criterion (i.e. 7-day mean, 1-day mean, instantaneous minimum).*
    - *Data variability affects the threshold*

For example, if the Chesapeake Bay Open Water 30-day mean dissolved oxygen criterion is satisfied by meeting the criterion threshold of 5.0 mg O_2/L, the Umbrella Criteria Assessment Team showed that there is less than a 10% chance that the 7-day dissolved oxygen criterion will be violated by the weekly mean (Figure X). However, it is necessary to understand that this particular result is based on having very accurate estimates of both the monthly mean and the weekly mean derived from near continuous, high temporal frequency time series of dissolved oxygen concentrations in Chesapeake Bay (i.e Continuous Monitoring sensor data sets of Shallow-water Monitoring Program).

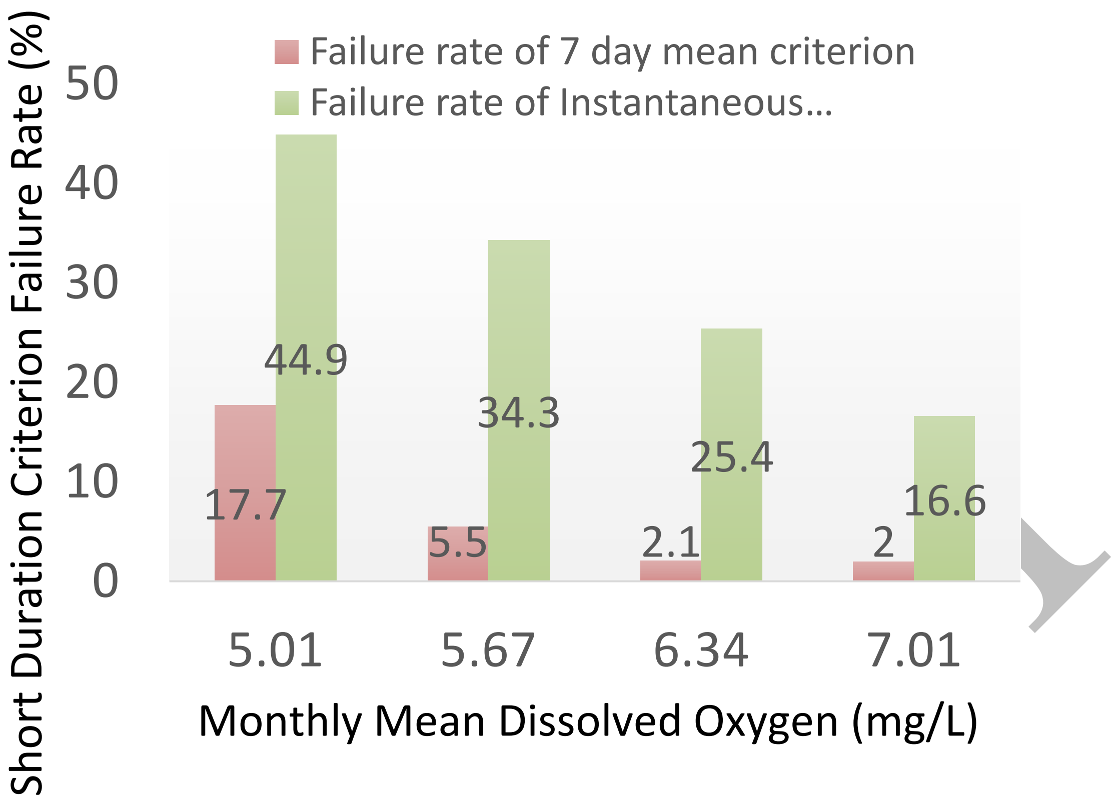

Figure X. Summary of violation rates over levels of sensor depth to illustrate time series violations associated with a gradient of open water 30-day means in dissolved oxygen. Results were derived from high frequency sensor data at depths of 6,5,4,3 m respectively.

By comparison, in the practice of conducting Chesapeake Bay dissolved oxygen criteria attainment assessments, the 30-day mean dissolved oxygen concentration is estimated from as few as one to two point observations per month under the existing Chesapeake Bay long-term, fixed station water quality monitoring program. The uncertainty of estimating the monthly mean dissolved oxygen concentration using so few observations is much greater than the uncertainty of a monthly mean from near continuous sensor data. The impact of small sample size is to weaken the Umbrella Effect (Table X below).

Without offshore, high frequency water quality profile data to compensate for the uncertainty of low sample size in estimating the 30-day mean, dissolved oxygen thresholds were developed. The dissolved oxygen thresholds are higher than the 30-day mean criterion. As the measured mean from two samples gets higher above the 30-day criterion, the ability to insure protection of short-duration criteria improves.

Table X. Estimates of risk of violating the 7-day criterion given the monthly mean estimate (column 1) and four levels of sampling variation (column 3). 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 estimates.

	Risk of violating 7-day criterion	
Monthly Mean DO	Near True Risk based on high frequency data	Small Sample Risk on Nonattainment SD=1.7358[2] SD=1.6054[3] SD=1.9287[4]
5.0	16%	27%-30%
5.1	14%	25-28%
5.2	12%	23-27%
5.3	10%	21-25%
5.4	8%	19-24%
5.5	7%	18-22%
5.6	6%	16-20%
5.7	5%	14-19%
5.8	4%	13-18%
5.9	3%	12-16%
6.0	2%	11-15%
6.1	2%	10-14%
6.2	1%	9-13%
6.3	1%	8-12%
6.4	<1%	7-11%
6.5	<1%	6-10%

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

SPECTRAL CASTING VALIDATION: USE NOT RECOMMENDED

Results showed that *application of the spectral casting technique to address short-duration criteria attainment assessment needs for the Chesapeake Bay DO criteria is limited by the large uncertainty of the low frequency sampling used by the Chesapeake Bay long-term water quality monitoring program network*. Validation tests for introducing estimated temporally dense, high frequency DO concentration time series at mid-channel water quality monitoring sites as a potentially new step in DO criteria attainment assessments is not recommended. The Umbrella Criteria Assessment Team tests showed application of variations available within the spectral casting method process were technically feasible to implement by Bay analysts (CBP-STAC 2012). Linear interpolation provided a better fit than FFT or cubic spline methods in the comparisons. The technical capacity to apply the technique to Chesapeake Bay water quality criteria assessments was not a limitation. The results demonstrated the continuing need for high temporal density water quality profile data rather than hybrid data via spectral casting to support accurate water quality criteria assessments.

Comparisons were made between estimated and measured dissolved oxygen conditions for an offshore monitoring site in the York River. The Umbrella Criteria Assessment Team found that dissolved oxygen varied similarly on a weekly scale. However, 24-hour periodicity was found to explain more dissolved oxygen variability in the time series and this time scale of comparison for nearshore and offshore dissolved oxygen patterning was not supported using the spectral casting approach.

INSTANTANEOUS MINIMUM ASSESSMENTS UNDER A 3-ZONE SUBSEGMENTATION OPTION (under TMAW/CAP review)

The Chesapeake Bay Program's Scientific and Technical Assessment and Reporting Team's Umbrella Criteria Assessment Team in conjunction with the Criteria Assessment Protocol Work Group and the Tidal Monitoring and Assessment Workgroup recommended a 3-zone option to support partial or complete Clean Water Act 303d impairment assessments (see chapter iv, *Instantaneous Minimum Dissolved Oxygen Criterion Framework: A Subsegmentation Option*, this document). Decisions to make separate zone assessments as subsegments of existing Chesapeake Bay management segments with coordinated approval between Bay state jurisdictions and U.S. EPA are supported by the differential behavior of dissolved oxygen in shallow water related to their juxtaposed habitats of open water mainstem Bay or major tributary compared with subestuaries off these primary water bodies. Data density and understanding of habitat conditions differs across the Bay habitats. The following recommendations address assessment in the 3-zones suggested for instantaneous minimum criteria attainment evaluations:

- Zone 1: Offshore. Subject to the Open Water designated use assessment of the instantaneous minimum. As recommended in chapter iv, enhanced monitoring to support high temporal density water quality profiles or the application of an Umbrella Criterion approach provide support for the Offshore habitat assessment using the 3-year CFD assessment.

