CHAPTER 1
Introduction

In April 2003, the U.S. Environmental Protection Agency (EPA) published the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* which was the foundation document defining Chesapeake Bay water quality criteria and recommended implementation procedures for monitoring and assessment (U.S. EPA 2003a). In October 2003, EPA published the *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability* which defined the five tidal water designated uses to be protected through the published Bay water quality criteria (U.S. EPA 2003b):

- Migratory fish spawning and nursery habitat;
- Open-water fish and shellfish habitat;
- Deep-water seasonal fish and shellfish habitat;
- Deep-channel seasonal refuge habitat; and
- Shallow-water bay grass habitat.

A total of seven addendum documents have been published by EPA since April 2003. Four addenda were published documenting detailed refinements to the criteria attainment and assessment procedures (U.S. EPA 2004a, 2007a, 2008, 2010) previously published in the original April 2003 Chesapeake Bay water quality criteria document (U.S. EPA 2003a). One addendum published Chesapeake Bay numerical chlorophyll *a* criteria (U.S. EPA 2007b). Three addenda addressed detailed issues involving further delineation of tidal water designated uses (U.S. EPA 2004b, 2005, 2010) building from the original October 2003 tidal water designated uses document (U.S. EPA 2003b). Finally, one addendum documented the 92-segment management scheme (U.S. EPA 2008) after refinements were addressed to the Chesapeake Bay Program analytical segmentation schemes (U.S. EPA 2005) building from the original U.S. EPA 2004 document (U.S. EPA 2004b).

The detailed procedures for assessing attainment of the Chesapeake Bay water quality criteria continued to be advanced through the collective EPA, States and District of Columbia partnership efforts. These partners continue to develop and apply procedures that incorporate the most advanced state-of-the-science, magnitude, frequency, duration, space and time considerations with, as available, biologically-based reference conditions and cumulative frequency distributions. As a rule, the best test of any new method or procedure is putting it to application with partner involvement and stakeholder input. Through the work of its Criteria Assessment Protocols Workgroup, the Chesapeake Bay Program partnership has an established forum for resolving issues, factoring in new scientific findings, and ensuring implementation of consistent bay-wide criteria assessment procedure development and implementation. The Workgroup draws upon the talents and input from state, federal, river basin commission and academic partners as well as local government and municipal stakeholders. This EPA 2015 Chesapeake Bay Criteria addendum provides previously undocumented features of the present procedures as well as refinements and clarifications to the previously published Chesapeake Bay water quality criteria assessment procedures.

Chapter 2 documents missing volumes for supporting 303d listing assessments in three Chesapeake Bay management segments: Western Branch Patuxent River Tidal Fresh, Maryland portion of Anactostia Tidal Fresh and Patuxent River Tidal Fresh.

Chapter 3 documents sub-segment boundary criteria using dissolved oxygen dynamics to support recommendations on options for States to consider in sub-segmenting the Open water designated use in water quality standards attainment assessments for dissolved oxygen.

Chapter 4 documents an update to the Chesapeake Bay submerged aquatic vegetation restoration goal and provides recommendations for alignment of the goal with the Chesapeake Bay water quality standards based goal for water clarity acres.

Chapter 5 documents support for assessment of short duration dissolved oxygen criteria and recommends the Umbrella Criterion approach as an option to assessing short duration dissolved oxygen criteria.

Chapter 6 documents refinements to the benthic index of biotic integrity assessment of the aquatic life use and recommends interim rules for water quality 303d listing status supporting aquatic life use assessments.

Chapter 7 documents monitoring support and recommended protocols for incorporating nontraditional partner data into regulatory Chesapeake Bay dissolved oxygen criteria attainment assessments.

Chapter 8 documents the development of a multimetric Chesapeake Bay water quality indicator for tracking progress toward Chesapeake Bay water quality standards achievement.

Appendices to these chapters provide more detailed documentation on derivation of the recommended refined criteria assessment procedures.

This document represents the sixth formal addendum to the original 2003 Chesapeake Bay water quality criteria document. As such readers should regard the sections in this document as new or replacement chapters and appendices to the original published Bay Criteria report (U.S. 2003a). The criteria assessment procedures published in this addendum also replace and otherwise supersede similar criteria assessment procedures published in the 2004, 2007, 2008 and 2010 addenda (U.S. EPA 2003a, 2004a, 2007a, 2007b, 2008, 2010). Publication of future addenda by EPA on behalf of the Chesapeake Bay Program watershed jurisdictional partners is likely as continued scientific research and management applications reveal new insights and knowledge that should be incorporated into revisions of state water quality standards regulations in upcoming triennial reviews.

LITERATURE CITED

U.S. Environmental Protection Agency. 2003a. *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. Environmental Protection Agency. 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* EPA 903-R-03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries − 2004 Addendum*. *October 2004*. EPA 903-R-04-005. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability – 2004 Addendum. October 2004.* EPA 903-R-04-006. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 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. Environmental Protection Agency. 2007a. *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. Environmental Protection Agency. 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. Environmental Protection Agency. 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. September 2008.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2010. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2010 Technical Support for Criteria Assessment Protocols Addendum. May 2010.* EPA 903-R-10-002. Region III Chesapeake Bay Program Office, Annapolis, MD.

Chapter 2

Accounting for Missing Volumes in the Chesapeake Bay Program Segmentation to Support 303d Listing Assessments: Western Branch Patuxent River Tidal Fresh, Anacostia Tidal Fresh MD, Patuxent Tidal Fresh

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 ecosystem 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 2004) provides documentation on the development of the spatial segmentation scheme and their associated water volumes for Chesapeake Bay and its tidal tributaries. Subsequently, a U.S. EPA (2005) addendum to U.S. EPA (2004) updated the segmentation scheme and 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 (U.S. EPA 2010).

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. Further, the Maryland portion of Anacostia Tidal Freshwater segment (ANATF MD) and the Patuxent Tidal Fresh (PAXTF) have water quality monitoring but their segment volumes have been considered unavailable for water quality standards attainment assessments. In this chapter a bathymetric Geographic Information System (GIS) layer and volume are established for the WBRTF management segment. A basis for ANATF MD and PAXTF segment volumes are provided.

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 (2004) indicates two tidal water quality monitoring states are present in this segment.

Previously, no volume estimate was available for WBRTF (Table 1 in USEPA 2004). 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 (CAP WG) and Tidal Monitoring Analysis Workgroup (TMAW) coordinated with U.S. EPA and Maryland Department of the Environment (MDE) staff to develop a segment bathymetry and establish a volume for WBRTF.

VOLUME ESTIMATION FOR WESTERN BRANCH PATUXENT TIDAL FRESH SEGMENT

MDE provided the CAP WG with transect data collected 09/07/2001 to support development of a bathymetry for segment WBRTF (Appendix 1). Chesapeake Bay Program (CBP) 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 transects 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, from an upriver to downriver perspective. The measurement unit is the foot.

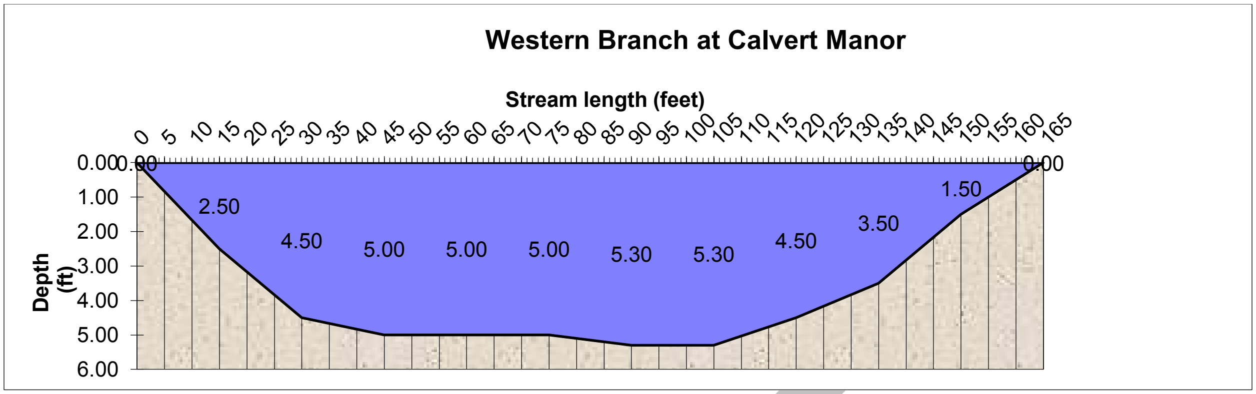

Figure 1. Station code = Station #1. Site location N 38 47.139 W 76 42.794 located 25 yards upstream of pier at Calvert Manor.

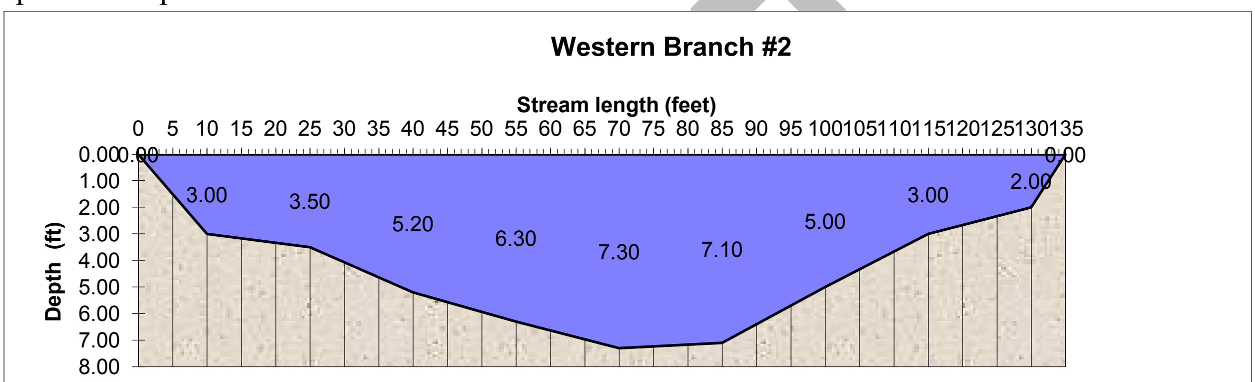

Figure 2. Station code = Station #2. Site location N 38 47.305 W 76 42.898 located 10 yards downstream of Horse Cavern Branch.

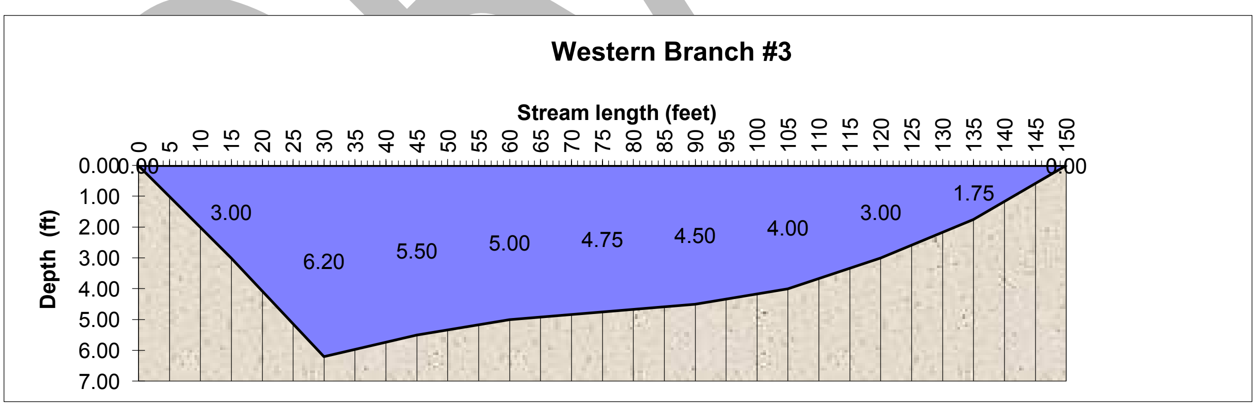

Figure 3. Station code = Station #3. Site location N 38 47.490 W 76 43.022.

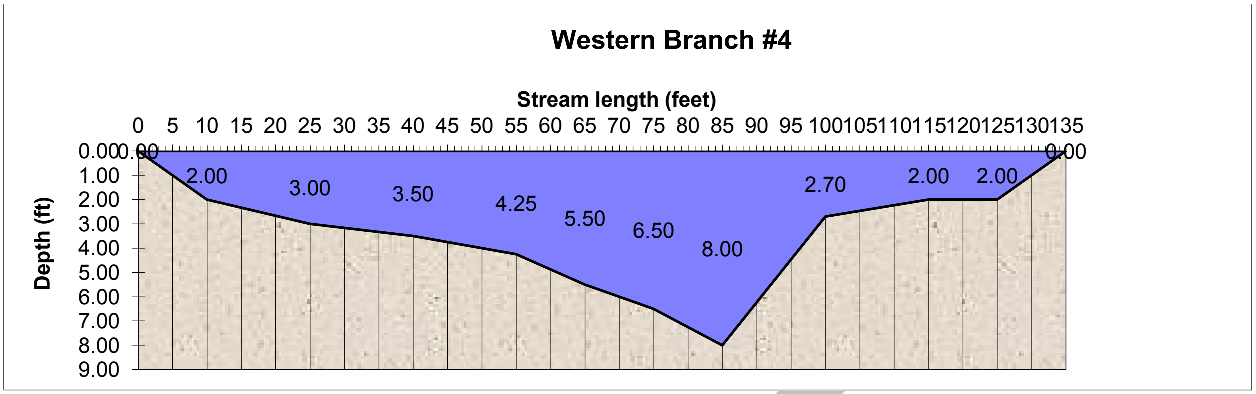

Figure 4. Station code = Station #4. Site location N 38 47.485 W 76 43.239 located downstream of a small unnamed tributary.

