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Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries

2015 Technical Addendum

November 2015

Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2015 Technical Addendum

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U.S. Environmental Protection Agency
Region III
Chesapeake Bay Program Office
Annapolis, Maryland

and

Region III
Water Protection Division
Philadelphia, Pennsylvania

in coordination with

Office of Water
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and

the states of
Delaware, Maryland, New York
Pennsylvania, Virginia, and
West Virginia and the District of Columbia

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PRINCIPAL AND CONTRIBUTING AUTHORS

This document resulted from the collaborative expertise and talent of Chesapeake Bay Program's state agency, federal agency, interstate river basin commissions, contract statistician and academic institutional partners. The follow are principal and contributing authors of this addendum:

Chapter 1. Peter Tango, U.S. Geological Survey.

Chapter 2. Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office; Elgin Perry, Statistics Consultant; Tish Robertson, Virginia Department of Environmental Quality; Walter Boynton, University of Maryland Chesapeake Biological Laboratory; Mark Trice, Maryland Department of Natural Resources; Claire Buchanan, Interstate Commission on the Potomac River Basin; Matt Hall, Maryland Department of Natural Resources; Will Hunley, Hampton Roads Sanitation District; Richard Batiuk U.S. Environmental Protection Agency Chesapeake Bay Program Office.

Chapter 3. Howard Weinberg, University of Maryland Center for Environmental Studies; Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office.

Chapter 4. Liza Hernandez, University of Maryland Center for Environmental Studies; Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office.

Chapter 5. Tish Robertson, Virginia Department of Environmental Quality; Matt Stover, Maryland Department of the Environment; Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office.

Chapter 6. Howard Weinberg, Rebecca Golden, Maryland Department of Natural Resources, Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office.

Chapter 7 Mary Ellen Ley, U.S. Geological Survey; Michael Mallonee, Interstate Commission on the Potomac River Basin Commission; Peter Tango, U.S. Geological Survey at the Chesapeake Bay Program Office.

CRITERIA ASSESSMENT PROTOCOL WORKGROUP

Peter Tango, Chair, U.S. Geological Survey/Chesapeake Bay Program Office; Liza Hernandez, Coordinator, University of Maryland Center for Environmental Studies; Cheryl Atkinson, U.S. EPA Region 3, Water Protection Division; Harry Augustine, Virginia Department of Environmental Quality; Mark Barath, U.S. EPA Region 3, Water Protection Division; Tom Barron, Pennsylvania Department of Environmental Protection; Stephen Cioccia, Virginia Department of Environmental Quality; Richard Eskin, Maryland Department of the Environment; Sherm Garrison, Maryland Department of Natural Resources; Darryl Glover, Virginia Department of Environmental Quality; Rick Hoffman, Virginia Department of Environmental Quality; Jackie Johnson, Interstate Commission on the Potomac River Basin/Chesapeake Bay Program Office; Jeni Keisman, University of Maryland Center for Environmental Science/Chesapeake Bay Program Office; Susan McDowell, United States Environmental Protection Agency Region III; Larry Merrill, United States Environmental Protection Agency; Bruce Michael, Maryland Department of Natural Resources; Ken Moore, Virginia Institute of Marine Science; Shah Nawaz, District Department of the Environment; Jennifer Palmore, Virginia Department of Environmental Quality; Tom Parham, Maryland Department of Natural Resources; Elgin Perry, Statistics Consultant; Charlie Poukish, Maryland Department of the Environment; Tish Robertson, Virginia Department of Environmental Quality; Matt Rowe, Maryland Department of the Environment; John Schneider, Delaware Department of Natural Resources and Environmental Control; Gary Shenk, United States Environmental Protection Agency; Donald Smith, Virginia Department of Environmental Quality; Scott Stoner, New York State Department of Environmental Conservation; Matt Stover, Maryland Department of the Environment; Bryant Thomas, Virginia Department of Environmental Quality; Mark Trice, Maryland Department of Natural Resources; David Wolanski, Delaware Department of Natural Resources and Environmental Control; Amanda Pruzinsky Chesapeake Research Consortium staffer, Lea Rubin Chesapeake Research Consortium Staffer; John Backus, Maryland Department of the Environment; Thomas Barron, Pennsylvania Department of Environmental Protection; Rich Batiuk, U.S. Environmental Protection Agency; William Hunley, Hampton Roads Sanitation District; Cindy Johnson, Virginia Department of Environmental Quality; Lee Karrh, Maryland Department of Natural Resources; Rodney Kime, Pennsylvania Department of Environmental Protection; Michael Lane, Old Dominion University (ODU); Roberto Llanso, Versar; Andrew Muller, U.S. Naval Academy; Diana Muller, South River Federation; Mike Naylor, Maryland Department of Natural Resources; David Parrish, Virginia Institute of Marine Science (VIMS) Cleo Stevens, Virginia Department of Environmental Quality; Richard Tian, University of Maryland Center for Environmental Science (UMCES); Howard Weinberg, University of Maryland Center for Environmental Science (UMCES); John Wolf, U.S. Geological Survey (USGS)

UMBRELLA CRITERIA ASSESSMENT TEAM

This report resulted from the collaborative expertise and talents of the Chesapeake Bay Program's state, federal agency, academic institutions, river commissions and contract partners. Peter Tango - USGS Chesapeake Bay Program Office - Coordinator; Walter Boynton - University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Tish Robertson - Virginia Department of Environmental Quality; Elgin Perry - Statistical Consultant; Claire Buchanan - Interstate Commission on the Potomac River Basin; Matt Hall - Maryland Department of Natural Resources; Mike Lane - Old Dominion University; and Jeni Keisman - University of Maryland College of Environmental Sciences Chesapeake Biological Laboratory Chesapeake Bay Program Office. Supporting analyses and syntheses were contributed by: Claire Buchanan, Interstate Commission on the Potomac River Basin; Elgin Perry, Statistics Consultant; Walter Boynton, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory, Eva Bailey, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory, Lisa Wainger, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory and Amy Drohan University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Matt Hall, Maryland Department of Natural Resources; Mark Brush, Virginia Institute of Marine Science; Iris Anderson, Virginia Institute of Marine Science; Howard Kator, Virginia Institute of Marine Science; Donna Bilkovic, Virginia Institute of Marine Science; David Rudders and David Jasinski, Chesapeake Research Consortium; Marcia Olson, National Oceanographic and Atmospheric Administration Chesapeake Bay Program Office; Tish Robertson, Virginia Department of Environmental Quality and Mike Lane, Old Dominion University.