- Zone 2: Subsegment a nearshore zone adjacent to open water. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdiction.
  - Use 3 seasons of continuous monitoring data (15 minute intervals).
  - One or more sites can be used.
  - Assess the time series at a **1% allowable exceedance level**, substituting a 10x lower allowable exceedance rate as compensation for the reduction in spatial coverage in a Chesapeake Bay management segment.

- Zone 3: Subsegment subestuaries off the mainstem tributaries and Bay. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdiction.

        - These small, shallow habitats are the least well studied and described for high frequency dissolved oxygen dynamics but have historical perspective from state monitoring programs (e.g. Virginia DEQ).
        - Use discrete monitoring, minimum of 10 samples per year, for 3 years, 10% allowable exceedance assessment with the minimum of a single site as representative of the subestuary water quality condition.

SUMMARY

MONITORING AND EVALUATION OPTIONS FOR ASSESSING SHORT-DURATION DISSOLVED OXYGEN CRITERIA ATTAINMENT

The Umbrella Criteria Assessment Team findings point to two primary monitoring options for assessing Chesapeake Bay short-duration water quality criteria. Further recommendations are provided by the Criteria Assessment Protocol Work Group supported by Tidal Monitoring and Assessment Workgroup specific to the Instantaneous minimum:

- *Enhanced Monitoring Approach*: Measure water quality profiles at high frequency using any one or an assortment of methods (e.g. depth transect of meters, water quality profiler, Underwater Autonomous Vehicles, etc.) and increased spatial resolution. Evaluate the high resolution data against the suite of water quality criteria using the present CFD Chesapeake Bay water quality criteria attainment assessment methods.
    - *Criteria assessment gaps filled*: 7-day mean, 1-day mean, instantaneous minimums.

- *Umbrella Criterion Approach- A Risk-based Assessment*:
    - *Existing Chesapeake Bay Partnership long-term water quality monitoring program sampling strategy:* Define and apply an acceptable risk (e.g. 10%) associated with meeting multiple criteria in a designated use when using the single 30-day mean criterion assessment under the present Chesapeake Bay Partnership long-term water quality monitoring program sampling strategy, or
        - *Decision rule: for each month of the 30-day mean 3-year 303d listing assessment, all cells in the interpolated surface must equal or exceed the 30-day mean value necessary to meet the 30-day mean plus the 30-day threshold value necessary to demonstrate water quality risk of nonattainment of a shorter duration criterion less than or equal to the acceptable risk (e.g. 10%).(Note: Rule under review).*

    - *Enhanced Monitoring Strategy*: Employ nearshore and offshore sampling strategies that collect high temporal frequency data and capture DO behavior throughout the water column for computing the 30-day mean assessment. Meeting the 30-day mean based on high frequency data (e.g. 15 minutes to 1 hour time steps) was shown to effectively lower the risk of violating the short-duration criteria protections assumption for 7-day mean when the 30-day mean meets the water quality standards criterion. However, when meeting the 7-day mean there remained a greater risk of violating the instantaneous minimum. Therefore, either a threshold for an acceptable level of risk for meeting the instantaneous minimum can be defined, or higher temporal and spatial density monitoring can be conducted.

- Instantaneous minimum alternative assessment: three subsegmentation zones.
  - Zone 1: Offshore. Subject to the Open Water designated use assessment of the instantaneous minimum. As recommended in chapter iv, enhanced monitoring to support high temporal density water quality profiles or the application of an Umbrella Criterion approach provide support for the Offshore habitat assessment using the 3-year CFD assessment.

  - Zone 2: Subsegment a nearshore zone adjacent to open water. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdiction.
    - Use 3 seasons of continuous monitoring data (15 minute intervals).
    - One or more sites can be used.
    - Assess the time series at a **1% allowable exceedance level**, substituting a 10x lower allowable exceedance rate as compensation for the reduction in spatial coverage in a Chesapeake Bay management segment.

  - Zone 3: Subsegment subestuaries off the mainstem tributaries and Bay. Subsegmentation boundary for a management segment is to be agreed upon on a case-by-case basis between U.S. EPA and the tidal water jurisdiction.
    - These small, shallow habitats are the least well studied and described for high frequency dissolved oxygen dynamics but have historical perspective from state monitoring programs (e.g. Virginia DEQ).
    - Use discrete monitoring, minimum of 10 samples per year, for 3 years, 10% allowable exceedance assessment with the minimum of a single site as representative of the subestuary water quality condition.

The Umbrella Criteria Assessment Team results (CBP-STAC 2012) support the U.S. EPA (2004) recommendation that site-specific buoy deployments may be necessary to either better quantify a relationship or assess attainment. U.S. EPA (2007a) also suggested collection of continuous measures of dissolved oxygen to resolve gaps in assessing short-duration dissolved oxygen criteria with statistical options that included logistic regression and time series analysis (i.e. spectral analysis) . As demonstrated through evaluation of the spectral analysis approach, statistically filling in the gaps in the need for high frequency data at long term monitoring sites is limited by the uncertainty introduced from estimating the 30-day mean dissolved oxygen conditions from one or two samples. Logistic regression remains a viable option acknowledging the strengths of the approach expressed in U.S. EPA (2007a) but with its limitations that are also linked to the temporal frequency of data available at the long term fixed station monitoring locations. An additional refinement of the recommendation for site specific buoy deployments is to target management segments near attainment with limited resources available for obtaining high frequency water quality profiles to support short-duration criteria assessments.

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chapter vii

Interim Rules for Water Quality 303d Listing Status Using the Chesapeake Benthic Index of Biotic Integrity to Support Aquatic Life Use Assessments.

BACKGROUND

The Chesapeake Bay benthic community restoration goals and the benthic index of biotic integrity (B-IBI) by which goal attainment is measured were developed in 1997 by Weisberg et al., and are today standard tools in management decision making. The B-IBI is used to assess and monitor trends in Chesapeake Bay health, report condition for impaired waters assessments under the Clean Water Act (305b reports), support ambient water quality criteria development and assessment, and characterize benthic condition in tributary basins to assist in setting restoration goals. In cooperation with EPA Region III, the Chesapeake Bay Program tidal Bay and tributary partners of Maryland, Virginia, DC and Delaware employ the Bay estuarine aquatic life use assessment methodology with estuarine benthic community biological (B-IBI) data. This methodology assures Bay-wide consistency in determinations of estuarine benthic impairments.

Sample size requirements are $n \geq 10$ to effectively apply the B-IBI assessment for aquatic life use assessment of Chesapeake Bay management segments. A 6-year assessment window is used to assist with meeting the minimum sample size requirement. This data window corresponds with data windows used, for example, in Virginia when assessing other non-Chesapeake Bay water quality criteria. The spatial assessment units for determining attainment of the general standard for aquatic life use using benthic community data are described in "*Chesapeake Bay Program Analytical Segmentation Scheme-Revisions, Decisions and Rationales: 1983 -2003,* CBP/TRS 268/04. Chesapeake Bay Program, Annapolis, Maryland" with the additional caveat that minor tidal tributaries are considered separate benthic assessment segments.

The B-IBI assessment methodology that is applied to water quality standards attainment status classifications of the aquatic life designated use in Chesapeake Bay tidal waters and its tidal tributaries incorporates uncertainty in the reference condition and is based on the confidence limit and bootstrap simulation concept described in Alden et al. (2002). Bootstrap simulation (Efron and Tibshirani 1998) is applied to incorporate uncertainty in reference conditions as well as sampling variability in the assessment data. For each habitat, a threshold based on percentiles in an unimpaired reference data set will be applied (i.e. 5th percentile). This threshold is not intended to serve as criteria for classifying individual B-IBI scores, rather it is used to categorize the segment as impaired or not based on the proportion of samples below the threshold and the variance associated with this estimate (see *Draft Guidance for 2014 IR Assessment Methodology* 25).The impairment assessment for each segment is based on the proportion of samples below the threshold with the variance in this proportion estimated by simulation. In each simulation run, a subset of the reference "unimpaired" data for each habitat is selected at random, and the threshold is determined (i.e., the B-IBI score at the 5th percentile of the un-impaired dataset). A random subset of the assessment data is compared to the threshold value to estimate the proportion of sites below the threshold. By repeating this process over and over again (2000 runs) an estimate of the variance in the proportion of sites below the threshold is derived from the bootstrapped estimates. For this analysis, it is assumed that each reference 'un-impaired" data set (by habitat) is a representative sample from a "super population" of reference sites. The assessment result for each benthic segment (i.e. % of area with IBI score below 5th percentile threshold) is then statistically compared ($p<0.05$) with the percentage that would be expected even if the segment is unimpaired.