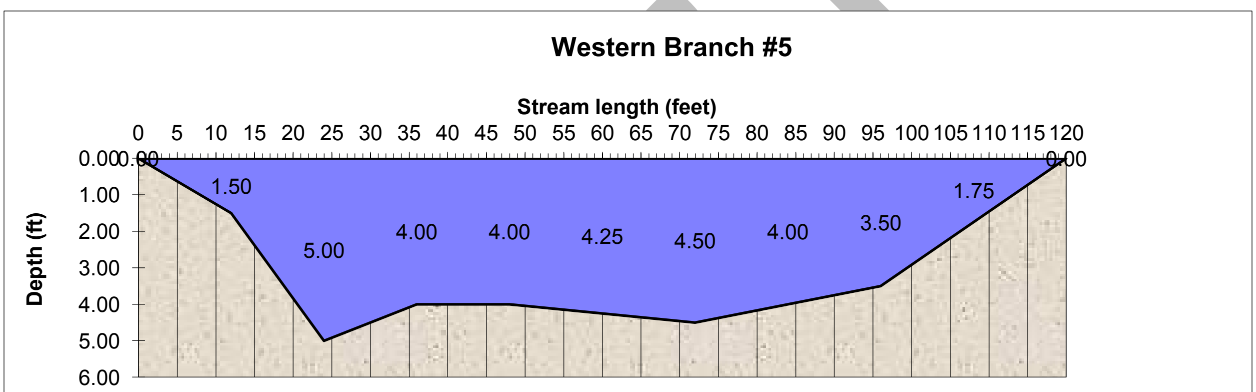

Figure 5. Station code = Station #5. Site location N 38 47.777 W 76 43.316.

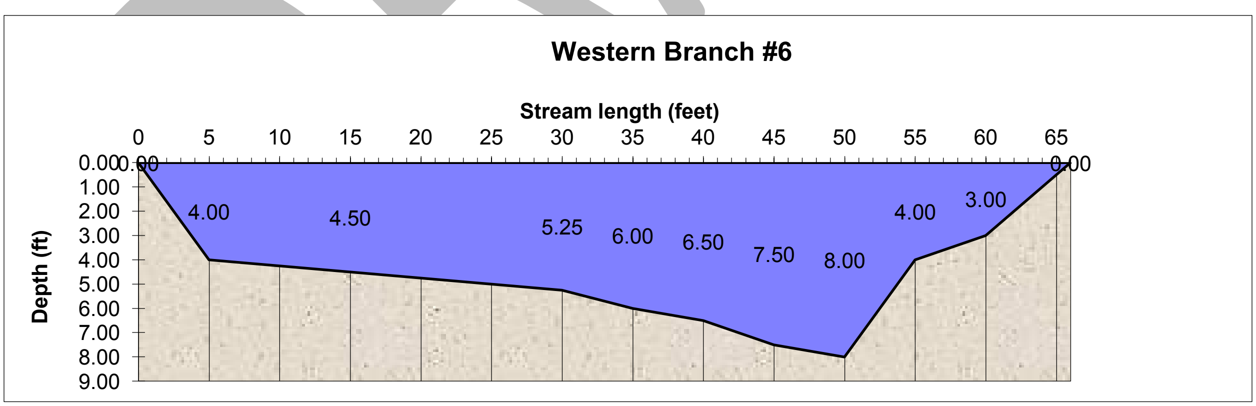

Figure 6. Station code = Station #6. Site location N 38 47.832 W 76 43.746 located 50 yards downstream of WSSC outfall.

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 into WBRTF from PAXTF 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.

ATERNATIVE APPROACH FOR STREAM VOLUME ESTIMATE OF WBRTF

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 (ft)	Cross sectional area (ft^2)	Section volume (ft^3)
1283 (headwaters)	315.3	404,465.75
2162	390	843,180
1594	481.1	766,873.4
1214	565.5	686,517
1124	618.5	695,194
861 (mouth)	631.5	543,721.5
Total volume (ft^3)		3,939,952
Total volume (m^3)		111,567

In GIS, the target grid cell volume was 2500m^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 7). 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 8). 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).

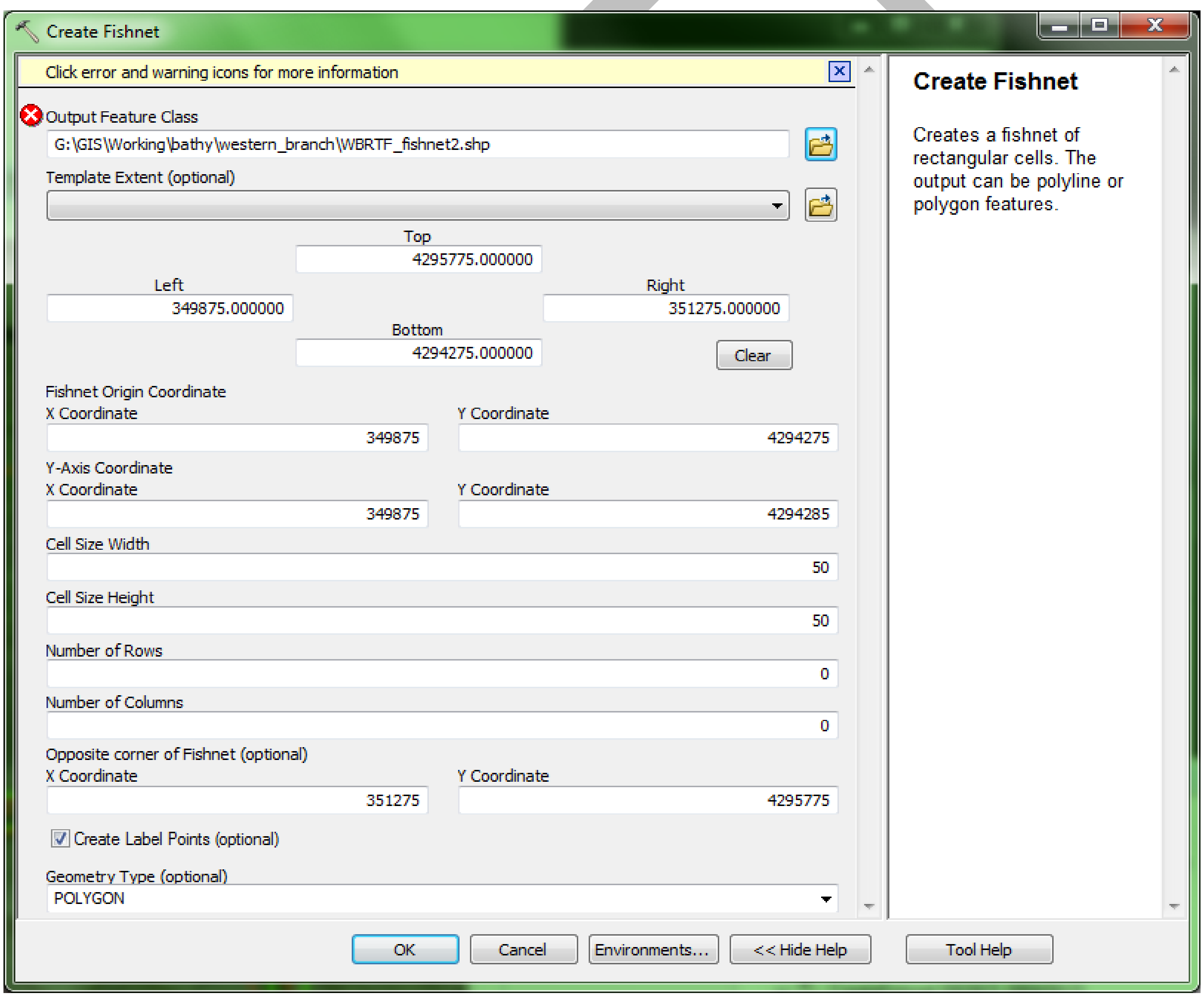

Figure 7. Screen capture of the grid tool used in ArcGIS to create the 50m x 50m cells of the WRBTF segment. Each cell was established as 1m deep.

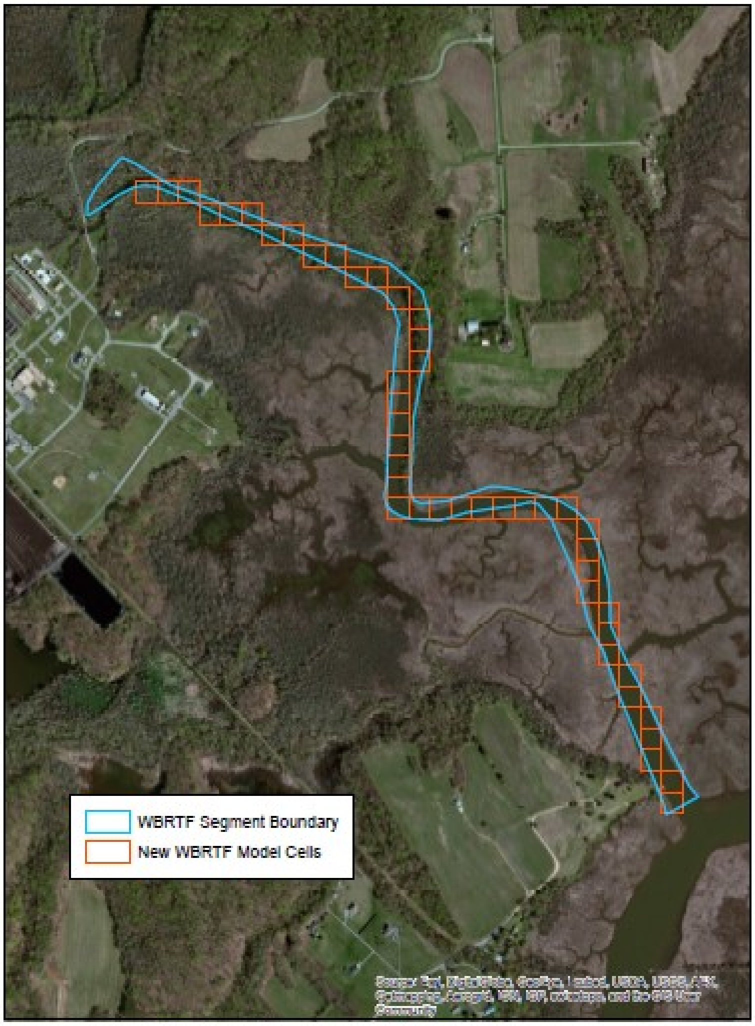

Figure 8. The new 2014 grid for Western Branch, Patuxent River (WRBTF).

ANACOSTIA TIDAL FRESH – MD (ANATF MD) and PATUXENT TIDAL FRESH (PAXTF)

Insufficient bathymetry has limited an interpolated volume estimate for ANATF MD and PAXTF. However, the Chesapeake Bay Water Quality Model conducts TMDL scenarios that requires volumes for all segments. As an interim volume estimate to allow for water quality standards attainment reporting of these two segments in Maryland, the CBP CAP WG worked with MDE to agree on using interim segment volumes as they are represented in the Chesapeake Bay Water Quality Model used to support the 2017 mid-point assessment of the Chesapeake Bay TMDL:

- PATUXENT TIDAL FRESH (PAXTF) model-based value of 11,025,000 cubic meters (m^3)
- ANACOSTIA TIDAL FRESH in Maryland (ANATF MD) model-based volume estimate is 172,500 cubic meters (m^3).

RECOMMENDATION

The following volume estimates are recommendation for filling gaps in 303d listing assessments for three management segments previously considered as gaps in reporting based on the research and agreements supporting their application.

- Western Branch Patuxent Tidal Fresh: 111,567m^3
- PATUXENT TIDAL FRESH (PAXTF) model-based value of 11,025,000 m^3.
- ANACOSTIA TIDAL FRESH in Maryland (ANATF MD) model-based volume estimate is 172,500m^3.

LITERATURE CITED

U.S. Environmental Protection Agency. 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. Environmental Protection Agency. 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. Environmental Protection Agency. 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.

U.S. Environmental Protection Agency. 2010. *Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment*. U.S. Environmental Protection Agency, Region 3 Chesapeake Bay Program Office, Annapolis, MD.

Chapter 3

Sub-segment Boundary Criteria Using Dissolved Oxygen Dynamics:

Recommendations Supporting Assessment Options for the Open Water Designated Use

BACKGROUND

The Chesapeake Bay Partnership expressed interest in developing sub-segmentation options or a revised boundary definition for open water related to Chesapeake Bay dissolved oxygen criteria attainment assessment of the open water designated use (MRAT 2009, CBP-STAC 2012). Designated use definitions have been published (U.S. EPA 2003a, 2003b, 2004a), refined (U.S. EPA 2010a) and adopted into 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 juvenile and adult fish and shellfish in tidal fresh to high salinity habitats (U.S. EPA 2003a).