WATER QUALITY GOAL IMPLEMENTATION TEAM

Larry Merrill Chair 1, New Chair 2, New Chair 3. Lucinda Power USEPA Coordinator, XXX CRC staffer, further updates of new members in 2015, but including the following: Dave Hansen, Co-Chair, University of Delaware; Robert Koroncai, Co-Chair, U.S. Environmental Protection Agency Region 3 Water Protection Division; Katherine Antos, Coordinator, Chesapeake Bay Program Office, U.S. Environmental Protection Agency; Victoria Kilbert, Staff, Chesapeake Research Consortium; Rachel Streusand, Staff, Chesapeake Research Consortium; Rich Batiuk, U.S. Environmental Protection Agency Region 3 Chesapeake Bay Program Office; Steve Bieber, Metropolitan Washington Council of Governments; Patricia Buckley, Pennsylvania Department of Environmental Protection; Collin Burrell, District Department of the Environment; Monir Chowdhury, District Department of the Environment; Frank Coale, University of Maryland; Lee Currey, Maryland Department of the Environment; James Davis-Martin, Virginia Department of Conservation and Recreation; Chris Day, U.S. Environmental Protection Agency Region 3; Ron Entringer, New York Department of Environmental Conservation; Richard Eskin, Maryland Department of the Environment; Normand Goulet, Northern Virginia Regional Commission; Krista Grigg U.S. Navy; Mike Haire,

U.S. Environmental Protection Agency Office of Water; Jeffrey Halka, Maryland Geological Survey; Carlton Haywood, Interstate Commission on the Potomac River Basin; Dave Heicher, Susquehanna River Basin Commission; Rick Hill, Virginia Department of Conservation and Recreation; Beth Horsey, Maryland Department of Agriculture; Ruth Izraeli, U.S. Environmental Protection Agency Region 2; Bill Keeling, Virginia Department of Conservation and Recreation; John Kennedy, Virginia Department of Environmental Quality; Teresa Koon, West Virginia Department of Environmental Protection; Felix Locicero, U.S. Environmental Protection Agency Region 2; Charles Martin, Virginia Department of Environmental Quality; Bruce Michael, Maryland Department of Natural Resources; Matt Monroe, West Virginia Department of Agriculture; Dave Montali, West Virginia Department of Environmental Protection; russel Morgan, U.S. Department of Agriculture Natural Resource Conservation Service; Matt Mullin, Chesapeake Bay Commission; Kenn Pattison, Pennsylvania Department of Environmental Protection; Russ Perkinson, Virginia Department of Conservation and Recreation; Alan Pollock, Virginia Department of Environmental Quality; Marel Raub, Chesapeake Bay Commission; John Rhoderick, Maryland Department of Agriculture; John Schneider, Delaware Department of Natural Resources and Environmental Control; Mohsin Siddique, D.C. Water and Sewer Authority; Jennifer Sincock, U.S. Environmental Protection Agency Region 3; Randolph Sovic, West Virginia Department of Environmental Protection; Tanya Spano, Metropolitan Washington Council of Governments; Ann Swanson, Chesapeake Bay Commission; Jennifer Volk, Delaware Department of Natural Resources and Environmental Control; Robert Yowell, Pennsylvania Department of Environmental Protection.

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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 Chesapeake Bay segmentation scheme (U.S. EPA 2008) after refinements to the Chesapeake Bay Program analytical segmentation schemes were documented (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 of, 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 (CBP) 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 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 recommendations for assessment of short duration Chesapeake Bay dissolved oxygen criteria based on sub-segmenting open-water designated use segments in up to three possible zones and applying the assessment procedures protective of each zone.

Chapter 3 documents previously undocumented water volumes in three Chesapeake Bay segments: Western Branch Patuxent River Tidal Fresh, Maryland portion of Anacostia Tidal Fresh and Patuxent River Tidal Fresh, where volumes were missing and, therefore, limiting reporting in Maryland's Clean Water Act 303d listing assessments.

Chapter 4 documents the development of a multi-metric Chesapeake Bay water quality indicator using the water quality standards attainment assessment results for dissolved oxygen, water clarity/underwater grasses and chlorophyll *a*, to support tracking progress toward achievement of the jurisdictions' Chesapeake Bay water quality standards.

Chapter 5 documents an update to the Chesapeake Bay underwater grasses restoration goal and provides recommendations for alignment of the goal with the jurisdictions' Chesapeake Bay water quality standards submerged aquatic vegetation restoration acres.

Chapter 6 documents refinements to the Chesapeake Bay 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 water quality monitoring program data into regulatory Chesapeake Bay dissolved oxygen criteria attainment assessments.

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 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.

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CHAPTER 2

Assessing Dissolved Oxygen Criteria Attainment: Short-Duration Criteria Attainment Assessments

BACKGROUND

U.S. EPA has published and Delaware, Maryland, Virginia, and the District of Columbia have adopted into their respective state's water quality standards regulations, the dissolved oxygen (DO) criteria protective of the published migratory spawning, open water, deep water and deep channel designated uses (Table II-1). These DO criteria include 30-day, 7-day and 1-day means along with instantaneous minima as needed to protect the variety of Chesapeake Bay living resource species and their life stages within each designated use (U.S. EPA 2003a). "Short-duration" as defined here will refer to a criterion with a temporal period of less than the 30-day mean DO criterion used to support assessments of jurisdictions' Chesapeake Bay water quality standards.