Water Quality Status Classifications

EPA encourages States/Tribes to use a five-category system for classifying all water bodies (or segments) within its boundaries regarding the waters' status in meeting the State's/Tribe's water quality standards. The categories are listed below. The classification system uses designated uses as the basis for reporting on water quality. Table 1.

Table 1. U.S. EPA 5-category system for classifying water quality status used as the basis for rerporting water quality for Clean Water Act section 303d listing assessments.

Classification Category for Water Quality Status	Description
Category 1	All designated uses are supported, no use is threatened.
Category 2	Available data and/or information indicate that some, but not all, designated uses are supported.
Category 3	There is insufficient available data and/or information to make a use support determination.
Category 4	Available data and/or information indicate that at least one designated use is not being supported or is threatened, but a TMDL is not needed.
• Category 4a	A State developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination.
• Category 4b	Other required control measures are expected to result in the attainment of an applicable water quality standard in a reasonable period of time.
• Category 4c	The non-attainment of any applicable water quality standard for the segment is the result of pollution and is not caused by a pollutant.
Category 5	Available data and/or information indicate that at least one designated use is not being supported or is threatened, and ***a TMDL is needed***.

The waters from Category 5 constitute the federal Clean Water Act Section 303(d) list of impaired or threatened waters within the State/Tribe's boundaries. EPA developed the multi-category classification system to help States/Tribes to report on incremental progress toward attaining water quality standards. States/Tribes may establish additional subcategories to refine their classifications further. For example, under Category 3, subcategories could be used to distinguish between segments for which no data/information is available and segments for which data/information is available but insufficient for making a use-support determination.

The following chapter addresses the need for interim rules in Chesapeake Bay Aquatic Life water quality status assignments using the Chesapeake Bay B-IBI output information while work progresses toward pending recalibration of the B-IBI.

Interim Rules for Chesapeake Bay Aquatic Life Use Water Quality Status:

Recent Section 303d Chesapeake Bay tidal water aquatic life designated use assessments showed several segments that were classified as unimpaired based on the B-IBI, however, they expressed two characteristics of concern: 1) a low mean IBI score (<2.7) and 2) high variability in scores producing wide confidence intervals on the B-IBI segment assessment. The Criteria Assessment Protocol Workgoup considered these results in the context of B-IBI development history. The B-IBI was last validated for tidal freshwater and oligohaline habitats by Alden et al. (2002). However, the paucity of data available at that time made the index less robust in the tidal freshwater and oligohaline regions than in the more saline habitats of the (R. Llanso, VERSAR Inc., and D. Dauer, Old Dominion University, Pers. Comm.). In addition, some performance issues have been identified throughout the years (R. Llanso, VERSAR Inc., and D. Dauer, Old Dominion University, Pers. Comm.):

1. When applied to small bays, correct classification levels are lower than those of the initial calibration effort.
2. Differences in pollution indicative and pollution sensitive species lists have been identified among the different salinity habitats, which affect index performance depending to which salinity habitat the index is applied.
3. Low mesohaline regions with abundant clam beds are very productive. The B-IBI biomass metric receives a "1" for excess biomass, but in these regions excess biomass is a desirable property of the community and thus thresholds need adjustment for these regions.
4. Benthic communities respond differently to low dissolved oxygen and sediment contaminants. Diagnostic approaches have been developed to determine sources of anthropogenic stress; however large data sets that were unavailable to Weisberg et al. can be used today to calibrate the B-IBI.

The Criteria Assessment Protocol Workgroup recognized that most of these issues were under review. A revision process was being initiated in 2014. Until the above issues were fully addressed and published updates to the B-IBI assessment protocol available for adoption into water quality standards by Chesapeake Bay Program partners, interim rules for better water quality status categorization of management segments were proposed. The rules addressed the most inconsistent, unreliable status classifications. To develop the rules, the Criteria Assessment Protocol Workgroup considered the characteristics of B-IBI results used to classify the status of Chesapeake Bay Management segments aquatic life designated use. Specific considerations focused on the B-IBI score and variability associated with the confidence intervals on the score. The Criteria Assessment Protocol Workgroup used the difference of 0.5 B-IBI units between confidence interval limits on a segment score as decision threshold for defining segments where the score deserved further investigation. This magnitude of the confidence limit on the B-IBI was consistent with high variability in segments scores. Second, high variability coincident with a mean B-IBI score of 2.7 was used as a threshold because this value was typical threshold for impairment.

The resulting rules for Chesapeake Bay B-IBI aquatic life designated use assessment, agreed upon by the U.S. EPA CBPO Criteria Assessment Protocol Workgroup and approved by the Water Quality Goal Implementation Team in 2013 is:

- For segments where “Impaired = No” identify those segments that have a breadth of confidence limits (Upper confidence Limit - Lower confidence Limit ≥ 0.5) of .5 or greater. Of that remaining subset of segments, those that have a Mean BIBI <2.7 would be classified as Category 3 (insufficient information) until more conclusive information is available.
    - Virginia refines this rule classification further such that a segment will be classified as Category 3B when the analysis suggests non-impairment but the difference between the upper and lower 95% confidence limits equals or exceeds 0.5 and the average BIBI score is less than 2.7, or, when the number of sites sampled during the six-year data window is less than 10, (i.e. where some data exist but are insufficient to determine support of the designated uses).

A revision of the water quality standards classification table for Chesapeake Bay assessments is provided (Table 2).

The application of this rule affects four segments in the most recent 303d listing assessment: In Virginia it is the Corrotoman Mesohaline (CRRMH), South Branch Elizabeth Mesohaline (SBEMH), and York River Polyhaline (YRKPH). In Maryland it is the Sassafras River Oligohaline (SASOH). These four segments will now be classified as Category 3B.

Table 2. Updated application of U.S. EPA 5-category system for classifying Chesapeake Bay aquatic life use water quality status as the basis for reporting water quality for Clean Water Act section 303d listing assessments.

Classification Category for Water Quality Status	Description
Category 1	All designated uses are supported, no use is threatened.
Category 2	Available data and/or information indicate that some, but not all, designated uses are supported.
Category 3	**All jurisdictions: There is insufficient available data and/or information to make a use support determination.**
• Category 3a	• **VA: no data are available within the data window of the current assessment to determine if any designated use is attained and the water was not previously listed as impaired.**
• Category 3b	• **VA: some data exist but are insufficient to determine support of designated uses. Such waters will be prioritized for follow up monitoring, as needed.**
• Category 3c	• **VA: data collected by a citizen monitoring or another organization indicating water quality problems may exist but the methodology and/or data quality has not been approved for a determination of support of designated use(s). These waters are considered as having insufficient data with observed effects. Such waters will be prioritized by DEQ for follow up monitoring.**
• Category 3d	• **VA: data collected by a citizen monitoring or other organization indicating designated use(s) are being attained but the methodology and/or data quality has not been approved for such a determination.**
Category 4	Available data and/or information indicate that at least one designated use is not being supported or is threatened, but a TMDL is not needed.
• Category 4a	• A State developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination.
• Category 4b	• Other required control measures are expected to result in the attainment of an applicable water quality standard in a reasonable period of time.
• Category 4c	• The non-attainment of any applicable water quality standard for the segment is the result of pollution and is not caused by a pollutant.
Category 5	Available data and/or information indicate that at least one designated use is not being supported or is threatened, and ***a TMDL is needed***.