CHESAPEAKE BAY MANAGEMENT SEGMENT AND SUB-SEGMENT BOUNDARY CRITERIA

The Chesapeake Bay Program partners have used various forms of a basic segmentation scheme to organize collection, analysis and presentation of environmental data. The *Chesapeake Bay Program Segmentation Scheme Revisions, Decisions and Rationales: 1983-2003* (U.S.EPA 2004a) provides documentation on the development of the spatial segmentation scheme of the Chesapeake Bay and its tidal tributaries. Segmentation has been used to compartmentalize the estuary into subunits based on selected criteria for setting boundaries, grouping regions having similar natural characteristics, so that differences in water quality and biological communities among similar segments can be identified and the source of their impacts elucidated (U.S. EPA 2004a). Segmentation also serves management purposes as a way to group regions to define a range of water quality and resource objectives, target specific actions and monitoring the response.

The Chesapeake Bay and tidal tributaries are estuaries offering brackish water habitats of varying salinity and other chemical characteristics. Most aquatic organisms have an optimum salinity concentration in which they thrive and a range of salinity concentrations they tolerate that govern their seasonal and spatial abundance and distribution. Salinity has therefore been a major factor in creating segment boundaries in the Bay segment scheme that aggregates data for analyses.

Factors previously considered in the development and revision of the Chesapeake Bay management-segment scheme have included salinity and natural geographic partitions and features (e.g. river mouths of major tributaries). Segment lines near mid-Bay islands were revised in the 1990s based on their surrounding shallow water habitat with submerged aquatic vegetation (SAV) assessments in mind (U.S. EPA 2004a). Bathymetry and large scale circulation patterns influenced small shifts in boundary lines in segments CB7 and CB8 located in the lower mainstem Bay. (U.S. EPA 2004a).

Sub-segments have been previously been created for state water quality standards applications (U.S. EPA 2004a). The 2003 Chesapeake Bay segmentation update included split segments in Maryland in order to establish attainable water clarity standards and SAV restoration goals for those segments. When actually defining the subdivision boundaries digitally in GIS, physical features in the landscape such as points or mouths of streams were used as endpoints wherever possible. In some segments, a 'natural break' between an area containing a lot of SAV and an area with little or no SAV was used to guide where the division boundary lines were drawn (U.S. EPA 2004b). In Virginia, the James River tidal fresh was sub-divided into an upper segment (JMSTF2) and a lower segment (JMSTF1) for application of the new water clarity and chlorophyll *a* water quality standards (U.S. EPA 2004a). The upper James River tidal fresh segment is narrower and faster flowing with a lower residence time for algal biomass to build up. The lower James River tidal fresh segment is wider with a greater photic zone and longer residence time.

The U.S. EPA designated use boundary definitions are another form of sub-segmentation within a segment. The designated use boundary definition for open water adopted by the three Chesapeake Bay tidal water states of Virginia, Maryland and Delaware, and the District of Columbia into their 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 use 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 bay grasses designated use with a single set of criteria. As a reference here, the shallow-water bay grass designated use is delineated based on light penetration through the water column that, within a range of water clarity characteristics, can penetrate to a specific depth. The science behind light limitation and photosynthesis coupled with the physics of light penetration through the water column was translated to depth-based restoration targets for each Chesapeake Bay segment. These depth-based targets provide bathymetric-based boundaries that constrain the water clarity criteria attainment assessments in space in Chesapeake Bay and its tidal tributaries. By contrast, there has not yet been a similar level of science using dissolved oxygen concentration data in designating fixed or transient vertical-boundary references. Such science-based boundary references could then support sub-segmenting open water habitats of the bay for dissolved oxygen standards attainment assessments.

With respect to separating nearshore and offshore waters for separate water quality standards criteria attainment assessments, Caffrey (2004) suggests management changes in a watershed, such as changes affecting nutrient loading, may be more apparent in shallow water than offshore waters of an estuary. Lyerly et al. (2014) highlights management successes in similar shallow-water environments described by Caffrey with examples of subestuaries of Chesapeake Bay illustrating positive water quality responses to local management actions (e.g. Gunston Cove, VA on the Potomac River and Corsica River, MD). However, 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)". U.S EPA (2007a) goes on to state that conditions in these nearshore waters are considered to vary greatly from the mid-channel habitats of the open water but had no scientific basis for a dissolved oxygen-based delineation between the two habitats. Acknowledging that habitat differences exist, a jurisdiction may, however, specifically delineate sub-segments within a Chesapeake Bay management segment (U.S. EPA 2007a).

The U.S. EPA (2003) 305b guidance highlights a 3-zone approach option to water quality assessment in estuarine habitats. Estuarine habitats are divided to define monitoring site representativeness by open water, sheltered bays and highly sheltered bays. The presence of fixed boundaries (e.g. mouth of a river) and transient water column features, e.g. the pycnocline, are already concepts represented in the boundary definition of the open water designated use. Analyses conducted by the Umbrella Criteria Assessment Team (UCAT) of the CBP in conjunction with newly published reports quantifying characteristics of dissolved oxygen behavior between nearshore and offshore habitats in Chesapeake Bay and its tributaries (Boynton et al. 2014, Lyerly et al. 2014). This combination of new science provides fresh insights and decision-support for options to be considered on sub-segmenting habitats for dissolved oxygen criteria attainment assessment purposes. With such scientific support, a similar zone-type assessment construct as that suggested in U.S. EPA (2003) 305b guidance for dividing estuarine habitats could be developed for application in Chesapeake Bay and its tidal tributaries supporting sub-segmenting options for the open water designated use.

THE IMPORTANCE OF SHALLOW WATER AREA IN CHESAPEAKE BAY

A supplemental issue was expressed by the CBP partnership that the sheer volume of offshore water regions may overwhelm signals of distress in shallow waters for tidal Chesapeake Bay and its tributaries. Significant differences in dissolved oxygen behavior for nearshore and offshore habitats could translate to disproportionate effects on segment-specific dissolved oxygen criteria attainment assessments due to their relative and varied habitat-area contributions across the Bay. (Figure 1)

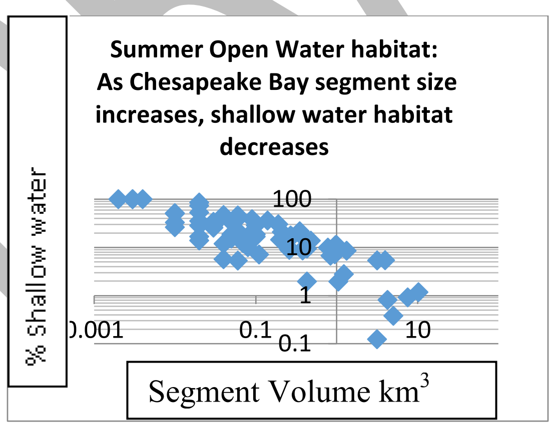

Figure 1.. The relationship of proportion of shallow water habitat as it relates to the size of Chesapeake Bay management segments. Total segment volumes (km3) were based on the U.S. EPA (2003b) listings; Percent shallow water volumes were calculated from SAV Tier III acres (0-2m), converted to volume 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.

As a general reference, shallow water habitat in Chesapeake Bay can be considered ≤2m (e.g. p38, U.S. EPA 2007a). Approximating the area and volume of all such 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) ≤ 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% of its surface area.

Assuming 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 4.6% of the total Bay volume or 2.6 km^3. The importance of this volume, for comparison, is that 2.6 km^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 2) (http://ian.umces.edu/ecocheck/summer-review/chesapeake-bay/2010/indicators/anoxia/).
Improving the deep water hypoxic volume of Chesapeake Bay to restore bay habitat health for living resources is a critical restoration outcome associated with the long term success of the TMDL. While not all available nearshore habitat of Chesapeake Bay and its tidal tributaries may be exhibiting hypoxic events, significant examples exist such as occurs in South River, MD (Muller and Muller 2014) or the Severn River, MD dead zones (see 2008 Severn River Report Card http://ian.umces.edu/pdfs/ian_report_card_212.pdf). Between 1987 and 2001 fish kill distributions in Maryland point to many more areas over time where Maryland Department of Environment attributed the cause to hypoxia (Figure 3). Mitigating the effects of nearshore hypoxia therefore has similar importance to the health of the Bay and its living resources as correcting deep water hypoxia issues due to its representative volume and area.

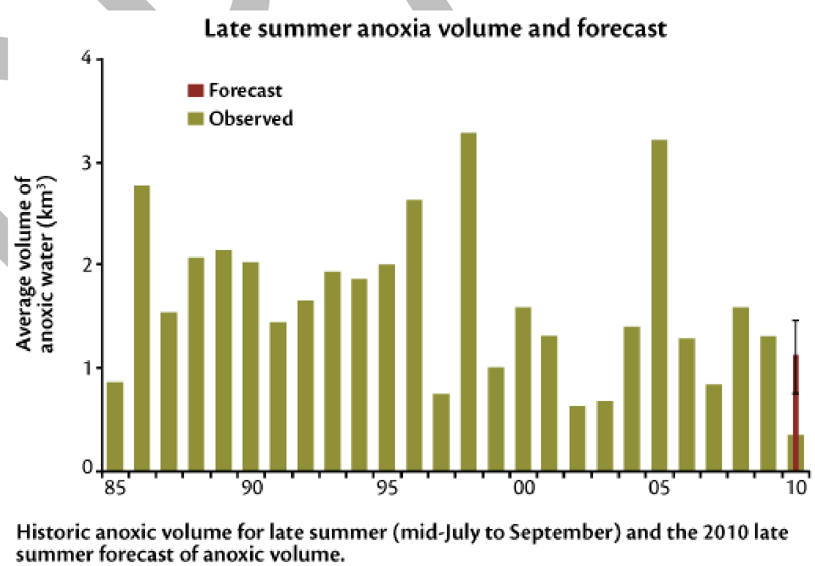

Figure 2. Historical time series of anoxic volume for late summer; also showing 2010 IAN-Ecocheck forecast.

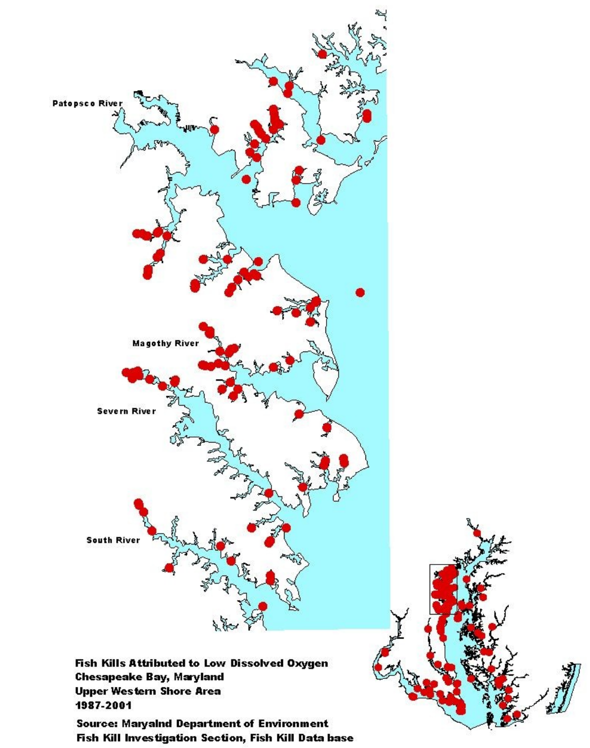

Figure 3. Distribution of fish kills attributed to low dissolved oxygen, Chesapeake Bay, MD. 1987-2001. Source: Maryland Department of Environment.

The following sections of this chapter discuss the development of a basis for sub-segmenting Chesapeake Bay open water designated use supporting the Chesapeake Bay Program partners Clean Water Act water quality standards attainment assessments including, 1) a historical review on the comparability of nearshore and offshore water quality in Chesapeake Bay tidal waters, 2) characteristics of Chesapeake Bay high frequency dissolved oxygen dynamics with an emphasis on shallow water habitat, 3) support for a 2-zone sub-segmentation option in the open water designated use based on nearshore-offshore dissolved oxygen relationships, 4) support for a 3-zone sub-segmentation options in the open water designated use and 5) recommendations regarding sub-segmenting habitats in the open water designated use for water quality monitoring, water quality standards attainment assessment and bay health management in Chesapeake Bay.

A BASIS FOR SUB-SEGMENTING OPTIONS IN THE OPEN WATER DESIGNATED USE

A Historical Review on the Comparability of Nearshore and Offshore Water Quality in Chesapeake Bay Tidal Waters.