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 DO criteria assessments, however, the fixed-station monitoring program was considered insufficient on its own to assess short-duration DO criteria. The temporal sampling schedule of the monitoring program was considered 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). Enhanced monitoring options were previously suggested to overcome short-duration DO criteria assessment gaps using "recommended" levels of monitoring (U.S. EPA 2003a). Enhanced monitoring remains a viable option for filling criteria assessment gaps. Alternatively, estimating probable attainment of a DO water quality standard at a temporal scale that is not directly monitored has also been recommended to assess short-duration criteria (p.179, U.S. EPA 2003a). Such a conditional attainment approach would address assessment needs where gaps exist for measuring and reporting water quality standards. Practical considerations of the conditional attainment method in the context of the Chesapeake Bay long term water quality monitoring program sampling design can limit its use in fulfilling all criteria assessment gaps. Sub-segmenting habitat and providing methods and decision making rules offers further options to provide sufficient monitoring to assess all applicable scales of the Chesapeake Bay DO criteria. This chapter provides documentation for recommended monitoring and assessment procedures to ensure the jurisdictions can full assess all their short-duration Chesapeake Bay DO criteria for protection of all designated uses adopted into state water quality standards regulations.

APPROACH FOR ASSESSING OPEN-WATER SHORT DURATION DISSOLVED OXYGEN CRITERIA

Assessing open-water short duration DO criteria builds on the recognition that even within an open-water designated use segment, there are different habitat zones which have different dissolved oxygen dynamics and characteristics—e.g., diurnal cycles in dissolved oxygen concentrations vs. relatively constant dissolved oxygen concentrations over extended periods of

times. These zones also provide habitat for different life cycles of living resources for which the open-water designated use was established to protect. By matching up assessment procedures with the characteristic dissolved oxygen dynamics and the life stages often present in these zones, the different sub-segments of an overall open-water designated use segment can be assessed using different assessment procedures while at the same time still ensuring full protection of the open water designated use.

Table II-1. Chesapeake Bay dissolved oxygen water quality criteria.

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

Source: U.S. EPA 2003a

Rationale for Sub-segmenting Open-Water Designated Use Segments into Zones

The Chesapeake Bay Program partners have used various forms of a basic segmentation scheme to organize collection, analysis and presentation of environmental data for over three decades. The *Chesapeake Bay Program Segmentation Scheme Revisions, Decisions and Rationales: 1983-2003* (U.S.EPA 2004b) provides documentation on the development of the spatial segmentation scheme of the Chesapeake Bay and its tidal tributaries. 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 2004b). 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.

As documented in detail in Appendix A, there is a strong scientific rationale for further sub-segmenting the existing Chesapeake Bay segments from a water quality criteria assessment perspective. Sub-segments have been previously been created for state Chesapeake Bay water quality standards applications (U.S. EPA 2004c, 2007a). The U.S. EPA (2003c) 305b guidance similarly highlights the Washington State Department of Ecology's 3-zone approach 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. Virginia Department of Environmental Quality already cites the U.S. EPA (2003c) guidance to support the same sub-segmentation for these three habitats for their existing non-Chesapeake Bay Program tidal and estuarine monitoring station location considerations (VADEQ 2014).

This 3-zone approach is supported by Caffrey (2004) and Boyton et al (2014) findings that nearshore monitoring sites with greater exposure to mainstem tidal bay and mainstem tidal tributary habitats show better water quality conditions than nearshore sites with more restricted exposures. Boynton et al. (2014) pointed to "tributaries of tributaries" having greater violation rates on average than monitoring stations located in the nearshore zone of the mainstem of a tributary. Both the tributary of tributary sites and the nearshore zones of tributaries had greater violation rates than monitoring sites exposed to the open waters of the mainstem Chesapeake Bay.

Acknowledging that there are scientific bases showing habitat differences exist in open-water habitats (Appendix A), and EPA and state policies and procedures already in place that support sub-segmentation of habitats to account for habitat differences (U.S. EPA 2003b, U.S. EPA 2004c, U.S. EPA 2007a, VADEQ 2014), a jurisdiction may specifically delineate sub-segments within a Chesapeake Bay segment's designated use for purposes of criteria application and criteria attainment assessment.

Three Zones within the Open-Water Designated Use

Applying the concept of 3 zones to Chesapeake Bay open-water habitats yields the following physically delineated 3 zones illustrated in Figure II-1.

Zone 1 – Open, well-mixed Chesapeake Bay mainstem and tidal tributaries: open, well-mixed tidal waters above the pycnocline located within the mainstem Chesapeake Bay, its tidal tributaries, and embayments.

Zone 2 – Shallow-water waters: waters equal to or less than 2 meters in depth.

Zone 3 – Isolated waters off of the mainstem Bay and tidal tributaries: physically isolated from the continuous nearshore and open-waters of larger mainstem Bay, tidal tributaries and larger embayments, not well-mixed "tributaries of tributaries".