Future recommendations:

As mentioned above, the B-IBI was last validated for tidal freshwater and oligohaline habitats by Alden et al. (2002). Further, the Chesapeake Bay Program partnership recognizes additional B-IBI assessment performance issues that have been outlined should be addressed to provide greater robustness to water quality standards impairment status classifications of the Chesapeake Bay tidal water aquatic life designated use. The following suggestions are proposed to address these issues by recalibrating the B-IBI. A recalibration effort will require several steps:

1. Acquire new data sets that have become available since the development of the B-IBI, such as MAIA, NOAA Status & Trends, and NCCA data sets.
2. Evaluate the new biological and contaminant data sets for completion, taxonomic consistency, consistency in sample identifiers, uniformity in units of measure, and relevance to project objectives.
3. Reevaluate reference ranges with new reference data.
4. Adjust thresholds and evaluate the performance of new metrics, such as new pollution indicative and sensitive species metrics.
5. Conduct sensitivity and reliability tests using the new metrics and thresholds.
6. After recalibration, compare open waters and creeks, and the new versus the old results by segment, stratum, and salinity regions. Readjust thresholds as necessary

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chapter viii

Monitoring To Support The Assessment of Chesapeake Bay Water Quality Criteria Attainment:

Protocol for Incorporating Nontraditional Partner Data Into Regulatory Chesapeake Bay Dissolved Oxygen Criteria Attainment Assessments

BACKGROUND

Data collection, assessment and interpretation are inextricably linked with water quality criteria that define a water quality standard. U.S. EPA (2003a) defines the Chesapeake Bay dissolved oxygen, water clarity and chlorophyll a criteria supporting water quality standards in tidal waters of Chesapeake Bay. The five refined designated uses are further described and implementation procedures to support assessment of the designated uses are provided. Assessment of the water quality standards was described according to a monitoring program framework that, at that time, relied on the Chesapeake Bay fixed-station water quality monitoring program. The Chesapeake Bay Program partnership's long term water quality monitoring network is a mid-channel station network with Bay-wide coverage, however, it was acknowledged that there were temporal and spatial limitations in supporting the range of water quality criteria assessments needed.

The dissolved oxygen criteria attainment assessment presently relies on the cumulative frequency distribution method (U.S. EPA 2003a) to assess Bay conditions against the water quality standards. The method uses the mid-channel fixed station water quality profiles data from each station and extrapolates measurements through a method of interpolation between stations across the Bay and its tributaries to get a 3-dimensional evaluation of dissolved oxygen conditions.

Data in the Chesapeake Bay long term water quality monitoring program are collected 1-2x per month. The dissolved oxygen criteria have temporal scales from instantaneous to 30-day means and are spatially assessed shore to shore and throughout the water column. U.S. EPA recognized monitoring needs to support the water quality standards attainment assessments were more varied than the program had in place at the time the criteria were developed and defined monitoring capacities as "recommended", "adequate" and "marginal" (pp 179-180 in U.S. EPA 2003a).

The application of shallow water monitoring capacities for Chesapeake Bay water quality criteria assessment were evolving with the availability and implementation of new monitoring technologies in Chesapeake Bay tidal waters through the 1990s and early 2000s (see *Evolution of shallow water monitoring programs and related science in Chesapeake Bay*, in chapter iii, *Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats: Considerations Supporting* *the Management Structure of the Open Water Designated Use,* this document**).** In 2004 a shallow water monitoring program was formally added to the Chesapeake Bay Program partnership's long term fixed station water quality monitoring network. The shallow water enhancement to the monitoring network provided greater spatial resolution to support water quality assessments and address a long standing gap in knowledge about water quality conditions in nearshore habitats. Specifically, calibration samples from the nearshore fixed station and offshore DATAFLOW monitoring elements of the shallow water monitoring program are presently included in the 30-day mean dissolved oxygen criteria attainment assessments. These samples provide greater spatial resolution of habitat conditions in a segment. The interpolation of these additional data then better reflect the variability in dissolved oxygen than mid-channel data can provide on their own.

The Chesapeake Bay Program partnership recognizes there are additional data needs to improve the accuracy of water quality standards attainment assessments. Frequent differences in the behavior of dissolved oxygen dynamics across nearshore and offshore habitats have been characterized in the recent analyses of the Chesapeake Bay Program's Umbrella Criteria Assessment Team (see Chapter iii *Dissolved Oxygen Dynamics of Nearshore and Offshore Habitats: Considerations Supporting the Management Structure of the Open Water Designated Use*, this document). Greater spatial resolution of assessments therefore remains desirable. Coincidently, short-duration criteria assessment would further benefit from the combination of high frequency water quality profiles with high temporal density in deep waters paired with similar high temporal density measures of habitat conditions in shallow waters.

U.S. EPA (2003a) recognized that some monitoring options are beyond the resources available to implement on a bay-wide scale. However, the Chesapeake Bay Program partnerships water quality monitoring program review (MRAT 2009) highlighted a range of monitoring alternatives to consider in expanding its data collection efforts to support water quality criteria attainment assessments for Chesapeake Bay and its tidal tributaries. Technology costs continue to decline and monitoring of the Chesapeake Bay has seen a proliferation of sensor deployments collecting season-long, high temporal density time series primarily in nearshore habitats. DATAFLOW has been surface mapping water quality since 2003. In 2013, there are multiple NOAA surface water sensing buoys, a single bottom sensor at Gooses Reef, and there three State supported water quality monitoring profilers operating to collect high frequency measurements in the tidal waters of the Bay and its tributaries. MRAT (2009) went on to identify nearly 300 water quality and living resource programs across the Bay and Basin that might be leveraged to improve water quality assessments. The MRAT-defined programs were outside of the traditional Chesapeake Bay tidal water jurisdiction's Clean Water Act grant-funded, long-term water quality monitoring programs. As of 2014, a small subset of these nontraditional partner programs is already contributing water quality monitoring data used in Clean Water Act 303d impairment listing assessments (e.g. Alliance for the Chesapeake – Virginia, South River Federation – Maryland,). A further subset of these nontraditional monitoring programs may be viable as additional partnering opportunities. Water quality monitoring data contributions of sufficient integrity to meet U.S. EPA standards can be used to expand the spatial and temporal coverages in tidal water quality monitoring programs. Such programming expansion can help better meet "recommended" levels of tidal water quality monitoring capacities supporting assessment of water quality criteria attainment.

This chapter outlines protocols for collecting, managing and delivering dissolved oxygen criteria assessment support data by nontraditional partners. Future considerations are provided to direct an expanded role of citizen monitoring and other nontraditional partner organization and institutions in collecting and delivering data for regulatory assessments and management decision-support analyses.

NONTRADITIONAL PARTNER DATA

There remains a significant opportunity for expanding data collection to further support classification of magnitude and extent of remaining impairments and track recovery of the Chesapeake Bay ecosystem with water quality standards attainment assessments. Clean Water Act section 303d listing assessments depend upon the integrity of the data collection process and management of the data set. Any Chesapeake Bay watershed state or other agency, institution, group or individual conducting water quality monitoring on Chesapeake Bay and its tidal tributaries in support of water quality impairment decisions is required to follow a published set of EPA approved field, laboratory and data management methods. In accordance with Section 117(b)(2)(B)(iii) of the Clean Water Act, implementing approved data collection protocols promotes consistent, bay-wide application of criteria attainment assessments in the common tidal water designated uses across jurisdictional boundaries. The minimum protocol for a water quality sampling program to contribute data suitable for consideration of inclusion into the Clean Water Act section 303d impairment listing decision assessments is described below.