The question of comparability of nearshore to offshore, midchannel water quality is a Chesapeake Bay issue with precedent. Batiuk et al. (2000) noted several such studies between 1991 and 1996 suggesting mid-channel data can be used to describe nearshore conditions. However, not all studies were in agreement. This issue was further assessed with Chesapeake Bay Program Long term Water Quality Monitoring Program data by Karrh (1999) and Batiuk et al. (2000). In a 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 and found wide variations between nearshore and mid-channel conditions both within and between tributaries (U.S. EPA 2007a). However, all 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 to support separating the open water designated use into nearshore and offshore zones for the purpose of dissolved oxygen criteria attainment assessments. However, with the evolution of the CBP Shallow Water Monitoring Program (Appendix 3) measuring water quality conditions in high-temporal and spatial densities, multiple years of nearshore habitat data were collected across a wide range of site conditions from across the tidal waters of the Chesapeake Bay, and in neighboring estuaries (e.g. the Maryland and Virginia Coastal Bays). The CBP's UCAT used more than a decade of Bay-derived high temporal density dissolved oxygen data to help characterize dissolved oxygen behavior across multiple time scales and habitats (CBP STAC 2012). The combined data sets contained more than 1 million data points. Intrasite, intersite and interannual variability are described. (http://www.chesapeakebay.net/channel_files/19060/final_umbrellacriterion_stacpub.pdf). A foundation of new dissolved oxygen focused analyses was created from the Chesapeake Bay Monitoring Realignment Action Team effort (MRAT 2009) and, work from the UCAT (CBP-STAC 2012). Byproducts of the UCAT effort helped inform the issue of nearshore versus offshore habitat comparability from the Chesapeake Bay Program perspective of dissolved oxygen behavior.

Characteristics of Chesapeake Bay High Frequency Dissolved Oxygen Dynamics With An Emphasis on Shallow Water Habitat.

The analysis of high temporal density dissolved oxygen data from the nearshore habitats, often show a diel scale of hypoxia (CBP-STAC 2012). Some locations experience severe hypoxia (e.g. Ben Oaks, Severn River, MD in Figure 4; see also Boynton et al. Appendix 4 *in* CBP-STAC 2012). 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 (see also Boynton et al. Appendix 4 *in* CBP-STAC 2012, U.S. EPA 2007a). Previously, U.S. EPA (2007a) suggested shallow water did not experience significant low dissolved oxygen levels.

Time series of nearshore continuous dissolved oxygen monitoring data further illustrate hypoxic and anoxic events beyond the diel scale. One example, illustrated from the Maryland Department of Natural Resources Piney Point monitoring site on the lower Potomac River, shows the intrusion of anoxic deep layer waters of the Bay into shallow water during a seiching event (Figure 5). Degraded dissolved oxygen conditions persisted beyond a diel cycle with habitat impacts evident for 48-72 hours while temperature and salinity were slower to recover to pre-event conditions. A second example from the Corsica River, MD (Figure 6) illustrated the impact of a nearly week-long water quality and fish kill event involving an algal die off during late September 2005; bacterial decomposition effects reduced dissolved oxygen measures to anoxia followed by a multiday recovery to normoxic conditions (CBP-STAC 2012). Boynton et al. (2014) examined high temporal density dissolved oxygen data records for full summer seasons (n=57) showing nearshore locations across Maryland tidal waters can experience a gradient of hypoxia from minutes to weeks.

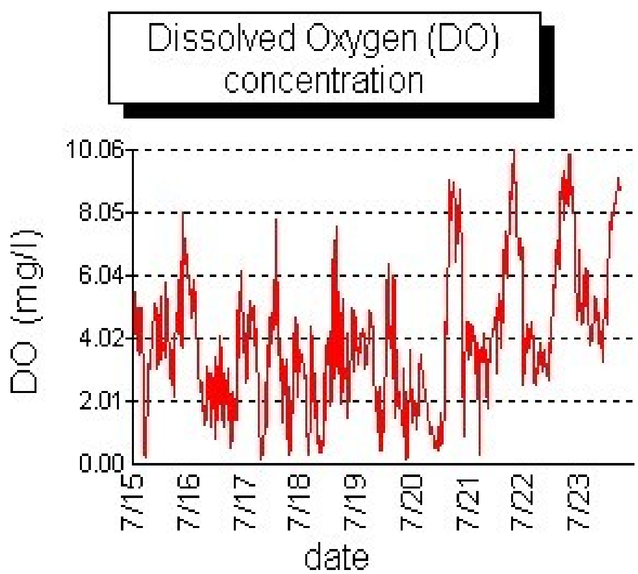

Figure 4. Ben Oaks, Severn River, MD example of diel hypoxia in shallow water. Data collected every 15 minutes. Graphic attributed to Maryland Department of Natural Resources.

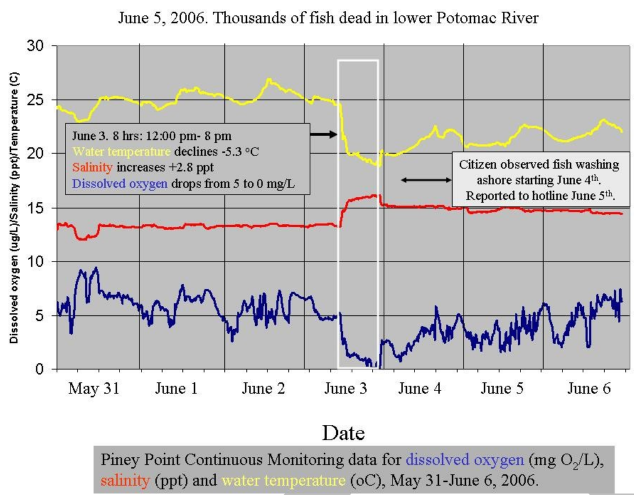

Figure 5. Lower Potomac River Piney Point Continuous Monitoring data (MD DNR) from May 31- June 6, 2006 shows intrusion of anoxic waters from the Bay. Such an intrusion affecting nearshore dissolved oxygen resources was linked with climate forcing effects of wind direction changes on 6/3/06 and a resulting seiche of bottom waters of the mainstem Bay. Graphics from P. Tango.

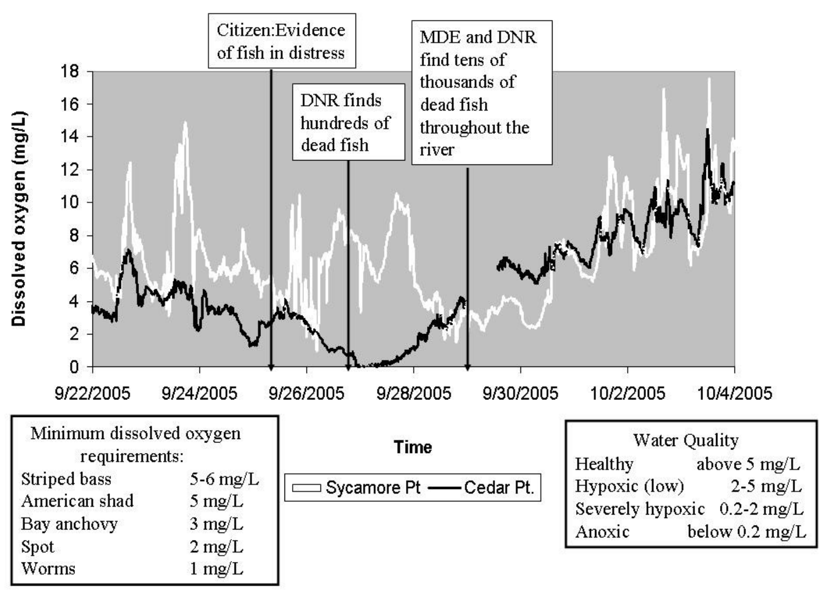

Figure 6. Corsica River, MD, 2005. Chronology of a fish kill and associated water quality. Graphic from Mark Trice, MDDNR originally released in P. Tango, 2005 Waterman's Gazette.

Based on Potomac River continuous monitoring data over multiple years and across seasons, seasonal shifts in dissolved oxygen concentration 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 and Perry Appendix 11 *in* CBP-STAC 2012). Perry (Appendix 11 *in* CBP-STAC 2012) combined data from 9 Potomac River sites and suggested spring may be more variable than summer and autumn.

Buchanan (Appendix 1B *in* CBP-STAC 2012) computed daily means at the 20 tidal Potomac embayment and river flank stations from 2004-2008 and showed a spring season range between 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. The Potomac River data 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.

Diel patterns in dissolved oxygen concentrations showed a positive bias with daytime measurements and negative bias for nighttime measures (Buchanan; Perry with Figure 8 from Perry Appendix 11 *in* CBP-STAC 2012)

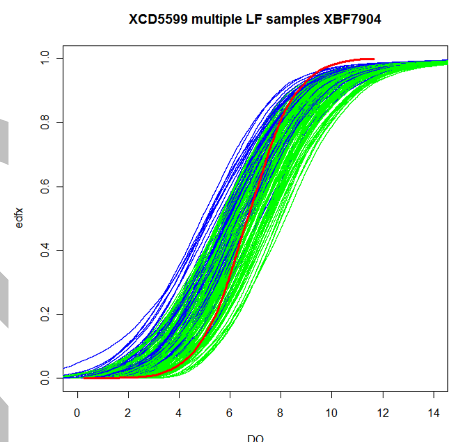

Figure 7. Empirical distribution functions illustrate variation in dissolved oxygen measurements due to multiple low-frequency samples from the receiving site using a Fourier Series interpolation. The sending site data set was held constant as a single two-week interval. Blue curves are synthetic DO 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.

SUPPORT FOR A 2-ZONE SUB-SEGMENTATION OPTION IN THE OPEN WATER DESIGNATED USE: NEARSHORE-OFFSHORE DISSOLVED OXYGEN RELATIONSHIPS.

Based on the UCAT analysis of high frequency continuous monitoring data from multiple tributaries across the Chesapeake Bay tidal waters, the behavior of nearshore dissolved oxygen concentrations was statistically similar to offshore dissolved oxygen concentrations at long time scales (7-day and 30 day mean assessments). However, nearshore dissolved oxygen concentration patterns through time were, statistically dissimilar at daily or shorter time steps (CBP-STAC 2012). In 2013, the Scientific and Technical Assessment Team's TMAW revisited the question with a paired comparison analysis of the best available high frequency, nearshore and offshore water quality monitoring data sets. Robertson and Lane previously used comparisons of nearshore continuous dissolved oxygen concentration monitoring data with synthesized offshore dissolved oxygen concentration data developed using a spectral casting technique (CBP-STAC 2012). Robertson (2013 TMAW) updated the analysis by replacing synthesized offshore data and using direct measurements from Virginia's offshore York River and Rappahannock River vertical water quality monitoring profilers to compare with co-located nearshore continous water quality monitoring measurements. Robertson's analyses reconfirmed the initial findings of CBP-STAC (2012) similarity between nearshore and offshore dissolved oxygen behavior at 7-day and 30-day mean scales of comparison but dissimilar at 1-day and instantaneous minimums.

Trice (2013 TMAW) provides additional insights into Robertson's findings regarding differences in dissolved oxygen patterns at the shortest time scales by 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. Trice showed nearshore conditions were worse 22 and 39 more days than offshore, respectively. Figure 9 provides a 2005 example from Trice (MD DNR) of hourly average comparisons illustrating the tendency for shallow water conditions to be lower than offshore for these two co-located sites. Boynton et al. 2014 described few differences between hourly averaged and 15 minute interval data for examining violation rate assessments.

These findings support sub-segmentation considerations might between nearshore and offshore habitats for the shortest duration criteria (e.g. instantaneous minimum of the open water designated use).

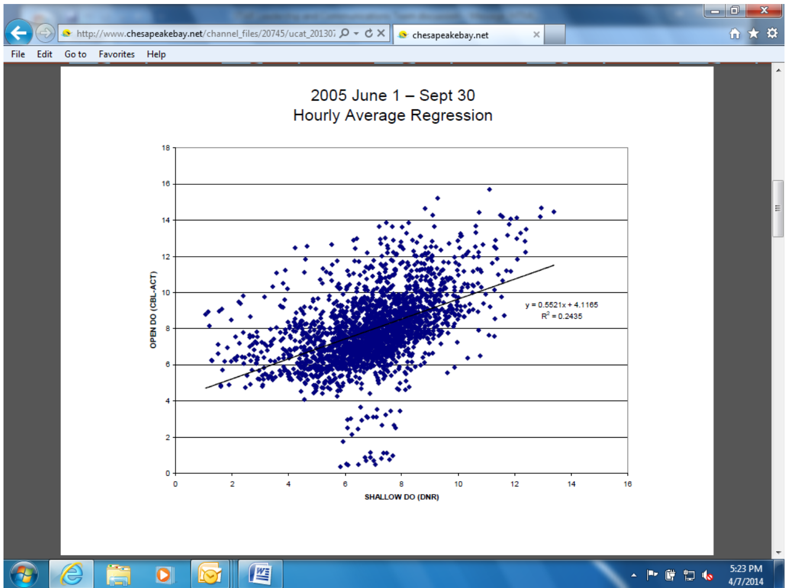

Figure 8. 2005 example of hourly average comparisons illustrating the tendency for nearshore shallow water conditions to be lower than offshore, Patuxent River. (MD DNR, Mark Trice)

SUPPORT FOR A 3-ZONE SUB-SEGMENTATION OPTION OF THE OPEN WATER DESIGNATED USE.

An extension of the 2-zone option to a 3-zone sub-segmentation option in the open water designated use is supported. Caffrey (2004) and Boynton et al. (2014) find that nearshore monitoring sites with greater exposure to mainstem Bay and mainstem tributary habitats show better water quality conditions than sites with more restricted exposures. Boynton et al. (2014) points to tributaries of tributaries having greater violation rates on average than monitoring stations located in the nearshore zone of the main body of a tributary, and more again than monitoring sites exposed to the open waters of the mainstem Bay. The science is consistent with the 3-zone approach in U.S. EPA (2003) 305b guidance highlighting how Washington State Department of Ecology similarly divides estuarine habitats to define monitoring site representativeness: open water, sheltered bays and highly sheltered bays. Virginia Department of Environmental Quality already 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). The 3-zone approach therefore offers and extension of the 2-zone approach option to sub-segmenting the open water designated use considering an additional zone accommodating the finer resolution of small waters in the tributaries of tributaries that are most sheltered, like the highly sheltered bays category suggested by Washington State.