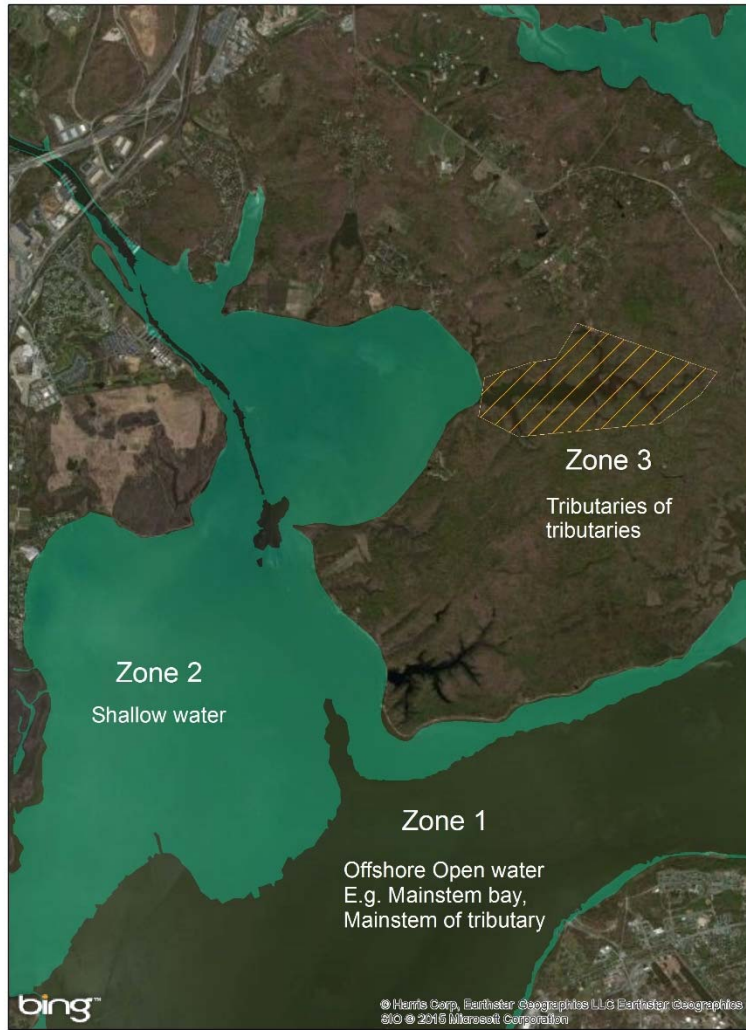


Figure II-1. Applying the concept of 3-zones to Chesapeake Bay open-water habitats.

In addition to their relatively unique dissolved oxygen dynamics, these three zones also have different levels of relative importance to the life stages of living resources inhabiting the open-water designated use habitats. The Zone 1 Chesapeake Bay mainstem and tidal tributary waters support a wide array of juvenile and adult fish, shellfish, and other aquatic life species and populations within the open, well-mixed water column. The healthy growth of this zone's juvenile and adult populations are protected specifically by the 5 mg/L 30-day mean and 4 mg/L 7-day mean DO criteria (U.S. EPA 2003a). Within the shallow-waters of Zone 2, one finds an abundance of early life stages of fish and shellfish, seeking food and shelter within the protection of the nearshore environment its vegetative and physical structures. Given routine exposures to diel cycling in DO concentrations, survival of these early life stages are principally protected by the 3.2 mg/L instantaneous minimum DO criterion. Within Zone 3, the

combination of isolated, not well mixed waters, the very limited total volume of these waters, and the focus on ensuring protection of survival endpoints, lend themselves to be characterized by discrete sampling and a separate assessment of 3.2 mg/L instantaneous minimum DO criterion.

Criteria Assessment Procedures Tailored towards the Three Zones

Given the recommended delineation of the three zones based on their unique dissolved oxygen dynamics and mixing characteristics in combination with the life stages generally present and the corresponding protective criteria, distinct sets of criteria assessment procedures can be aligned with each zone (Table II-2). When these criteria assessment procedures are applied to each respective zone, the result is the ability to assess all applicable open-water dissolved oxygen criteria throughout each open-water designated use segment.

Table II-2. Applicable criteria assessment procedures for each of the three zones.

Zone	Description	Applicable Criteria Assessment Procedures
1	Open, well-mixed mainstem Bay and tidal tributaries	<ul style="list-style-type: none"> • CFD-based assessment of the 30-day mean • CFD-based assessment of the 7-day mean with enhanced temporal frequency of monitoring • Conditional attainment assessment of the 7-day mean
2	Shallow-water waters	<ul style="list-style-type: none"> • Continuous monitoring-based assessment of the instantaneous minimum
3	Isolated waters off of the mainstem Bay/tidal tributaries	<ul style="list-style-type: none"> • Discrete sampling-based assessment of the instantaneous minimum

ASSESSING CONDITIONAL ATTAINMENT ACROSS DISSOLVED OXYGEN CRITERIA

Conditional attainment refers to using the mathematical results of computing one statistic from a set of DO concentration measurements collected to support water quality standards attainment assessments at a specific temporal scale (e.g., 30-day mean) to evaluate DO criteria attainment at another temporal scale (e.g., 7-day mean, 1-day mean, instantaneous minimum). The Chesapeake Bay long term, fixed station tidal water quality monitoring program supports 30-day mean DO assessments, however, the monitoring program has thus far been considered insufficient on its own to assess short-duration DO criteria (U.S. EPA 2003a, CBP STAC 2012). For example, the Open Water designated use has summer season DO set of criteria that includes a 30-day mean, 7-day mean and instantaneous minimum that must be met simultaneously for a Bay segment to be considered in attainment under the Clean Water Act 303(d) impairment assessments. However, the Chesapeake Bay long term water quality monitoring program measures habitat conditions biweekly which thus far only supports DO standards assessment for the 30-day mean portion of the three applicable criteria elements (Table II-1). The value of applying a conditional attainment assessment method for addressing water quality standards attainment of Chesapeake Bay dissolved oxygen criteria within a designated use is: 1) multiple duration criteria are addressed; 2) attainment

of criteria of different durations must be met simultaneously; and 3) not all scales of criteria are being directly measured through the present Chesapeake Bay long term water quality monitoring program.