PROTOCOL FOR DATA COLLECTION AND DELIVERY TO SUPPORT CHESAPEAKE BAY DISSOLVED OXYGEN CRITERIA ATTAINMENT ASSESSMENTS

Documentation

Quality Assurance Project Plans and Standard Operating Procedures

The Chesapeake Bay Quality Assurance Program requires the development and implementation of a Quality Assurance Project Plan (QAPP) for each of its monitoring activities. The QAPP must cover the activities to be performed and procedures to be used by a participant. The purpose of the QAPP is to: 1) ensure that the level of needed data quality will be determined and stated before the data collection efforts begin and 2) ensure that all monitoring data generated and processed will reflect the quality and integrity established by the QAPP. The QAPP is composed of standard elements covering all aspects and activities of the monitoring, from planning, through implementation, to data quality assessment. **The document *EPA Requirements for QA Project Plans (QA/R-5)* fully describes the necessary QAPP elements.**

Written standard operating procedures (SOPs) are an important aspect of the QAPP. SOPs for the collection of dissolved oxygen data must describe specific step-by-step directions to be carried out by field personnel. SOPs should reflect actions as they are currently performed and be consistent with the protocols established by Chesapeake Bay Program partnerships monitoring and analysis workgroups. (See **Chapter 4 of the Recommended Guidelines for Sampling and Analysis http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem__tributary_field_procedures.pdf**). Procedures should cover the use of calibration logs, calibration standards preparation, field sheets, etc. to ensure that traceable records are available for historical reconstruction of how each data set was collected.

Chesapeake Bay Program staff reviews new partner QAPPs and SOPs for conformance with the Bay Program protocols. An on-site audit will be conducted to assess the organization's capacity to produce comparable data and ability to carry out the approved procedures. All documents must be approved and deficiencies resolved before the actual data can be considered water quality standards assessments.

Documentation

Quality Assurance Project Plans and Standard Operating Procedures

The CBP Monitoring Program participating agencies are required to submit documentation to the Chesapeake Bay Program Monitoring Coordinator each year, which includes an overview of their monitoring and quality assurance programs. Project documentation includes such information as:

- project title;
- project beginning and ending date, and sampling schedule;
- principal investigator, project manager, QA/QC manager, and Data Manager;
- administrative organization, collecting organization, and analytical laboratory;
- project summary;
- parameter list;
- station table and station description; and,
- data entry and verification methods.

The Chesapeake Bay Quality Assurance Program requires the development and implementation of a Quality Assurance Project Plan (QAPP) for each monitoring project. The QAPP must cover in detail all activities to be performed and procedures to be used by a participant. The purpose of the QAPP is to: 1) ensure that the level of needed data quality will be determined and stated before the data collection efforts begin and 2) ensure that all monitoring data generated and processed will reflect the quality and integrity established by the QAPP. The document *EPA Requirements for QA Project Plans (QA/R-5)* fully describes the necessary elements.

Written standard operating procedures (SOPs) are an important aspect of the QAPP. SOPs for the collection of dissolved oxygen data must describe specific step-by-step directions to be carried out by field personnel. SOPs should reflect actions as they are currently performed and be consistent with the protocols established by Chesapeake Bay Program workgroups. (See Chapter 4 of the Recommended Guidelines for Sampling and Analysis http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem__tributary_field_procedures.pdf). Procedures should cover the use of calibration logs, calibration standards preparation, field sheets, etc. to ensure that traceable records are available for historical reconstruction of how each data set was collected.

The Chesapeake Bay Program Quality Assurance Coordinator will review new partner QAPPs and SOPs for conformance with the Bay Program protocols and conduct an on-site audit to assess the organization's ability to produce comparable data and capacity to carry out the approved procedures. All documents must be approved and deficiencies resolved before the actual data can be considered for use in water quality standards assessments.

Data Submittal and Quality Review

Potential partners will submit a preliminary data set to the Chesapeake Bay Program Water Quality Data Manager to establish a basic level of quality. Data must be formatted into two Microsoft Access® Tables named: a) WQ_DATA (Table 1) and b) WQ_EVENT (Table 2). The content of each table is shown below; descriptions of the field names may be found in the document "DUET Data Submittal Lookup Tables, Version 3, Feb. 6, 2014". (URL to be established)

Table 1. Water Quality data table example.

WQ_DATA Table				
Field Name	**Data Type**	**Field Size**	**Decimal Places**	**Primary Key**
PROJECT	Text	10		Yes
SOURCE	Text	10		Yes
STATION	Text	15		Yes
SAMPLE_DATE	Date/Time	m/d/yyyy		Yes
SAMPLE_TIME	Date/Time	Short Time		Yes
DEPTH	Number	Single	Auto	Yes
LAYER	Text	2		Yes
SAMPLE_TYPE	Text	4		Yes
SAMPLE_ID	Text	7		Yes
PARAMETER	Text	15		Yes
QUALIFIER	Text	1		
VALUE	Number	Single	Auto	
UNITS	Text	10		
METHOD	Text	4		
LAB	Text	10		
PROBLEM	Text	2		
PRECISION_PC	Text	4		
BIAS_PC	Text	4		
COMMENTS	Memo			

Table 2. Water Quality monitoring event table example.

WQ_EVENT Table				
Field Name	**Data Type**	**Field Size**	**Decimal Places**	**Primary Key**
CRUISE	Text	10		
SOURCE	Text	10		Yes
AGENCY	Text	10		Yes
PROGRAM	Text	10		Yes
PROJECT	Text	10		Yes
STATION	Text	15		Yes
SAMPLE_DATE	Date/Time	m/d/yyyy		Yes
SAMPLE_TIME	Date/Time	Short Time		Yes
TOTAL_DEPTH	Number	Single	Auto	
UPPER_PYCNOCLINE	Number	Single	Auto	
LOWER_PYCNOCLINE	Number	Single	Auto	
AIR_TEMP	Number	Single	Auto	
WIND_SPEED	Text	2		
WIND_DIRECTION	Text	3		
PRECIP_TYPE	Text	2		
TIDE_STAGE	Text	1		
WAVE_HEIGHT	Text	2		
CLOUD_COVER	Text	2		
GAGE_HEIGHT	Text	4		
PRESSURE	Text	4		
EVENT_TYPE	Text	4		
EVENT_REMARK	Text	4		
COMMENTS	Memo			

Latitude/Longitude Coordinates

The Chesapeake Bay Program adheres to the EPA's national geospatial data policy, which requires consistent use of latitude/longitude coordinates to identify the location of entities. Please see http://www.epa.gov/geospatial/policies.html for a copy of the policy.

All data to be served on the Internet via the Chesapeake Information Management System must have latitude and longitude information for each sample location. Field-measured locations shall be accurate to the best practical geographic positioning method - either the North American Datum 1983 (NAD83) or World Geodetic System 1984 (WGS84) horizontal reference or the North American Vertical Datum 1988 (NAVD88) vertical reference.

Data Submittal and Quality Review

The CBP Water Quality Data Manager will manually inspect the data to ensure that the tables are complete, correct and that reported values are within normal ranges. Common gross errors in reporting data include:

- Decimal point errors
- Data transposition errors
- Field data type mismatches; outliers
- Incorrect sample date & time formats
- Fields missing or named incorrectly

After problems in the "trial" data set are resolved and the protocols described above (sampling design, field methods, quality assurance documents and on-site audit) are approved, then the participant will be allowed to routinely submit data sets and related metadata using the Chesapeake Bay Program Data Upload and Evaluation Tool (DUET). DUET is an electronic data submission system that automatically reviews, transforms and archives water quality data and the related metadata into the Chesapeake Bay Information Management System (CIMS). Detailed instructions for submitting water quality data may be found in the DUET User Guide at: http://www.chesapeakebay.net/channel_files/21473/duet_user_guide_v2_1_03dec2013.pdf

Each partner's water quality data set is uploaded and reviewed by DUET, and on the basis of that review, DUET will generate routine reports with selected metadata on the following:

- Timeliness of the Submissions;
- Completeness of the submitted data, in relation to the data expected;
- Quality of the submitted data, in relation to possible clerical errors, extreme values, logical relational expressions and data accuracy if precision and bias data are submitted.

Potential partners will submit data that is tabulated in a format compatible to CIMS. Each data will go through a standard set of checks that establish a basic level of quality: CBP data reviewers inspect the data to ensure that the data set is complete and that values are within normal ranges. Common errors in reporting include:

- Decimal point errors
- Data transposition errors
- Field data type mismatches
- Incorrect sample date & time formats
- Fields missing or named incorrectly

In-situ Data Collection

Calibration

Routine calibration of sensors ensures accurate dissolved oxygen (DO), pH, and conductivity (salinity) measurements. Field personnel must fully calibrate sensors before and after each sampling event, deployment, or multiple-day cruise to ensure that the instrument readings are correct. Calibration information must be recorded in a calibration log to document that it occurred. Calibrations are performed according to the manufacturers' specifications, with the following requirements and recommendations.