RECOMMENDATION

RECOMMENDATIONS FOR OPTIONS SUPPORTING SUB-SEGMENTATION OF THE OPEN WATER DESIGNATED USE FOR DISSOLVED OXYGEN WATER QUALITY STANDARDS ATTAINMENT ASSESSMENT

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 long-term tidal water quality monitoring program.

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

Therefore, the CAP WG, supported by the UCAT, 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 across space in a region (e.g. management segment) over long averaging periods (i.e., 7-day mean, 30-day mean).

- However, short-duration (i.e., instantaneous minimum) time scale assessments of dissolved oxygen dynamics were shown to be significantly different between co-located nearshore and offshore habitats. Two and three categories of exposure effects have been described to justify and support States options in requesting sub-segmentation 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.

    - OPTION 1. 2-ZONES

        - Zone 1: Offshore. Subject to the Open Water designated use assessment.
        - Zone 2: Sub-segment a nearshore zone adjacent to open water. Sub-segmentation 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.

    - OPTION 2. 3-ZONES.
        - Zone 1: Offshore. Subject to the Open Water designated use assessment.

- Zone 2: Sub-segment a nearshore zone adjacent to open water. Sub-segmentation 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.
- Zone 3: Sub-segment subestuaries off the mainstem tributaries and Bay. Sub-segmentation 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).

Habitat specific protocols of instantaneous minimum dissolved oxygen assessment are provided in chapter 5, *Assessing Dissolved Oxygen Criteria Attainment: A Focus on Short-Duration Criteria Attainment Assessments,* this document.

LITERATURE CITED

Batiuk, R. W.M. Kemp, P. Bergstrom, M. Kemp, E. Koch, L. Murray, J. Court Stevenson, R. Bartleson, V. Carter, N.B. Rybicki, J.M. Landwehr, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K.A. Moore, S. Ailstock and M. Teichberg. 2000. Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis. CBP/TRS 245/00. EPA 903-R-00-014. December 2000. EPA Chesapeake Bay Program, Annapolis MD. 220pp.

Boyton, W.R., J.M. Testa, C.L.S. Hodgkins, J.L. Humphrey, and M.A.C. Ceballos. 2014. Maryland Chesapeake Bay Water Quality Monitoring Program. Ecosystem Processes Component. Level one Report No. 31. Interpretive Report. August 2014. Tech. Report Series No. TS-665-14 of the University of Maryland Center for Environmental Science. UMCES-CBL 2014-051.

Caffery, 2004. Factors controlling net metabolism in U.S. Estuaries. Estuaries 27(1):90-101.

CBP-STAC 2012 *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*: Findings of the Umbrella Criterion Action Team Tidal Monitoring and Analysis Workgroup (TMAW) August 2012, STAC Publ. 12-02, available at: http://www.chesapeakebay.net/channel_files/19060/final_umbrellacriterion_stacpub.pdf .

Karrh, L.1999. Comparison of Nearshore and Midchannel Water Quality Conditions. 200pp. Chesapeake Bay Program, Annapolis, Maryland.

Muller, A. and D. Muller. 2014. Analysis of nontidal point pollution, variability and sustainability in mesohaline tidal creeks. Marine Poll. Bull. 85:204-213.

Lyerly C.M., A.L. Hernandez Cordero, K.L. Foreman, S.W. Phillips, W.C. Dennison. 2014. New insights: science-based evidence of water quality improvements, challenges and opportunities in the Chesapeake. http://ian.umces.edu/press/reports/publication/438/new_insights_science_based_evidence_of_water_quality_improvements_challenges_and_opportunities_in_the_chesapeake_2014-02-24/

Trice 2013 TMAW (Weblink to presentation needed)

Robertson 2013 TMAW (Weblink to presentation needed)

Severn River Riverkeeper. Dead Zones. Weblink needed.

U.S. Environmental Protection Agency. 2003a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries*. EPA 903-R-03-002. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability*. EPA 903-R-03-004. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

USEPA 2003 305b guidance. : http://water.epa.gov/type/watersheds/monitoring/upload/2003_07_03_monitoring_305bguide_v2ch2.pdf

U.S. Environmental Protection Agency. 2004a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries. 2004 Addendum*. EPA 903-R-03-002. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability – 2004 Addendum*. EPA 903-R-04-006. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2007a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries—2007 Addendum*. EPA 903-R-07-003. CBP/TRS 285-07. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2007b. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries—2007 Chlorophyll Criteria Addendum*. EPA 903-R-07-005. CBP/TRS 288-07. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2010. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries—2010 Technical Support for Criteria Assessment Protocols Addendum. May 2010. EPA 903-R-10-002.* Region III Chesapeake Bay Program Office, Annapolis, MD.

VADEQ 2014 the 305(b)/303(d) assessment guidance manual. The 2014 Draft guidance manual is found at http://www.deq.state.va.us/Programs/Water/WaterQualityInformationTMDLs/WaterQualityAssessments/2014DraftWQAGuidanceManual.aspx

Chapter 4

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

BACKGROUND

Assessment of either submerged aquatic vegetation (SAV) acreage, water clarity acres or a combination of both, serves as the basis for determining attainment or impairment of the shallow-water Bay grasses designated use in Chesapeake Bay, its tidal tributaries and its embayments (U.S. EPA 2007). In the absence of sufficient shallow-water monitoring data to determine the availability of water clarity acres or assess water clarity criteria attainment using the Cumulative Frequency Distribution-based assessment procedure, the EPA recommends that the states assess shallow-water bay grass designated use attainment based on the acres of the annual overflight mapping and analysis of SAV (see Chapter 8 of U.S. EPA 2007).

The SAV restoration acreage 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.

From 2012 to 2014, the Chesapeake Bay Program's Criteria Assessment Protocol Workgroup (CAP WG) conducted a water quality criteria assessment protocols review process in support of the 2017 TMDL mid-point assessment. Chesapeake Bay Program staff identified a difference between the 2003 SAV restoration goal target (185,000 acres) adopted by the Chesapeake Bay Program partnership and the SAV target acreage goal based on the sum of Chesapeake Bay water quality standards for the 92 management segments (192,000 acres). The basis, derivation, revision and adoption of the 185,000 acre bay-wide SAV 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). The subsequent development of the water quality standards was not, however, a direct adoption of the published U.S. EPA (2003a) 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 (SAV WG) assisted the CAP WG 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 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. In setting the 192,000 acre SAV goal, the States had the benefit of the body of history used to develop the 185,000 acre goal and new information available after the publication of U.S. EPA (2003a) and adoption of the water quality standards. 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.

The following chapter reviews the history of establishing Chesapeake Bay SAV target restoration goals supporting the assessment of water quality standards attainment for the water clarity standard in the shallow-water bay grass designated use. The results of the review support updating the Chesapeake Bay Program partnership's SAV restoration goal to be consistent with the Bay jurisdictions combined water quality standards based target for Bay grasses of 192,000 acres.

SAV RESTORATION GOAL HISTORY IN BRIEF

The original tiered SAV restoration acreage goal 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 SAV restoration targets were supporting 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).

U.S. EPA (2003b, p.118) reported that the Chesapeake Bay 2000 agreement committed to revising the existing SAV 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 a*"*historical" SAV distribution as being assessed from aerial photographs from the 1930s to the early 1970s (U.S. EPA 2003b). 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 2003b). SAV abundance was classified according to Chesapeake Bay management segments and depths that were designated for the new Chesapeake Bay shallow-water bay grass designated use (U.S. EPA 2003a, b).

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 the shallow water bay grass use (U.S. EPA 2003a). U.S. EPA (2003b, 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 the 185,000 acre goal adoption consistent with the goals of Chesapeake 2000.). Goal options were provided during the revision process that 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) U.S. EPA (2003b, p119).

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

During 2013 and early 2014, the SAV WG of the CBPs Habitat Goal Implement Team reviewed the SAV restoration acreage goal setting methodology (used to determine the single best year of SAV abundance). Chesapeake Bay Program staff working with the SAV WG identified differences between the segment-specific SAV restoration acreage targets supporting the 185,000 acre goal published in 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 Chesapeake Bay Program partnership used data through 2000 for its single best year assessment and considered a 2001 underwater acreage total (U.S. EPA 2003b, Figure IV-31) as a potential goal when setting the 185,000 acre restoration target. The subsequent 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.

The 2003 goal setting approach leading to the 185,000 SAV acre goal included many cases of undercounting SAV. The undercounting was due to estimated acres of SAV with 'clipped' SAV beds within the GIS analyses. '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 clipped SAV from a segment as viewed through the lens of GIS because it would be classified as being 'on land' and could not have an associated bathymetry for that area. The inaccuracy of the GIS 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 shoreline data set (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 underwater flats around islands due to shifting shorelines. This issue is acknowledged in U.S. EPA (2004, pp92-93).

To account for the SAV undercounting issues, "*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). Further, as described in U.S. EPA (2004), EPA recognizes the officially adopted SAV restoration goals involved in defining the 185,000 acre goal but encouraged 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 Chesapeake Bay management segments. SAV in these ponds was excluded. Lack of bathymetric data affected the accounting for SAV in 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 acreages for each Chesapeake Bay management segment, U.S. EPA (2004) 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 segment-specific submerged aquatic vegetation (SAV) restoration goal acreages…necessary to support restoration of those acreages of SAV into each jurisdiction's 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 Program SAV WG working with 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. With few exceptions around the Bay, the water quality standards segment-specific management goals for SAV restoration acreages are equal to or greater than the segment acreage goals supporting the 185,000 acres. The Chesapeake Bay tidal water jurisdictions of Maryland, Virginia, Delaware and Washington, D.C. were consistent in their consideration for adding back previously missing acres into the management segment goals due to GIS method-related clipping away of visible SAV acres on the aerial photographs. Most of these 'clipped' acres were considered as 'on land' even though they were clearly visible and identifiable between the GIS layer land boundary and the shoreline of the photographs. Additional excluded acres that were added back to the segments had previously missing bathymetry or were segments without established goals (Table 1).

Table 1. Summary of the decision support provided to derive the water quality standards acreages by Chesapeake Bay management segment.[1]

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

1. This table uses the split segments as individual segments. It is a comparison of water quality standards 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.

RECOMMENDATION

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

The 192,000 acre goal is the sum of water clarity acre water quality standards for the tidal water Bay states of Maryland, Virginia and Delaware and Washington D.C. 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. 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).

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 for segments without goals at this time. The Chesapeake Bay Program SAV WG could work to develop SAV acreage goals. The basis of the recommended bay-wide SAV restoration goal is firmly established in the underlying support developed for the originally published 185,000 SAV acreage goal. 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, for example, Maryland adopted the Virginia model, the additional deep water acres in Maryland beyond their existing goal acreages would increase the 192,000 goal by about 14,000 acres to 206,000. 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.

Literature Cited

Batiuk, R. A., R. J. Orth, K. A. Moore, W. C. Dennison, J. C. Stevenson, L. W. Staver, V. Carter, N. B. Rybicki, R. E. Hickman, S. Kollar, S. Bieber, and P. Heasly. 1992. *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis.* Chesapeake Bay Program, Annapolis, MD., CBP/TRS 83/92, Contract No. 68-WO-0043. 248 pp.

Batiuk, R. W.M. Kemp, P. Bergstrom, M. Kemp, E. Koch, L. Murray, J. Court Stevenson, R. Bartleson, V. Carter, N.B. Rybicki, J.M. Landwehr, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K.A. Moore, S. Ailstock and M. Teichberg. 2000. Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis. CBP/TRS 245/00. EPA 903-R-00-014. December 2000. EPA Chesapeake Bay Program, Annapolis MD. 220pp.Chesapeake Executive Council 1989. *Submerged Aquatic Vegetation Policy for the Chesapeake Bay and Tidal Tributaries.* Annapolis, MD. July.

Chesapeake Executive Council. 1993. *Submerged Aquatic Vegetation restoration goals directive 93-3. U.S. EPA. Annapolis, MD.*

Dennison, W. C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Koller, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Bioscience. 143:86-94.

U.S. Environmental Protection Agency. 2003a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries*. EPA 903-R-03-002. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* EPA 903-R-03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries. 2004 Addendum*. EPA 903-R-03-002. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2007. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2007 Addendum. July 2007*. EPA 903-R-07-003. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

Chapter 5

Assessing Dissolved Oxygen Criteria Attainment: 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, U.S. EPA 2003a, Kemp et al. 2004). 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 protect 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 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), 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 $\geq$ 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 $\geq$ 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 $\geq$ 5.5 mg/L (tidal habitats with $\leq$0.5 salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species	Year-round
	30-day mean $\geq$ 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 $\geq$ 4 mg/L	Survival of open-water fish larvae.	
	Instantaneous minimum $\geq$ 3.2 mg/L	Survival of threatened/endangered sturgeon species[1]	
Deep-water seasonal fish and shellfish use	30-day mean $\geq$ 3 mg/L	Survival and recruitment of bay anchovy eggs and larvae.	June 1 – September 30
	1-day mean $\geq$ 2.3 mg/L	Survival of open-water juvenile and adult fish	
	Instantaneous minimum $\geq$ 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 $\geq$ 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

APPROACHES TO INFORM CHESAPEAKE BAY WATER QUALITY MONITORING AND ASSESSMENT STRATEGY: SHORT-DURATION DISSOLVED OXYGEN CRITERIA ASSESSMENT 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, 2007). 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 (2007 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, 2007, 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 2. 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 protecting 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.