Therefore, having a method of using DO concentrations measurements collected for assessing DO criterion attainment at one temporal scale and using the results to inform a decision about water quality either passing or failing of another, unmeasured scale of criteria attainment would provide beneficial support for a short-duration criteria attainment assessment method. Such a method would then be applicable to Clean Water Act 303d list impairment reporting and tracking progress in water quality standards attainment across Chesapeake Bay and its tidal tributaries and embayments. Conditional attainment as an assessment approach proposes using the idea of an umbrella-like DO criterion effect to support multiple criteria assessment simultaneously. This concept is borrowed from conservation biology's use of 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 accounting for an umbrella effect provides a simpler way to manage ecological communities, for example, considering multi-species protections based on the presence of one umbrella species in a habitat (e.g., Dunk et al. 2006). In this case, meeting a stated DO threshold from one scale of measurement is meant to provide levels of habitat protection for one or more other, shorter duration, DO habitat protection criteria.

Demonstrating Conditional DO Attainment

Through the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team's Criteria Assessment Protocol Workgroup efforts, the Chesapeake Bay Program partnership has explored the relationship between 30-day mean DO measurements and 7-day mean, 1-day mean and instantaneous minimums in the same 30-day period. The partnership's analysts used Chesapeake Bay-specific high temporal density water quality data sets (Appendix B). Further similar analyses have been conducted using the Chesapeake Bay Program's Water Quality/Sediment Transport Model (U.S. EPA 2010b). By evaluating water quality relationships for mutual and simultaneous habitat protection across different temporal application scales of the Chesapeake Bay DO criteria, the scientific and management communities have developed a foundation of understanding regarding habitat protections between measured criteria (e.g. 30-day mean) and unassessed, shorter duration temporal scales of DO criteria attainment (e.g., 7-day mean, 1 day mean and instantaneous minimum).

Historical perspective

Previously, Jordan et al. (1992) developed regression equations to derive the seasonal mean concentrations that could be presumed protective of target, shorter-duration assessment DO thresholds in a given Chesapeake Bay segment. They concluded that knowing the seasonal mean DO concentration for a given region in the Bay permitted "a good estimate of what proportion of actual DO observations are likely to meet, or fail to meet, each of the target DO concentrations". Further, in 2004, CBP analysts explored mutual protection among the new 2003 Chesapeake Bay DO criteria with different durations (U.S. EPA 2003a). Olsen et al. (cited in U.S. EPA 2004) primarily used 147 buoy-based, high temporal frequency dissolved oxygen data sets collected between 1987-1995 (where dates were noted) from the EPA's Environmental Monitoring

and Assessment Program showing that: 1) the open water 30-day mean DO criterion attainment was generally protective of the open water 7-day mean DO criterion in those segments where both criteria applied; and 2) deep-water 30-day mean DO criterion attainment is protective of the 1-day mean and instantaneous minimum DO criteria.

Similarly, mutual protection between one measured DO criteria and a second DO criteria of a different duration was tested in the course of developing the Chesapeake Bay Total Maximum Daily Loads (TMDL). Analysts at the Chesapeake Bay Program Office (CBPO) conducted an assessment of how well DO criteria that are already measured with the current Chesapeake Bay Program partnership's long term water quality monitoring program mutually protected the unmeasured, short-duration criteria (U.S. EPA 2010b, 2010c). Using hourly output from a calibration run of the Chesapeake Bay Water Quality/Sediment Transport Model (WQSTM), the Chesapeake Bay Program Office analysts produced a summer season test of the "umbrella criterion". Note that for the purposes of developing the Chesapeake Bay TMDL, the summer season (June 1 – September 30) 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). Chesapeake Bay Program Office analysts determined that evaluation of attainment of the open water and deep water 30-day mean DO criteria was sufficient to determine attainment of the remaining open-water and deep-water designated uses dissolved oxygen criteria (U.S. EPA 2010b, 2010c). 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 protective of the deep channel designated use were higher than for any other open water and deep water designated use criteria for the same segment. Thus, the criteria currently being assessed using the Chesapeake Bay long term water quality monitoring program data – open-water 30-day mean, deep-water 30-day mean and deep-channel instantaneous minimum appear to be "umbrella criteria" – the most restrictive of all available criteria mutually protective of the full range of criteria by designated use (U.S. EPA 2010b, 2010c). These findings provided support for using an approach of estimating probable attainment to address water quality standards decisions for unmeasured criteria, however, further evidence of the suitability of the approach was requested by CBP partners before adopting it into their water quality standards regulations.

Recent perspective

Perry (cited in CBP STAC 2012) conducted a study on probable DO water quality standards attainment across different scales of DO criteria when measuring one scale, 30-day mean. Perry notes that in order for the summer, open water 30-day mean DO criterion to serve as a conditional criteria attainment measure for the 7-day mean DO criterion, there is the need to show that if the 30-day mean DO criterion is satisfied, there is a small probability that the 7-day mean DO criterion is going to be violated. Using 'less than 10 percent' as an acceptable risk of wrongly concluding that the 7-day mean DO criterion is satisfied when it is in fact violated, then this condition of mutual attainment is satisfied when the standard deviation for the distribution of the differences between the weekly mean from the monthly mean is 0.7805 or smaller. At this level of variability in the weekly deviations from the monthly mean, excursions of the weekly mean below the 7-day mean criterion of 4.0 mg/L O₂ while the monthly mean is at the 30-day criterion of 5.0 mg/L O₂ would be about 10 percent (Figure II-2). This scenario would be strong

evidence that the 30-day mean criterion is mutually protective of habitat with the 7-day mean DO criterion of 4.0 mg/L O₂.