For dissolved oxygen, a calibration check is recommended at the beginning of each sampling day. If a daily check deviates by ≥ 0.30 mg DO/L from the expected value, the sensor must be recalibrated before use. If a calibration check (daily or post-calibration) is ≥ 0.50 mg DO/L of the expected value, all data corresponding back to the last calibration check is invalid.

Temperature probes and thermometers must be verified for accuracy at least once a year against a NIST-certified thermometer over a range of temperatures. If the temperature is off by 1°C or more, have a service representative recalibrate the probe or develop a correction factor for a thermometer.

Electronic depth sensors should be verified at the beginning of each sampling day at a known depth below the surface. The depth reading should be accurate to 0.2 meters or the tolerance given by the manufacturer.

Minimum criteria for calibration frequency, post-calibration tolerance and reporting limits are provided in Table 3.

Physiochemical Profile

An *in-situ* vertical profile for water temperature, dissolved oxygen and conductivity is required at every sampling station. A multi-parameter water quality instrument (sonde) equipped with sensors for temperature, dissolved oxygen, pH, conductivity (salinity) and depth is highly recommended. The instrument must be outfitted with a data logger or computer to display the measurement values.

Table 3. Quality Control Specifications for *In-situ* Field Measurements

PARAMETER	INSTRUMENTS	CALIBRATION FREQUENCY	POST-CALIBRATION TOLERANCE	REPORTING LIMIT
Dissolved Oxygen	Clark-cell or Optical DO Probe	Each event with day of use check	± 0.3 mg DO/L	0.1– 0.2 mg DO/L
Specific Conductance		Each event	± 5% of calibration standards.	1 µmho/cm
Salinity	Specific Conductance	NA	NA	0.1 psu
Water Temperature	Thermistor or Thermometer	Annual	1.0°C	0.1°C
Depth	Depth finder, Pressure sensor or Calibrated line	Day of use check	± 0.2 meter	0.5 meter
pH		Each event	± 0.2 units	0.1 pH unit
Secchi Depth	20 cm Disk	Annual	NA	0.05 - 0.1 meter

(See **Chapter 4 of the Recommended Guidelines for Sampling and Analysis** **http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem__tributary_field_procedures.pdf** for complete details.

The sonde is lowered to the desired depths and allowed to stabilize prior to recording values. Take the surface measurements at 0.5 meters below the surface. Take subsequent readings at 1, 2 and 3 meters below the surface, then at least every 2 meters until 1 meter above the bottom. Collect measurements every meter to the bottom if: a) the total depth is less than 10 meters; b) the change in DO is more than 1.0 mg/L every 2 meters or c) specific conductance changes more than 1,000 µmhos/cm every 2 meters.

Sampling sites that are located off the shoreline and are accessed by boat using a GPS. The engine may be turned off and the vessel either anchored or allowed to drift. Avoid drifting to shallower or deeper waters as this may result in real differences in water quality. Record the actual GPS coordinates on the field sheet or in the captain's log.

Total depth of the site may be determined from the vessel depth finder, the pressure sensor on the instrument or calibrated markings on lines attached to sampling equipment. Record weather and sea conditions at the time of sampling, i.e., cloud cover, air temperature, precipitation type, wind speed, wind direction, wave height and tidal current stage.

(See **Chapter 4 of the Recommended Guidelines for Sampling and Analysis** **http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem__tributary_field_procedures.pdf**) for complete details.

RECOMMENDATIONS FOR SAMPLING EFFORT (Adding text – under review)

Chesapeake Bay Tidal Water Quality Monitoring Program is a fixed-station network comprised of 160 mid-channel sampling sites representing the open and deep waters of the Chesapeake Bay and its tidal tributaries. Twenty-two field and laboratory parameters are monitored each month for nutrients, suspended solids, dissolved oxygen (DO), salinity, temperature and chlorophyll *a*. This design serves multiple purposes including the development of water quality standards, status and trends analyses, water quality modeling and a variety of research investigations.

DO, salinity and temperature are required for the assessment of DO criteria in all designated use areas. The majority of assessment data are from programs with mid-channel, fixed-station sampling designs; however, the assessment protocol does accommodate data from probability-based sampling designs.

Frequency Considerations – Collection of data on additional sampling dates will increase temporal resolution and improve estimates of the 30-day and 7-day means. DO criteria assessment protocols are based on three consecutive years of data collected in the months of May through September. Both long-term and short-term seasonal monitoring programs that cover these time frames will be considered.

Spatial Considerations – Data from additional sampling sites will increase spatial resolution and improve estimates of the 30-day and 7-day means. Additional data will be particularly helpful in segments with relatively few sampling sites from which data are interpolated to the entire segment.

FUTURE EXPANSION OF NONTRADITIONAL PARTNER DATA COLLECTION AND SUBMITTALS

The Chesapeake Bay Program partnership collects data supporting dissolved oxygen water quality standards attainment assessments in the tidal waters of Chesapeake Bay and its tidal tributaries. The role of nontraditional partner efforts in completing these assessments has gradually increased in the last decade. There are, however, a wider range of data needs that support other water quality standards attainment requirements (e.g. water clarity, submerged aquatic vegetation, chlorophyll a). Nontraditional partners are already contributing to the integrity of such data needs. Citizen scientists have long worked with state agencies for example to verify information on density and species distributions in underwater Bay grass beds. The vegetation data makes up part of the annual assessments of water clarity and factor into water clarity standards attainments.

Additional data on nutrient and sediment concentrations in the Bay and watershed and benthic macroinvertebrate data are examples of data that do not directly fit the water quality standards attainment needs of the 5 primary designated uses in Chesapeake Bay yet can provide valuable insights on spatial patterns of water quality conditions. These additional data may provide targeting information to local and regional managers. The 2014 Chesapeake Bay agreement will have broader goals and outcomes with new opportunities for nontraditional partners to contribute data collected according to required protocols to support the status assessment and tracking of Bay recovery.

LITERATURE CITED

Chapter 4 of the Recommended Guidelines for Sampling and Analysis
http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem__tributary_field_procedures.pdf)

MRAT 2009

U.S. EPA 2003a

EPA Requirements for QA Project Plans (QA/R-5)

TRACKING CHANGES IN CHESAPEAKE BAY HEALTH

chapter ix

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

BACKGROUND

In order to achieve and maintain the water quality conditions necessary to protect the aquatic living resources of the Chesapeake Bay and its tidal tributaries, the U.S. Environmental Protection Agency Region III have developed and published guidance in *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance) April 2003* (U.S. EPA. 2003a) and subsequent supporting documentation (Table 1 – list of USEPA criteria documents). The documentation presents EPA's regionally-based nutrient and sediment enrichment criteria expressed as dissolved oxygen, water clarity and chlorophyll a criteria applicable to the Chesapeake Bay and its tidal tributaries. The EPA guidance is issued in accordance with Section 117(b) of the Clean Water Act and water quality standards regulations (40 CFR Part 131).

Quantified water quality criteria contained within water quality standards are essential to a water quality-based approach to pollution control providing a reference for the measuring, tracking and reporting of progress towards attaining the standards. This *Regional Criteria Guidance* and subsequent support documentation has provided Chesapeake Bay States and Washington District of Columbia with recommendations for establishing water quality standards consistent with Section 303(c) of the Clean Water Act. The States of Maryland, Virginia, Delaware, and the Washington, District of Columbia have subsequently adopted into water quality standards a set of scientifically defensible water quality criteria that are protective of designated and existing uses for Chesapeake Bay and its tidal tributaries. The four tidal water jurisdictional partners – Delaware, District of Columbia, Maryland, and Virginia—and EPA work collaboratively to assess water quality standards attainment based on the criteria applicable to the designated uses (Figure 1).