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 4, 5)

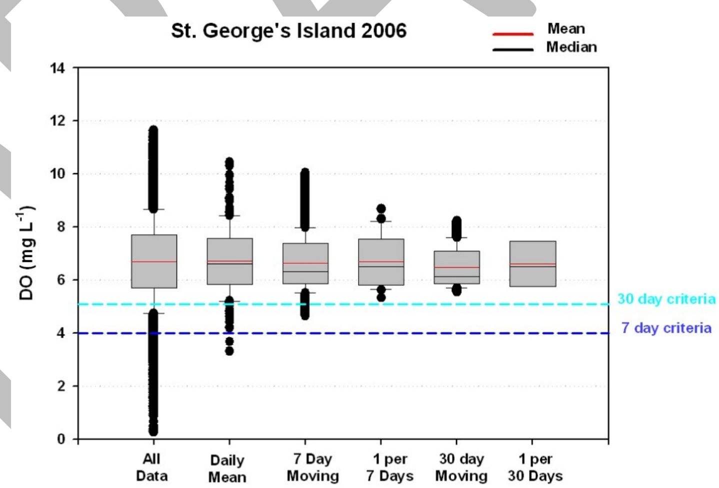

Figure 1. Box and whisker plots for summer season assessments of St. George Island 2006 continuous dissolved oxygen monitoring data.

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 2). 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 6).

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.

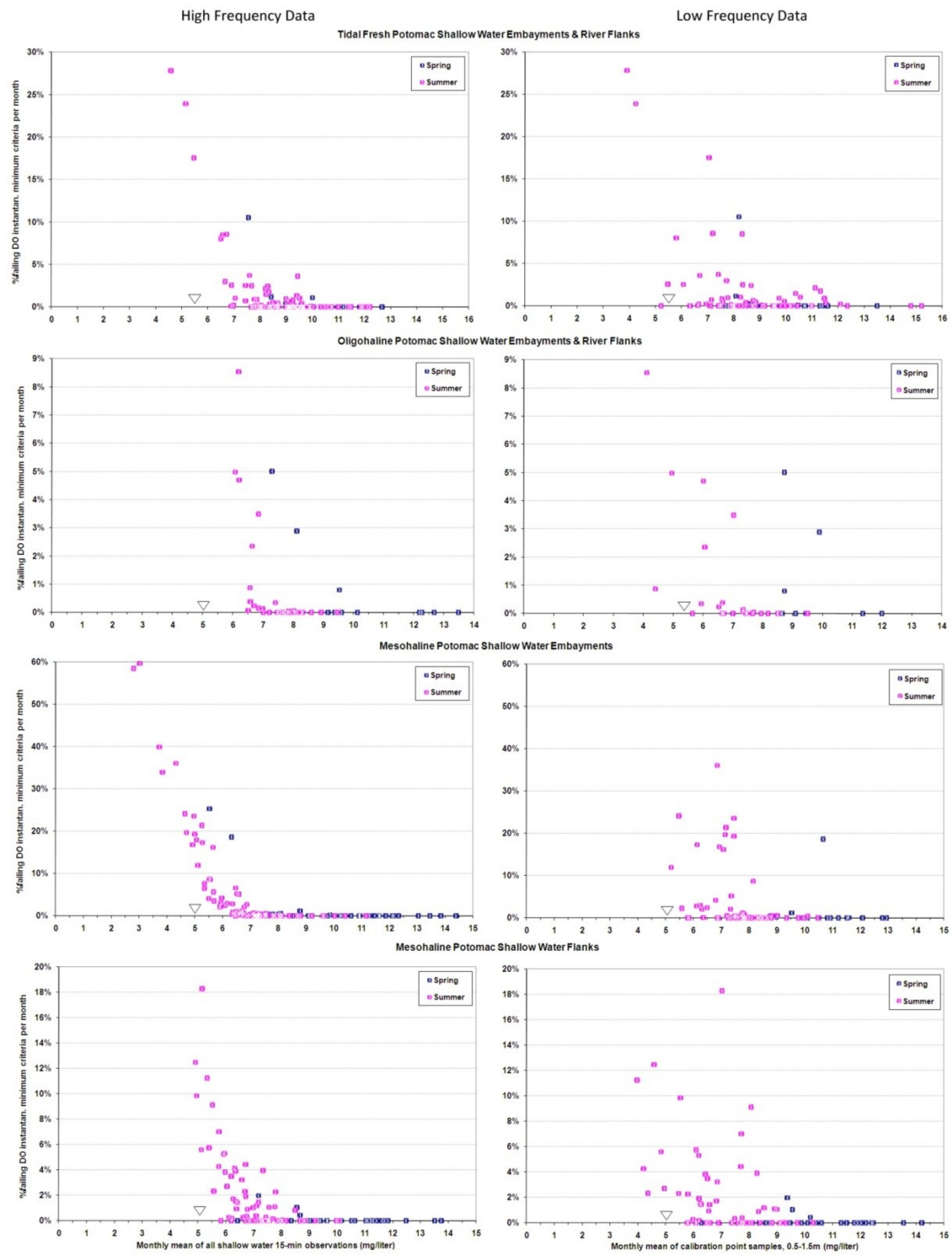

Figure 2. Example of biplots with frequency per month using rolling 7-day periods (1-day step) fail the 7-day mean DO criteria, plotted against the corresponding 30-day mean DO. Overall, 175 of the 415 months (42.2%) represented in the 20 tidal Potomac shallow water stations between 2004 and 2008 had failures of the instantaneous minimum DO criteria. Most instantaneous minimum criteria failures occurred in months where the 30-day mean criteria are met (Appendix 6)

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 (Figure 3). 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 7.

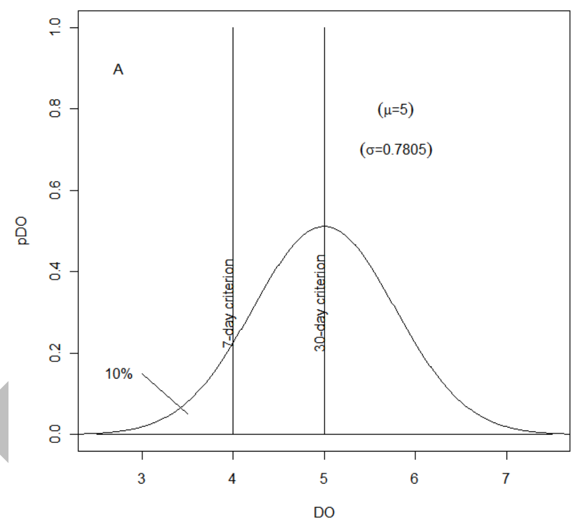

Figure 3. Illustration of the level of variability of the 7-day mean about the 30-day mean that results in up to 10 % violations of the 7-day mean criterion when the 30-day mean criterion is met.

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 4 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 8 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 9 provides details of the analysis approach.

REASSESSMENT OF THE SPECTRAL CASTING METHOD FOR FILLING DATA GAPS: 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. 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). 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.

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.

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 the 30-day 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) when dealing with temporally sparse data.*
    - *Data variability affects the 30-day mean threshold needed for protecting the shorter-duration criteria.*
    - *The 30-day mean thresholds differ depending on the short-duration criteria being protected.*

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 4). 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).

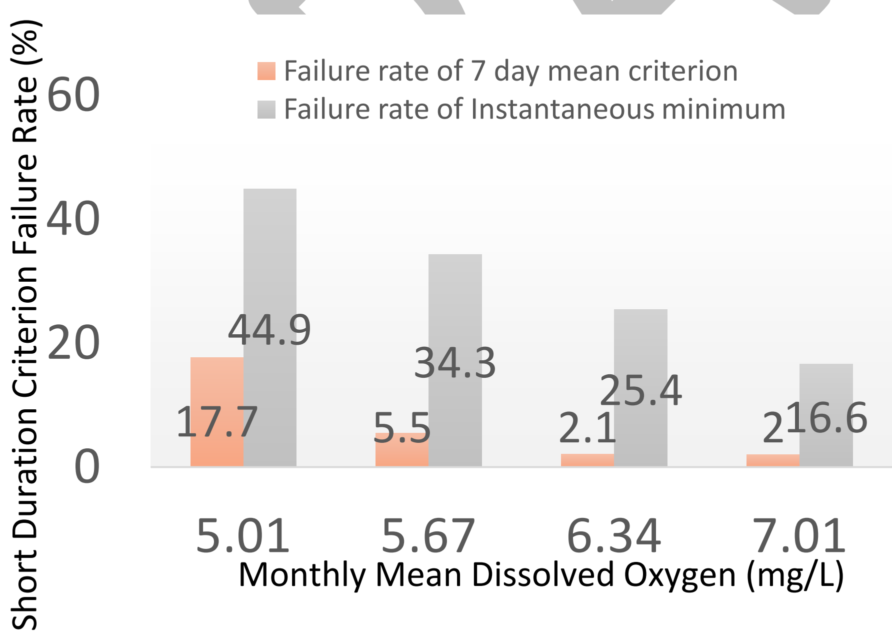

Figure 4. Summary of violation rates over levels of sensor depth to illustrate time series violations associated with a gradient of open water 30-day means in dissolved oxygen. Results were derived from high frequency sensor data at depths of 6,5,4,3 m respectively.

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 3 below).

DISSOLVED OXYGEN THRESHOLDS TO INFORM UMBRELLA PROTECTION OF THE SHORT DURATION CRITERIA.

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 to protect decisions from the uncertainty surrounding estimating a 30-day mean from 1-2 samples per month. As the measured mean estimated from two samples gets higher above the 30-day criterion, the ability to insure protection of achieving attainment for short-duration criteria improves.

Applying a 30-day mean threshold dissolved oxygen value above the criterion value is necessary to demonstrate mutual protection of one criterion result for another criterion. No published criteria are changed. The 30-day mean threshold value is necessary to account for uncertainty due to sampling variability and the natural variability expressed by the parameter of interest, i.e. dissolved oxygen. Assessing dissolved oxygen attainment using the threshold values therefore limits the risk in decisions regarding nonattainment of protecting a shorter duration criterion.

UCAT results show that a 30-day mean of at least 6.1 mg/L is required to limit the risk of nonattainment to ≤ 10% based on two water quality sample assessments per month. By comparison, computing the 30-day mean for the same location based on data collected at 15 minute intervals requires a mean of 5.3 mg/L to limit the risk of nonattainment to ≤ 10%. These results highlight the return on investment in monitoring to support decision-making showing the difference in thresholds needed for achieving mutual protection of criteria that are lower when data temporal density is high compared with low temporal density data. The following example illustrates the application of the Umbrella Criterion Approach for a bay-wide assessment.

AN EXAMPLE OF APPLICATION OF THE UMBRELLA CRITERION APPROACH FOR DISSOLVED OXYGEN WATER QUALITY STANDARDS ATTAINMENT IN CHESAPEAKE BAY

To illustrate the combined effects of sample size and dissolved oxygen thresholds when making decisions on protecting multiple short duration criteria using the 30-day mean criterion, CBP staff conducted a test of the Umbrella Criterion approach to dissolved standards attainment assessment of open water summer season conditions. This real example is based on dissolved oxygen attainment assessments conducted for 2011-2013 Chesapeake Bay data.

To account for uncertainty on making a statement of support for attainment when the 30-day mean is based on 2-samples, Table 3 indicates a minimum dissolved oxygen value of 6.1 mg/L to limit the risk of nonattainment to 10% for a statement about attaining the 7-day mean dissolved oxygen criterion. In order to make this assessment the dissolved oxygen attainment assessment was first conducted on the 30-day mean as a standard assessment with the criterion of 5.0 mg/L according the published method 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).

Next, the same assessment program is rerun on the same data changing only the criterion of 5.0 mg/l to 6.1 mg/L. The effect of this change is to now apply the Umbrella Criterion protection threshold rule for the short duration criterion to the same data. In this case 6.1 mg/L in order to make an assessment on the protection of the 7-day mean dissolved oxygen attainment. The output regarding attainment for each segment is interpreted at segments where meeting the 30-day dissolved oxygen mean threshold of 6.1 mg/L not only protects the 30-day mean of 5.0 mg/L, but now is shown to further protect the 7-day mean with no more than a 10% risk of nonattainment as the decision-rule.

Figure 4 illustrates how we may apply the same assessment again to evaluate the 30-day mean protection of the instantaneous minimum. For this example, the analyses to date show that a 30-day mean of 7.0 mg/L based on 2 samples per month is needed if we accept a risk of non-attainment of 16.6% instead of 10%. A 30-day mean greater than 7.0 mg/L, based on the results to date about 7.3 mg/L, would be needed to limit the risk of nonattainment of the 30-day mean protecting the instantaneous minimum at a level of 10%. CBP staff however evaluated the 2011-13 results using 6.5 and 7.0 mg/L for illustration purposes demonstrating the effect of higher thresholds necessary for attainment assessments.