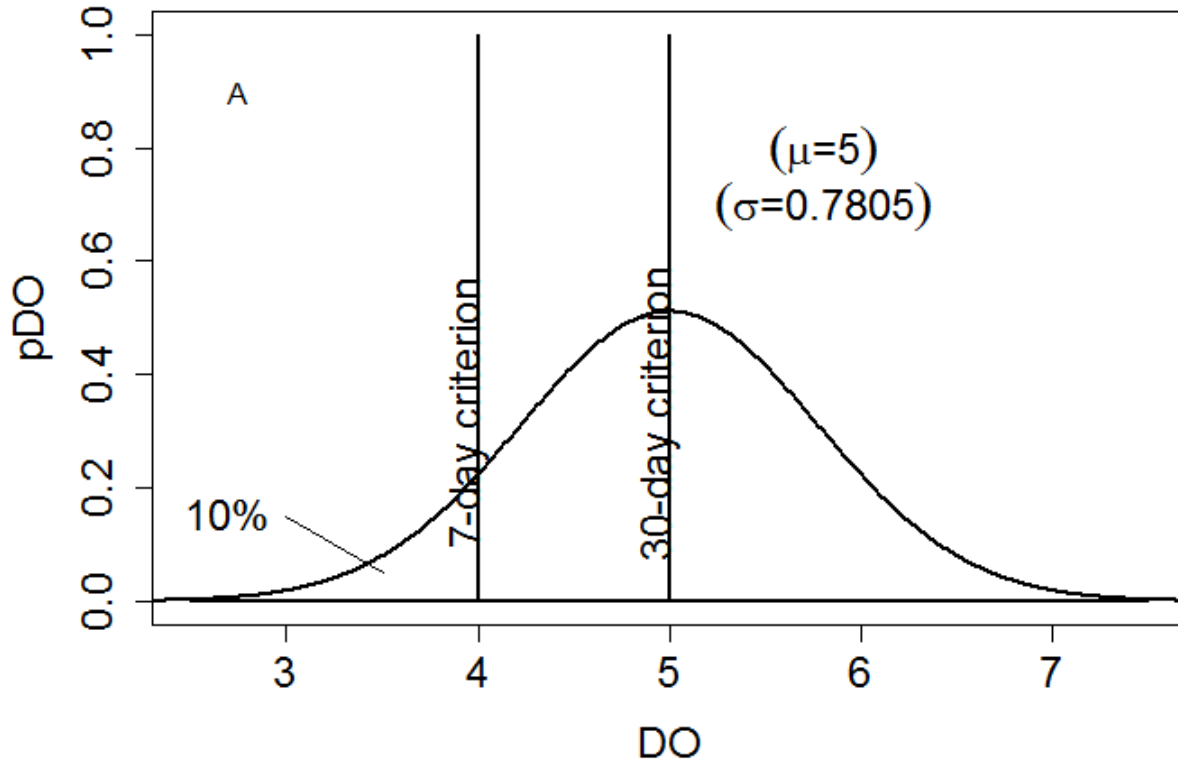


Figure II-2. Illustration of the 30-day criterion serving to simultaneously protect the 7-day criterion when the standard deviation of the differences between the monthly mean and weekly mean is 0.7805 or less.

Using tidal Potomac River continuous monitoring data for monitoring stations located across all salinity zones and the summer seasons from 2004-2009, the standard deviation of the differences between the weekly mean from the monthly mean exceeds this ideal 0.7805 value and is estimated to be 1.005 or very close to 1.0. At this level of variability, the risk of violating the 7-day criterion when the 30-day criterion is satisfied exactly is about 16 percent (Figure II-3, blue dashed line). However, increasing the monthly mean DO concentration to 5.285 mg/L O₂ again brings the risk of violations of the 7-day mean DO criterion to an acceptable level of 10 percent (Figure II-3, blue solid line). Because it is unlikely that under the natural conditions of the Bay and its tidal tributaries and embayments, the monthly mean will hover in this narrow window of dissolved oxygen concentrations (5.0, 5.285) for an extended time then it seems reasonable to consider that the 7-day criterion is satisfied if the 30-day mean DO criterion is satisfied. This evidence is one key supporting fact for the CBP’s Scientific, Technical Assessment and Reporting Team’s Umbrella Criteria Assessment Team conclusion that the 30-day mean DO criterion is mutually protective for the 7-day mean DO criterion. It is important to recognize that

this conclusion depends on both the true monthly mean and the true weekly mean are being estimated with great precision. The high level of precision is obtained here by using a near continuous record of DO concentrations (i.e., data collected at 15 minute intervals through the Chesapeake Bay Program's Shallow-water Monitoring Program).