The Presidential Chesapeake Bay Executive Order 13508 and supporting strategy published in 2010 supports a water quality outcome based on Chesapeake Bay water quality standards attainment:

"*Meet water quality standards for dissolved oxygen, clarity/underwater grasses and chlorophyll a in the Bay and tidal tributaries by meeting 100 percent of pollution control reduction actions for nitrogen, phosphorus and sediment no later than 2025, with 60 percent of segments attaining water quality standards by 2025*".

Table 1. U.S. EPA published Chesapeake Bay Water Quality Criteria support documents. (still being filled out)

U.S. EPA publication	Title
U.S. EPA. 2003	*Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance) April 2003*. EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, MD.
U.S. EPA. 2003	*Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* October 2004. Region III. Chesapeake Bay Program Office. EPA 903-R-0*-00*. Annapolis, MD.
U.S. EPA. 2004	*Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability – 2004 Addendum.* October 2004. Region III. Chesapeake Bay Program Office. EPA 903-R-04-006. Annapolis, MD.
U.S. EPA. 2004	*Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. October 2004*. Region III Chesapeake Bay Program Office, Annapolis, MD. EPA 903-R-04-008.
U.S. EPA. 2005	*Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. 2005 Addendum. December 2005*. Region III Chesapeake Bay Program Office, Annapolis, MD. EPA 903-R-05-004.
U.S. EPA. 2007	*Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2007 Addendum. July 2007*. EPA 903-R-07-003. Region III Chesapeake Bay Program Office, Annapolis, MD.
U.S. EPA. 2007	U.S. EPA 2007b. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – Chlorophyll a Addendum. October 2007*. EPA 903-R-07-00*. Region III Chesapeake Bay Program Office, Annapolis, MD.
U.S. EPA. 2008	USEPA 2008
U.S. EPA. 2010	USEPA 2010

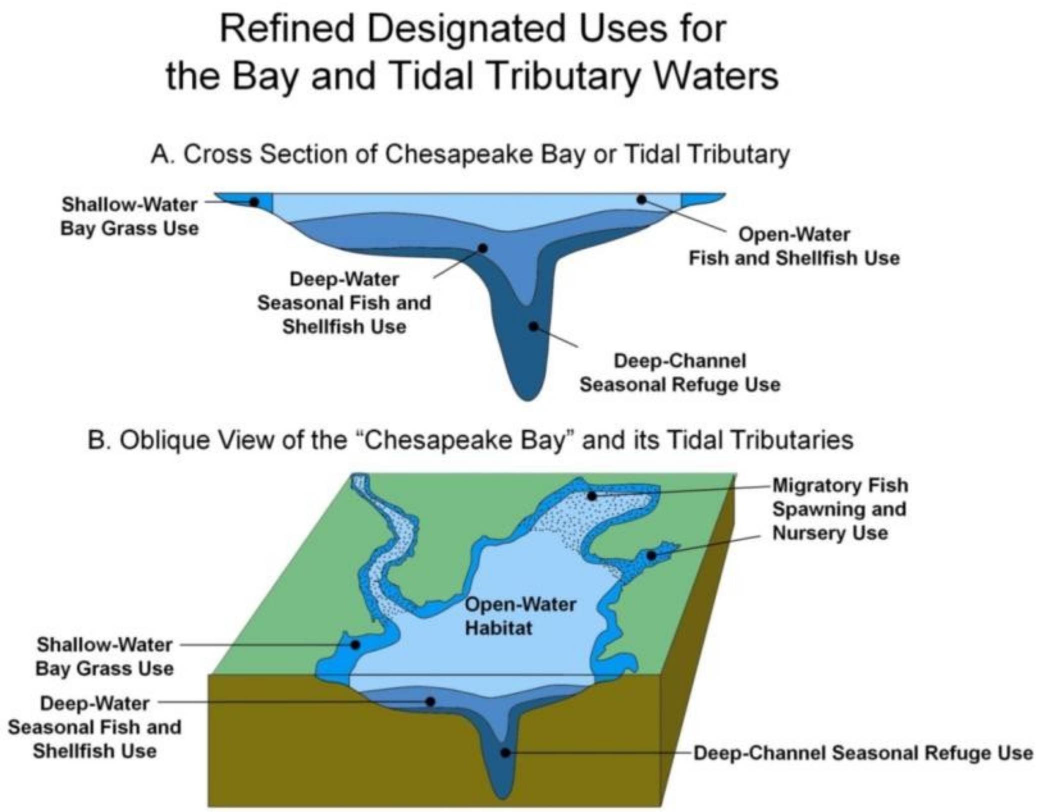

Figure 1. Conceptual illustration of the five Chesapeake Bay tidal water designated use zones.

Source: U.S. EPA 2003a

Section 117 of the Clean Water Act authorizes a Chesapeake Bay Program's office to publish information pertaining to the environmental quality of the Chesapeake Bay, as well as to coordinate Federal, State, DC and tribal efforts to improve the quality of the Bay. Currently, the Chesapeake Bay Program partnership has separately tracked and reported dissolved oxygen, water clarity, underwater grasses and chlorophyll *a* indicators to chronicle changes in Bay health (http://www.chesapeakebay.net/trackprogress). In addition, all of the individual indicator assessments were not precisely aligned with their respective water quality standards attainment assessment methods. Therefore, in order to track the composite of water quality standards attainment for the 92 Chesapeake Bay and tidal tributary management segments in the TMDL, a new indicator was needed. This new indicator needed to be a combined, multimetric indicator measuring progress toward meeting the complete set of water quality standards, based on the water quality standards attainment results, and applied to all designated uses adopted by the tidal Bay states and DC.

This chapter provides the background, development and application of an integrated indicator for use measuring and reporting on progress toward the Chesapeake Bay's Executive Order water quality outcome. Further, this combined indicator would still provide complementary tracking of Bay health as expressed by the individual indicator reporting results for dissolved oxygen, water clarity, underwater grasses and chlorophyll *a*.

MULTIMETRIC WATER QUALITY STANDARDS INDICATOR FOR TRACKING HABITAT CHANGE IN CHESAPEAKE BAY AND ITS TIDAL TRIBUTARIES

The U.S. EPA 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 multimetric indictor options. These analyses considered attainment for each segment by each of its unique tidal water designated uses (e.g., middle James River open-water) and applicable water quality criteria (e.g., chlorophyll *a*, water clarity, dissolved oxygen).

The resulting Chesapeake Bay water quality standards indicator is based on annually reported Chesapeake Bay water quality criteria assessment results, which are based on a three-year assessment period. It combines the dissolved oxygen, water clarity and chlorophyll *a* assessment results and will be reported annually as a bay-wide percentage of water quality standards in attainment. The method of assessment for each of the individual metrics used to create the combined multimetric score is briefly described and referenced below.

- 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 U.S. EPA 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 U.S EPA (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 U.S. EPA (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, it is assumed that attainment of the 30-day mean open-water dissolved oxygen criterion can serve as an "umbrella" assessment protective of the remaining short duration dissolved oxygen criteria in each designated use. In this way, attainment can be assessed 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.

Chesapeake Bay Interpolator and related FORTRAN programs are used to determine the volumetric extent of compliance of DO and chlorophyll *a* standards. ArcGIS is 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. Further information about each of the methods is highlighted in Appendix A1.

There are a variety of unique combinations of Chesapeake Bay water quality criteria applied, where appropriate, to each of the five tidal water designated uses within each of the 92 segments. Each segment can have between one (e.g., Eastern Branch of the Elizabeth River which only has open water) 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) (Appendix X). 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.

Count, volume-weighted and area-weighted approaches were all considered in the analyses. However, the area-weighted approach most effectively factors in the relative size of each segment, ensuring that reporting is for 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. The decision, approved by the CBP Partnership's Scientific, Technical Assessment and Reporting Team's (STAR) Criteria Assessment Protocols (CAP) Workgroup and Water Quality Goal Implementation Team, was using the surface area of each of the 92 segments times the number of applicable designated uses for that segment. The indicator consolidates the bay-wide water quality standards results in the final calculations and reports percent of Bay water quality standards meeting attainment as a single measure (Table 2, Figure 2, 3). Note, in practice the assessment is aligned with the present Clean Water Act 303d list reporting protocol for Chesapeake Bay water quality standards attainment assessments using a 3-year assessment period (Figure 3).