Table 3. 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

The summary table below (Table 4) illustrates the application of the Umbrella Criterion. Forty segments meet the 30-day mean 5.0 mg/L summer mean open water dissolved oxygen criterion. Of those, 8 segments also meet the 6.1 mg/L threshold. These 8 segments meeting the 6.1 mg/L threshold, can be effectively stated as also in attainment for the 7-day mean criterion as supported by a 10% level of acceptable risk decision-rule.

If more stringent decision rules are applied, e.g. a 30-day mean must meet a threshold of 6.5 mg/L, then no segments are in attainment for the 7-day mean. If we further consider the assessment of the 30-day mean protecting the instantaneous minimum with an acceptable risk of 16.6% (threshold = 7.0 mg/L), then we see no segments where the data available at 2-sampes per month can be said to show mutual protection for the 30-day mean and the instantaneous minimum dissolved oxygen criterion.

Table 4. Results of applying the Umbrella Criterion approach to 2011-13 dissolved oxygen water quality standards attainment assessment for open water summer conditions. Tests are for two thresholds compared with 7-day mean dissolved oxygen criterion attainment assessment (6.1 mg/L and 6.5 mg/L) and instantaneous minimum (7.0 mg/L).

Segments attaining the 30-day mean open water summer criterion of 5.0 mg/L 2011-2013 assessment	Segments that also pass at the threshold level of 6.1 mg/L for mutual protection of the 7-day mean.	Segments that also pass at the level of 6.5 mg/L for mutual protection of the 7-day mean.	Segments that also pass at the level of 7.0 mg/L for mutual protection of the instantaneous minimum.
CB1TF, CB3MH, CB4MH, CB5MH, CB8PH, CHSMH, EASMH, JMSMH, JMSPH, JMSTFU, MPNTF, PIAMH, PMKTF, POCMH, MPCMH, VPCMH, POTMH, POMMH, POVOH, POTTF, DCPTF, MDPTF, TAMMH, APPTF, BIGMH, BOHOH, CNDOH, CHKOH, ELKOH, FSBMH, MANMH, MD5OH, MIDOH, NANMH, NORTF, PISTF, SASOH, SEVMH, SOUMH, VA5MH	POCMH, MPC, VPCMH, POVOH, APPTF, BIGMH, FSBMH, MANMH	No segments meet requirements for protection of the 7-day mean	No segments meet requirements for protection of the instantaneous minimum

INSTANTANEOUS MINIMUM CRITERION ASSESSMENTS WHEN SUB-SEGMENTING THE OPEN WATER DESIGNATED USE (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 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** (*under review and revision Oct 2014*) 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.
  - 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.

RECOMMENDATION

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 and temporal 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%) for decisions supporting attainment associated with meeting multiple criteria in a designated use when applying the 30-day mean criterion assessment under the present Chesapeake Bay Partnership long-term water quality monitoring program sampling strategy.

- Instantaneous minimum alternative assessment: up to 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 jurisdication.

- 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.

LITERATURE CITED

Brietburg, D.L. 1990. Monitoring dissolved oxygen in a variable environment: Site comparisons and the detection of biologically meaningful events *in* New Perspectives in the Chesapeake System: A research and Management Partnership. Proceedings of a Conference. 1990. CRC Publication No. 137.

CBP-STAC 2012 *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*: Findings of the Umbrella Criterion Action Team Tidal Monitoring and Analysis Workgroup (TMAW) August 2012, STAC Publ. 12-02, available at: http://www.chesapeakebay.net/channel_files/19060/final_umbrellacriterion_stacpub.pdf .

Dunk, Jeffrey R., William J. Zielinkski and Hartwell H. Walsh, Jr. 2006. "Evaluating reserves for species richness and representation in northern California." *Diversity and Distributions*, Vol. 12, 434-442.

Jordan, J., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resource habitats. CBP/TRS 88/93. Chesapeake Bay Program, Annapolis, MD.

Kemp, W.M, W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, L.W. Harding, Jr., E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: Historical trends and ecological interactions. *Marine Ecology Progress Series,* 303:1–29.

Launer, Alan E. and Dennis D. Murphy. 1994. "Umbrella Species and the Conservation of Habitat Fragments: A Case of a Threatened Butterfly and a Vanishing Grassland Ecosystem." *Biological Conservation*, Vol. 69, No. 2, 145-153

MRAT 2009. Monitoring Re-alignment Action Team. Final report to the Chesapeake Bay Management Board. http://www.chesapeakebay.net/content/publications/cbp_52995.pdf

Neerchal, N.K., G. Papush, and R. Shafer. 1992. Statistical method of measuring DO restoration goals by combining monitoring station and buoy data. Chesapeake Bay Program, Annapolis, MD.

Newcombe, C.L. and W.A. Horne. 1938. Oxygen-poor waters of the Chesapeake Bay. Science 88:80-81.

Newcombe, C.L., W.A. Horne and B.B. Shepherd. 1939. Studies of the physics and chemistry of estuarine waters in Chesapeake Bay. Journal of Marine Research 2(2):87-116.

Roberge, Jean-Michael and Per Angelstam. 2004. "Usefulness of the Umbrella Species Concept as a Conservation Tool." *Conservation Biology*, Vol. 18, No. 1, 76-85

Sale, J.W. and W.W. Skinner. 1917. The vertical distribution of dissolved oxygen and the precipitation of salt water in certain tidal areas. Franklin Institute Journal184:837-848.

Shenk and Batiuk 2010

Smith, D.E., M. Leffler and G. Mackiernan (eds.). 1992. Oxygen dynamics in Chesapeake Bay: A synthesis of recent research. Maryland and Virginia Sea Grant College Program, College Park, MD.

U.S. EPA. 2003a. *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. 2004a. *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. 2004b. *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 2007a. *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 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. *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.

U.S. EPA. 2010a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2010 Technical Support for Criteria Assessment Protocols Addendum.* EPA 903-R-10-002. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2010b. *Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment*. U.S. Environmental Protection Agency, Region 3 Chesapeake Bay Program Office, Annapolis, MD.

U.S. EPA Water Quality Standards Handbook (http://water.epa.gov/scitech/swguidance/standards/handbook/chapter03.cfm#section5)

Wilcox, Bruce A. 1984. "In situ conservation of genetic resources: Determinants of minimum area requirements." *In National Parks, Conservation and Development, Proceedings of the World Congress on National Parks*. J.A. McNeely and K.R. Miller, Smithsonian Institution Press, pp. 18-30.

Chapter 6

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

BACKGROUND

The benthic community health assessment supports state's tidal waters Clean Water Act 303d listing decisions for the Aquatic Life designated use. The benthic index of biotic integrity (B-IBI) assessments are separate from the Chesapeake Bay water quality criteria attainment assessment determinations and reported for segments as stand-alone or supplemental information for the states to use in their 303d listing cycle decisions (U.S. EPA 2007).

Maryland (Department of the Environment, Department of Natural Resources), Virginia (Department of Environmental Quality) and U.S. EPA (Region 3 Water Protection Division and Chesapeake Bay Program Office) reached agreement on the protocol to assess Chesapeake Bay benthic community health. The assessment protocol (see Appendix J Chesapeake Bay Estuarine Benthic Communities Assessment Protocol for Maryland and Virginia 305b/303d Integrated Reports in U.S. EPA (2007) builds directly on the more detailed assessment method recommended by Llanso et al. (2005) (see Appendix K 2006 303d Assessment Methods for Chesapeake Bay Benthos in U.S. EPA (2007). This methodology assures bay-wide consistency in determinations of estuarine benthic impairments.

Phase I of a three phase protocol supporting estuarine benthic impairment assessment involves evaluation of the sample size available from the waterbody segment during the six-year assessment window. Sample size requirements are $n \geq 10$ to effectively apply the B-IBI assessment for aquatic life use assessment of Chesapeake Bay management segments. If the sample size requirement is not met an impairment based solely on these analyses is not possible. The 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 U.S. EPA (2004) "*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.

Phase II consists of the impairment assessment of aquatic life use attainment based on a comparison of Benthic Index of Biotic Integrity (B-IBI) scores and can only be performed when the number of B-IBI scores within a specified water body segment is sufficient to meet the sample size requirements of the approved statistical method ($n \geq 10$). Phase II can result in one of two possible outcomes: (1) the segment is not impaired for Aquatic Life use due to benthic community status, or (2) the segment fails to support aquatic life use due to benthic community status and is assessed as impaired. Best professional judgment can be applied to override (reverse) the outcome of the formal statistical analysis results but such reversals must be justified and documented (U.S. EPA 2007).

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 B-IBI score (<2.7) and 2) high variability in scores producing wide confidence intervals on the B-IBI segment assessment. The Criteria Assessment Protocol Workgroup (CAP WG) 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 for determining the B-IBI scores 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 compared to sediment contaminants. Diagnostic approaches have been developed to determine sources of anthropogenic stress; however, large data sets that were unavailable to Weisberg et al. but are now available can be used today to calibrate the B-IBI.

The CAP WG recognized that most of these issues were under review. A B-IBI revision process was being initiated in 2014 through U.S. EPA Clean Water Act grant support of a B-IBI recalibration. Interim rules for better water quality status categorization of management segments were proposed 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.

This chapter recognizes this suite of issues affecting the use of the Chesapeake Bay B-IBI in water quality status assignments that support assessment of the Aquatic Life use. Best professional judgment in cases involving the range of issues affecting results is codified into an interim decision rule. The rules are intended to be interim in light of new research being supported in 2014 by U.S. EPA to update the reference community database and subsequent recalibration of the B-IBI.

REVISION OF FRAMEWORK FOR BENTHIC INDEX OF BIOTIC INTEGRIY ASSESSMENTS WITH AN INTERIM DECISION RULE

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. The B-IBI methodology 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 or 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 (Table 1). The classification system uses designated uses as the basis for reporting on water quality.

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.

RECOMMENDATION

INTERIM RULES FOR DEFINING CHESAPEAKE BAY AQUATIC LIFE USE WATER QUALITY STATUS.

The recommended interim decision rules addressed the most inconsistent, unreliable water quality status classifications output from the Chesapeake Bay B-IBI. To develop the interim 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 a decision threshold for defining segments where the B-IBI 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 decision threshold because this value was the typical decision threshold for impairment status of a management segment in Chesapeake Bay.

The resulting interim rules recommended 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 are:

- 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 B-IBI 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).

An update of the water quality standards classification table supporting decisions involving the Aquatic Life use in Chesapeake Bay assessments consistent with the application of the recommended interim decision rules is provided (Table 2).

The application of this rule affects four Chesapeake Bay management segments in the most recent 303d listing assessment: In Virginia it affects 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

LITERATURE CITED

Alden, R.W. III. 1992. Uncertainty and sediment quality assessments: Confidence limits for the Triad. Environmental Toxicology and Chemistry 11:645-651.

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical verification of the Chesapeake Bay Benthic Index of Biotic Integrity. Environmetrics 13:473 498.

Dauer, D.M., M.F. Lane, and R.J. Llansó. 2002. Development of diagnostic approaches to determine sources of anthropogenic stress affecting benthic community condition in the Chesapeake Bay. *Draft Guidance for 2014 IR Assessment Methodology* 26 Report submitted to the USEPA Chesapeake Bay Program Office, Annapolis, Maryland, by Old Dominion University Department of Biological Sciences, Norfolk, Virginia. 65 pp.

Efron, B. and R. Tibshirani. 1998. An Introduction to the Bootstrap. Chapman & Hall/CRC.

Llansó, R.J., J.H. Vølstad, and D.M. Dauer. 2003. Decision Process for Identification of Estuarine Benthic Impairments. Final Report submitted to Maryland Department of Natural Resources, Tidewater Ecosystem Assessments, Annapolis, Maryland, by Versar, Inc., Columbia, Maryland.

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. Environmental Protection Agency. 2007a. *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.

Weisberg, S.B., J. A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20:149-158.

Chapter 7

Monitoring to Support Water Quality Standards Attainment of Chesapeake Bay Tidal Waters:

Protocol for Incorporating Nontraditional Partner Data into Regulatory Clean Water Act 303d List Chesapeake Bay Dissolved Oxygen Criteria Attainment Assessments

BACKGROUND

The goal of the Clean Water Act (CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C §1251(a)). Under section 303d of the CWA, states, territories, and authorized tribes, collectively referred to in the act as "states," are required to develop lists of impaired waters. The term "303(d) list" is short for the list of impaired and threatened waters (stream/river segments, lakes) that the CWA requires all states to submit for EPA approval every two years on even-numbered years. The states identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards.

The CWA includes two basic approaches for protecting and restoring the nation's waters. One is a technology-based, end-of-pipe approach, whereby EPA promulgates effluent guidelines that rely on technologies available to remove pollutants from waste streams. These guidelines are used to derive individual, technology-based National Pollutant Discharge Elimination System permit limits. The other approach is water-quality based and is designed to achieve the desired uses of a water. The 303(d) program is at the core of the water-quality based approach.

Water quality standards are the foundation of the water-quality based control program mandated by the CWA. Water quality standards define the goals for a waterbody by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. By adopting water quality standards, states are able to determine which healthy waters need protection, which waters must be restored and how much pollutant reductions are needed. Consequently, these water quality standards set a goal for restoring and protecting a watershed over the long term.