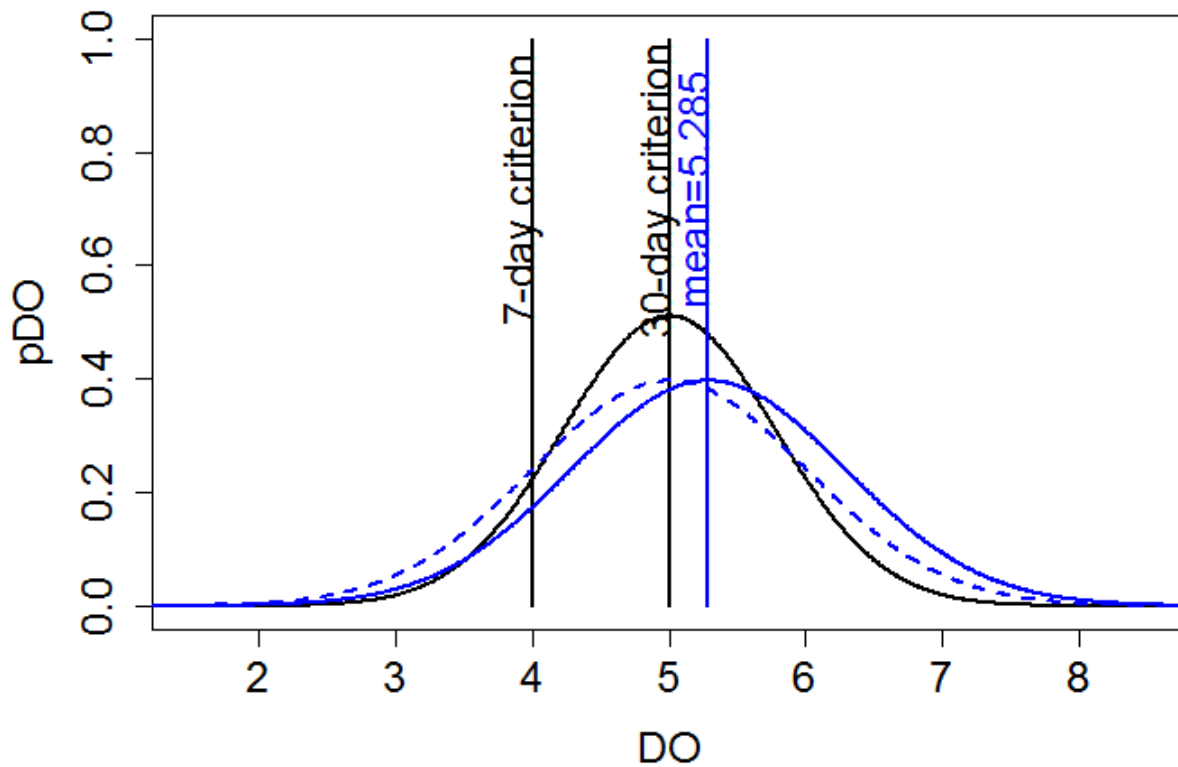


Figure II-3. Illustration of the change in the distributions from an ideal (black line) to account for natural dissolved oxygen dynamics in the Bay (dashed blue line) and subsequent shift in the monthly mean required to meet 10% risk tolerance for the 7-day criterion when the weekly mean deviation is 1.005 (solid blue line).

By contrast, the Chesapeake Bay Program long term fixed station water quality monitoring program collects DO profiles through the water column one to two times a month which serves as the basis for assessing attainment of the 30-day mean DO water quality standard. When the 30-day mean DO concentration is estimated by a sample size of two observations then the variability of the deviations between the 30-day mean DO estimate and the 7-day DO means increases by 60 to 90 percent (Figure II-4). At this higher level of variability, satisfying the 30-day criterion exactly results in a 28 percent risk of violating the 7-day criterion (Figure II-5 red dashed line). Estimates of the 30-day mean have to exceed a threshold of 6.22 to insure that the risk of violating the 7-day mean criterion is 10 percent or less (Figure II-5 red solid line).

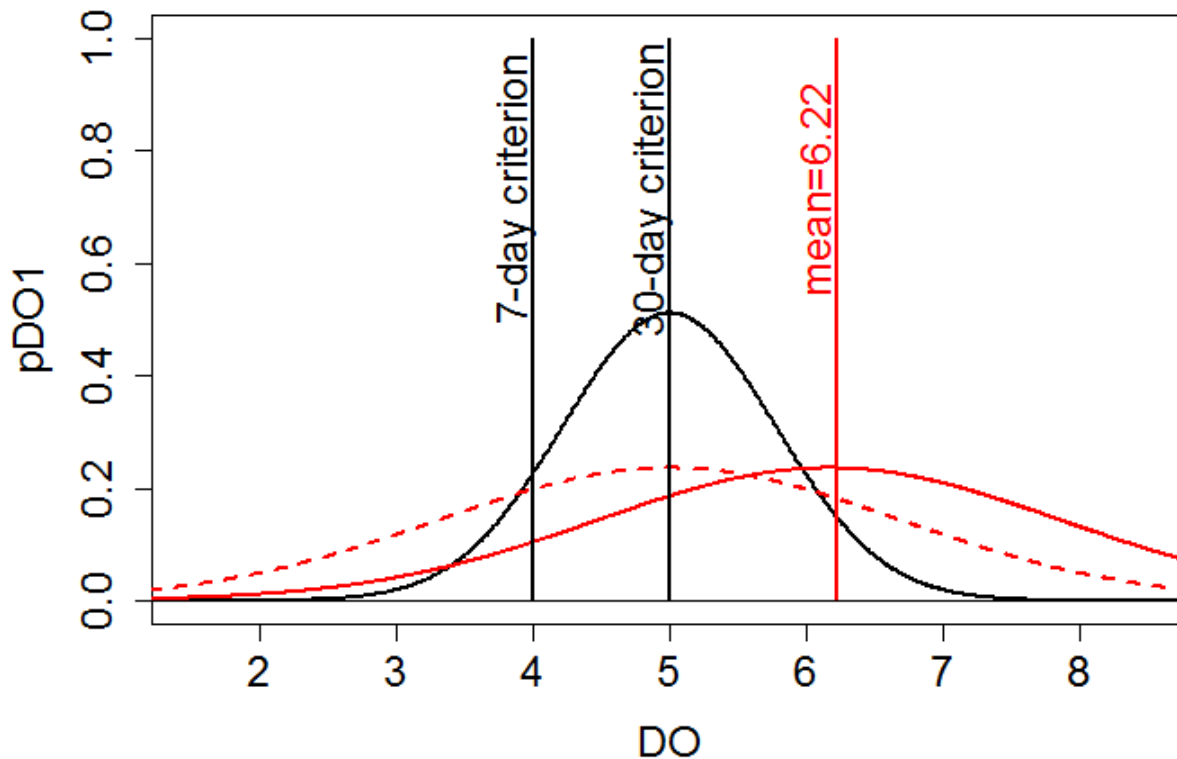


Figure II-5. Illustration of the shift—from red dashed line to red solid line—in the monthly mean required to meet 10% risk tolerance for the 7-day criterion when the weekly mean deviation of 1.74 accounting for the uncertainty in estimating the mean due to small sample sizes ($n=2$).

The direct application of the conditional probability analysis approach used above was not suitable for understanding protection of the 30-day mean for an instantaneous minimum criterion. Perry (cited in CBP STAC 2012) used parametric simulation of DO dynamics to generate time series that have properties similar to observed Chesapeake Bay DO concentration time series. Autoregressive (AR) modeling is a parametric simulation tool that has been used to describe certain time-varying processes in nature. Perry (cited in 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 from the U.S. EPA Environmental Mapping and Assessment Program as compiled by Olsen (cited in U.S. EPA 2004). Details of the autoregressive modeling approach are provided in Appendix C.