Table 2. A hypothetical example of creating a water quality standards attainment score for a single year using the area-based approach that has been adopted by the Chesapeake Bay Program partnership for this multimetric water quality standards indicator

AREA-BASED APPROACH			
289 Designated-Use Segments (contained within the 92 Chesapeake Bay segments)			
Chesapeake Bay Tidal Water Designated Use	Total Surface Area of Designated-Use Segments (km^2)	Total Surface Area of Designated-Use Segment Attaining WQS (km^2)	Designated Use Percent Attainment
Migratory Fish Spawning and Nursery	5565101169.36	0.00	0
Open Water – DO	11660174083.95	0.00	0
Open Water – CHLA (spring + summer)	620327627.29	0.00	0
Deep Water – DO	6932558324.18	0.00	0
Deep Channel – DO	4404190644.45	83660695.00	2
Shallow-Water Bay Grasses – SAV/Water Clarity	11558645485.84	2616220341.04	23
Surface area totals (km^2)	**40740997335.07**	**2699881036.04**	**--**
Baywide Percentage of WQS Attainment[1] = 2699881036.04/40740997335.07 * 100 = 7			

1. Percent Attainment = (Sum of Surface area attaining in a designated use) /(Sum of Surface area available) X 100

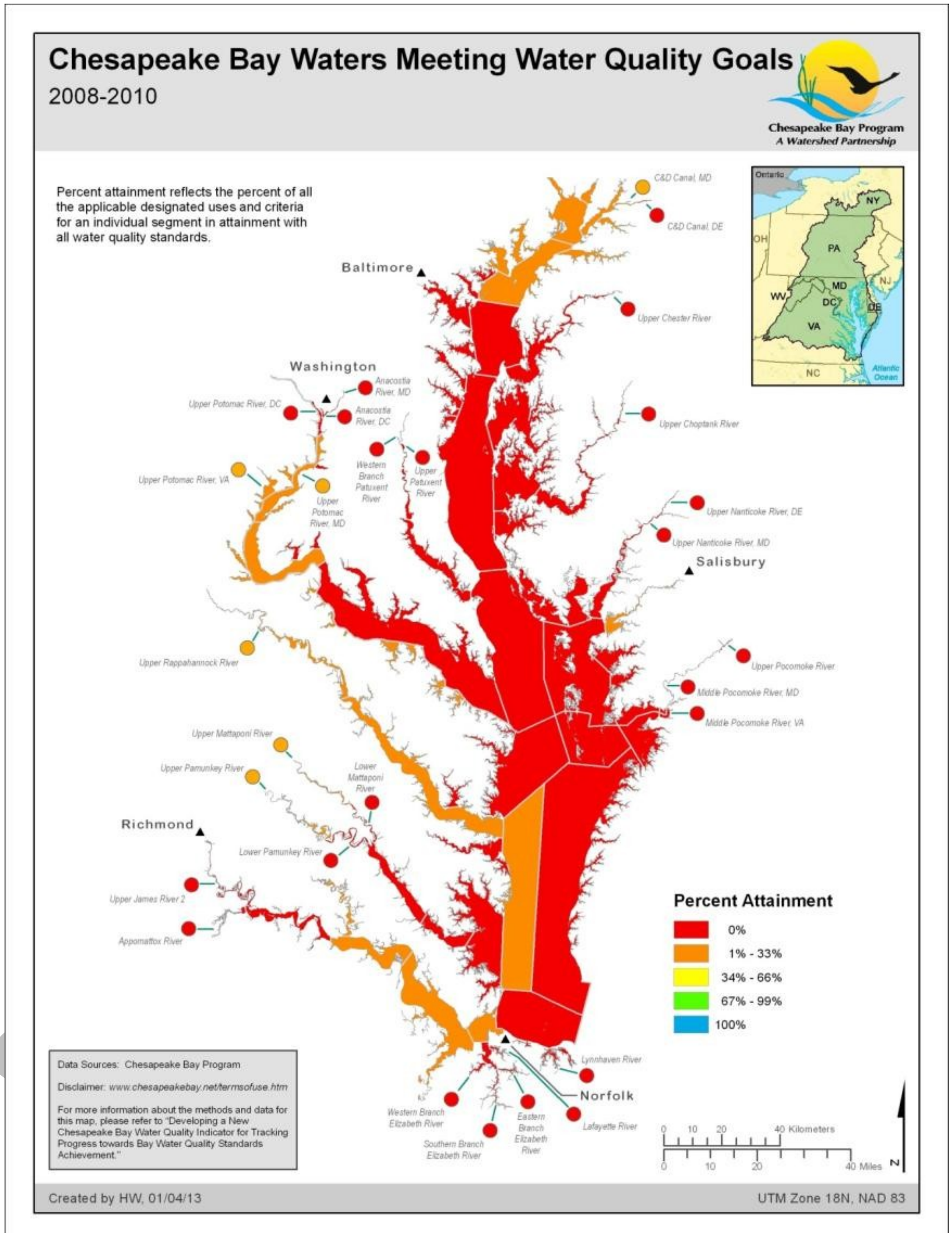

Figure 2. Visual illustration of the water quality standards indicator status, expressed as a percentage, for each of the 92 Chesapeake Bay TMDL segments (2008-2010 listing cycle). The number of water quality criteria applied varies across the 92 Bay segments based on the applicable designated uses (i.e., migratory spawning and nursery, open-water, deep-water, deep-channel, and shallow water bay grasses) and criteria (e.g., chlorophyll *a*). Percent attainment reflects all the applicable designated uses and criteria for that individual segment which are in attainment with all water quality standards.

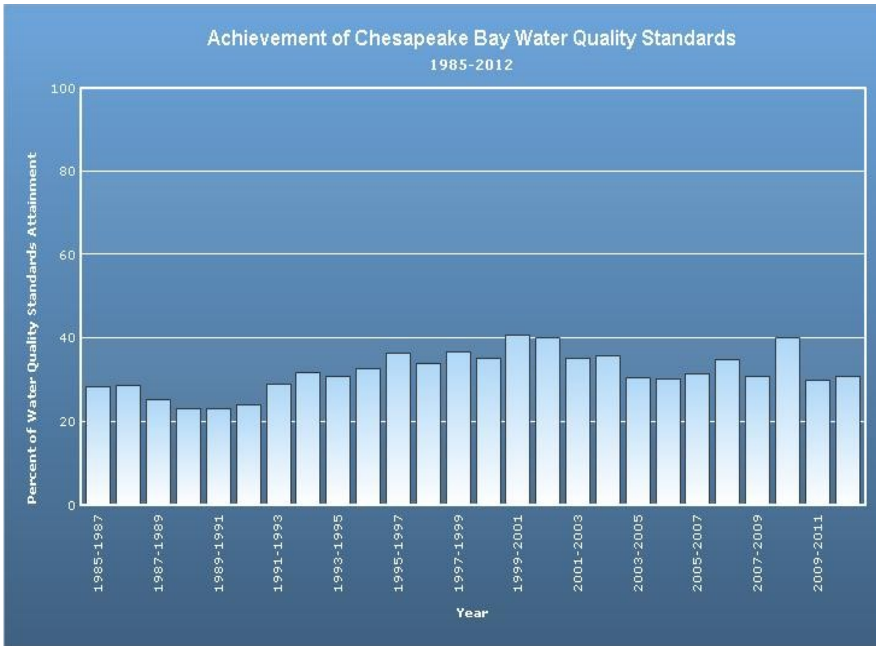

Figure 3. Retrospective time series illustration of the Chesapeake Bay Water Quality Standards indicator status, expressed as a percentage of goal attained for each of the 92 Chesapeake Bay TMDL segments (1985-present listing cycle). The number of water quality criteria applied varies across the 92 Bay segments based on the applicable designated uses (i.e., migratory spawning and nursery, open-water, deep-water, deep-channel, and shallow water bay grasses) and criteria (e.g., chlorophyll *a*). Percent attainment reflects all the applicable designated uses and criteria for that individual segment which are in attainment with all water quality standards.

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