Water quality monitoring provides the data to characterize waters and identify changes or trends in water quality over time. The collection of monitoring data enables states to identify existing or emerging water quality problems and determine whether current pollution control mechanisms are effective in complying with the regulations. The CWA requires that each state monitor and assess the health of all their waters and report their findings every two years to EPA. This list of data and findings is called the 305(b) report or "biennial water quality report."

Under section 303(d) of the CWA, monitoring data as well as other information, must be used by the states to develop a list of "water-quality limited segments," i.e., waters that will not meet water quality standards for a particular pollutant even after a technology-based permit is in place, also known as impaired waters. Regulations say states must evaluate "all existing and readily available information" in developing their 303(d) lists (40 C.F.R. §130.7(b) (5)). Usually due to a lack of resources, most state water quality agencies are able to monitor only a small percentage of their waters consistently enough to detect water quality problems. Many state agencies use data collected from outside organizations and the public to compile their lists. Within the Chesapeake Bay Parternship, these outside organizations and the public are referred to as "nontraditional partners". "Traditional partners" refers to those organizations and entities that have been involved in Clean Water Act 117 program supported long term water quality monitoring programs since the advent of the monitoring efforts by the Chesapeake Bay Program Office in 1984. There are usually requirements for data collection and submission before state agencies will consider the data.

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.

CHESAPEAKE BAY PROGRAM PARTNER DATA

CWA 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 water quality 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 on dissolved oxygen standards attainment is described below.

TRADITIONAL PARTNER DATA

U.S. EPA (2003a) defines the Chesapeake Bay dissolved oxygen, water clarity and chlorophyll 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 protocols of the water quality standards were 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, Appendix 3,* 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.

NONTRADITIONAL PARTNER DATA CONTRIBUTIONS SUPPORT TO WATER QUALITY STANDARDS ATTAINMENT ASSESSMENTS FOR DISSOLVED OXYGEN

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.

RECOMMENDATION

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

Documentation

Quality Assurance Project Plans and Standard Operating Procedures

In the CBP Long term Water Quality 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.

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 1.

Table 1. 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.

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.

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.

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

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 2) and b) WQ_EVENT (Table 3). 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". (as of 10/28/2014: URL to be established.)

Table 2. 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 3. 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			

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.

Sampling Effort

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.

Additional considerations for sampling design and effort by nontraditional partners to support Clean Water Act 303d listing assessments as well as other supplemental data needs supporting decision-making and adaptive management within the Chesapeake Bay Program partnership will be developed through the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team.

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. Wardrop, D. and C. Haywood. Monitoring Re-alignment Action Team Final Report to the Chesapeake Bay Program Management Board on behalf of the Monitoring Re-alignment Synthesis Team. October 27, 2009.

U.S. EPA. 2003a. *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.

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

Chapter 8

Development of a Multimetric Chesapeake Bay Water Quality Indicator for Tracking Progress toward Chesapeake 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 has 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 (U.S. EPA 2003b, 2004a, 2004b, 2005, 2007a, 2007b, 2008, 2010a). 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*".

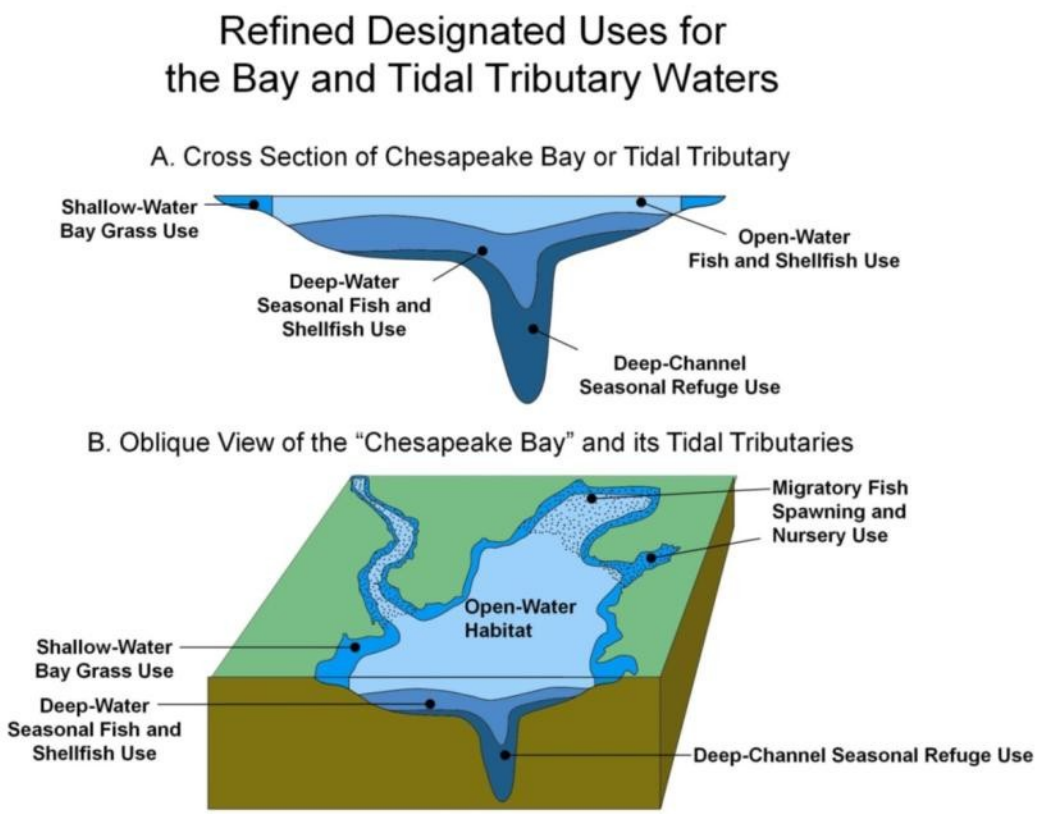

Figure 1. Conceptual illustration of the five Chesapeake Bay tidal water designated use zones.

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 on dissolved oxygen, water clarity, underwater grasses and chlorophyll *a* indicators to chronicle changes in Bay health (http://www.chesapeakebay.net/trackprogress). However, 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 Chesapeake Bay TMDL (U.S. EPA 2010b), 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 bay-grasses and chlorophyll *a*.

RECOMMENDATION

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. These results use the most recent three-year assessment period as the data assessment window. The indicator 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 10.

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 11). 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 (km²)	Total Surface Area of Designated-Use Segment Attaining WQS (km²)	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

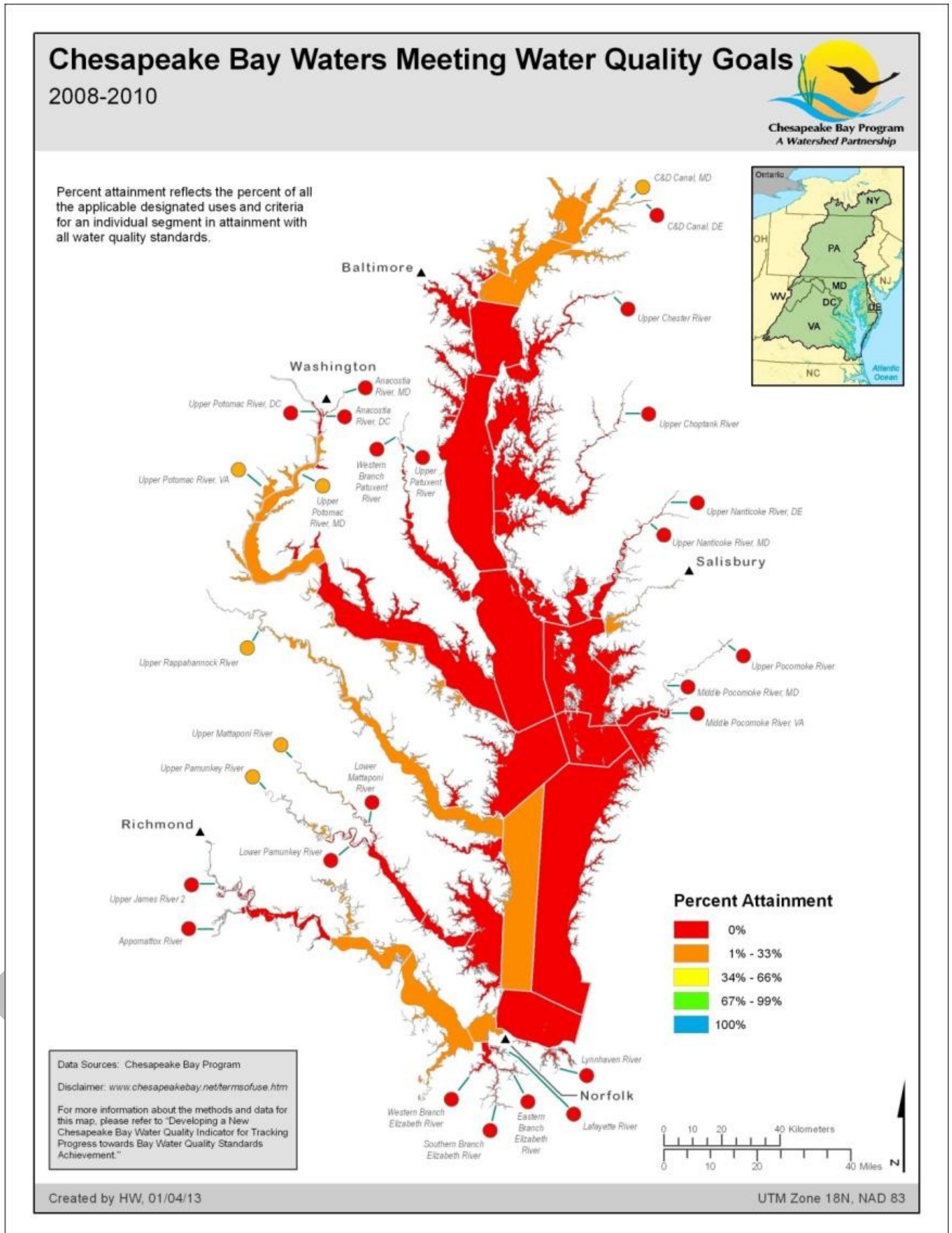

Figure 2. Visual illustration of the water quality standards indicator status, expressed as a percentage, for each of the 92 Chesapeake Bay TMDL segments (2008-2010 listing cycle). The number of water quality criteria applied varies across the 92 Bay segments based on the applicable designated uses (i.e., 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.

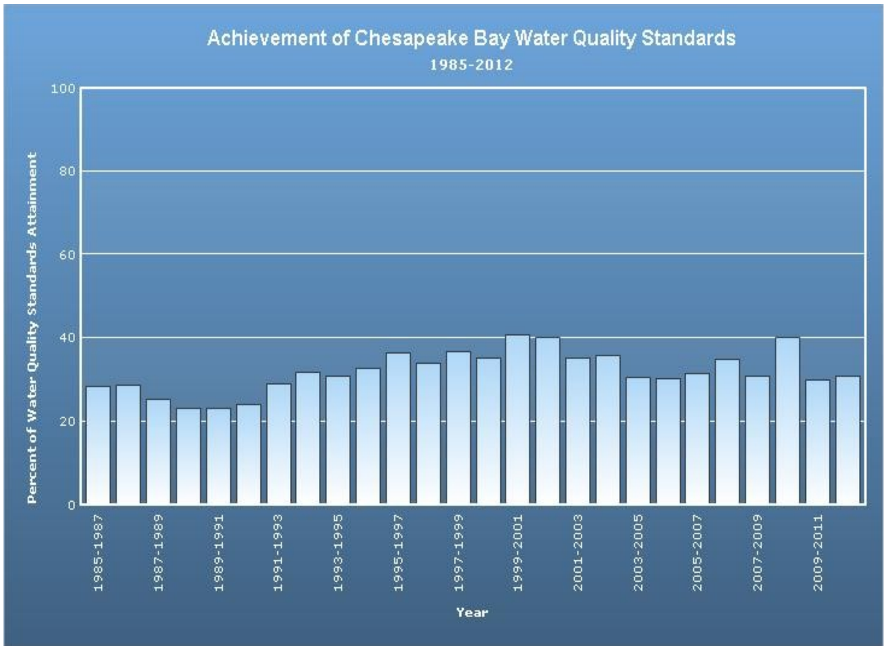

Figure 3. Retrospective time series illustration of the Chesapeake Bay Water Quality Standards indicator status, expressed as a percentage of goal attained for each of the 92 Chesapeake Bay TMDL segments (1985-present listing cycle). The number of water quality criteria applied varies across the 92 Bay 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.

LITERATURE CITED

U.S. Environmental Protection Agency. 2003a. *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. Environmental Protection Agency. 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* EPA 903-R-03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries − 2004 Addendum*. *October 2004*. EPA 903-R-04-005. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2004b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability – 2004 Addendum. October 2004.* EPA 903-R-04-006. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 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. Environmental Protection Agency. 2007a. *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. Environmental Protection Agency. 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. Environmental Protection Agency. 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. September 2008.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2010a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2010 Technical Support for Criteria Assessment Protocols Addendum. May 2010.* EPA 903-R-10-002. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. Environmental Protection Agency. 2010b. *Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment*. U.S. Environmental Protection Agency, Region 3 Chesapeake Bay Program Office, Annapolis, MD.