Results of the autoregressive analysis demonstrate protection levels for meeting a 30-day mean DO concentration and mutually protecting the summer open water instantaneous minimum criterion (Table II-3). Whereas we previously saw achievable thresholds in protection of the 7-day mean DO criterion using 30 day means derived from high and low frequency monitoring data in Chesapeake Bay, applying the conditional criteria attainment approach for protecting the

instantaneous minimum by the 30-day mean with less than a 10 percent risk of non-attainment could not be achieved with a 30-day mean even as large as 7.01 mg/L O₂. An alternative level of acceptable risk greater than 10 percent would need to be considered acceptable for declaring attainment in order for the conditional attainment procedures to apply. Otherwise, direct measurement or other assessment methods are recommended for evaluating attainment of the instantaneous minimum DO criteria.

Table II-3. Parametric simulation results for a gradient of dissolved oxygen mean data and their ability to mutually protect the summer, open water instantaneous minimum DO criteria.

	Summer Season, Open-water 30-day Mean DO			
	5.0058	5.6732	6.3407	7.0082
Criteria failure rates: Rate of instantaneous criterion > 10 percent	47.6%	32.5%	25.3%	18.5%

Source: CBP STAC 2012

An Example of Conditional Attainment Assessment for Chesapeake Bay DO standards.

An example of the relevance of this range of 30-day mean DO was developed. Table II-4 below illustrates the application of the conditional attainment assessment for the 2011-2013 Chesapeake Bay open water summer season designated use DO assessment. First, 40 of 92 Chesapeake Bay segments attained the summer open water designated use for dissolved oxygen under the 30-day mean criterion of 5.0 mg/L O₂. This is based on the standard CFD attainment assessment.

Next, for the sake of illustration, we want to apply the conditional attainment approach and show segments that simultaneously meet the 30-day DO mean criterion and the 7-day DO mean criterion without having the temporal density of measurements to support direct water quality standards attainment assessment of the 7-day DO mean. Such segments would be considered as passing both criteria under the rules of conditional attainment. For demonstration purposes in this example, we assume the required DO concentration threshold to achieve simultaneous protection is 6.1 mg/L O₂. (Note, this value would have a 10 percent risk of nonattainment if the standard deviation is 1.61. The proposed threshold value of 6.22 mg/L was shown in Figure II-4 has a similar standard deviation of 1.74. See Appendix C for the associated reference table.)

The results of the dissolved oxygen assessment are re-run through the same CFD attainment assessment. However, the protocol requires using the 6.1 mg/L O₂ threshold in place of the 5.0 mg/L O₂ threshold for assessing simultaneous protection of the 7-day DO mean based on the 30-day DO mean. The assessment of passing or failing are now interpreted as evidence for meeting the 7-day DO mean and the 30-day DO mean while accounting for uncertainty due to the CBP water quality monitoring program sampling design. In this illustration, 8 of the 40 segments that met the 30-day mean 5.0 mg/L summer mean open water dissolved oxygen criterion also meet an example DO threshold of 6.1 mg/L O₂, providing protection of the open water designated use under the 7-day DO mean criterion considering the uncertainty of measuring the 30-day DO mean from two days each month. These 8 segments which met the 6.1 mg/L O₂ threshold, supported by a 10 percent level of acceptable risk decision-rule, can be effectively stated as also in attainment for the 7-day DO mean criterion. It is noteworthy that 11 more of the Chesapeake Bay segments were less than 1 percent from demonstrating mutual protection of the 30-day and 7-day means

when applying the 6.1 mg/L threshold and requiring no more than a 10 percent level of risk to be considered protective for the 7-day DO mean criterion: CB1TF, CB3MH, CB5MH, PIAMH, DCPTF, GUNOH, MD5MH, NORTF, SASOH, SOUMH, and VA5MH. Due to the uncertainty of estimating the 30-day mean from 2 samples per month under the natural variability exhibited by dissolved oxygen in Chesapeake Bay, these 11 segments would be prime targets for enhanced monitoring to demonstrate that the 7-day mean dissolved oxygen criterion is being protected by the 30-day mean water quality for dissolved oxygen.

Protecting other short duration criteria may require more using more stringent DO thresholds. Under more stringent mutual protection decision rules, e.g. if a 30-day mean must now meet a threshold of 6.5 mg/L O₂, then in this illustration no segments demonstrate sufficient water quality to show the 30-day mean can mutually protect any short-duration dissolved oxygen criteria that requires a 30-day mean at or above 6.5 mg/L O₂. Three Eastern Shore Maryland segments are, however, less than 1% from meeting the 6.5 mg/L threshold (NORTF, FSBMH, and BIGMH). This finding provides an important perspective when considering the instantaneous minimum DO criteria that needs a 30-day mean DO assessment well above 7.01 mg/L O₂ in order to be in attainment. Therefore conditional attainment assessment provides a viable method of assessment but very likely an unattainable measure of DO concentrations. This does not mean the instantaneous minimum criterion is unattainable. Rather, this issue highlights the practical limits of applying this method of attainment in the context of accounting for the uncertainty of small sample size on estimating the 30-day mean and trying to make an effective decision about habitat protection at another time scale. Further alternative sampling densities and risk levels of non-attainment need to be considered to address assessment of the instantaneous minimum criterion.

Table II-4. Output showing the use of the conditional attainment assessment approach applied to the 2011-13 dissolved oxygen water quality standards attainment assessment for the open water summer season. Tests are for two threshold values to show mutual protection for the 30-day and 7-day mean DO criteria.

Segments attaining the 30-day mean DO criterion ¹ .	Segments that further pass attainment of the 30-day mean DO criterion using 6.1 mg/L dissolved oxygen threshold ² .	Segments that also pass a 30-day mean using a 6.5 mg/L dissolved oxygen threshold.
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, MPCMH, VPCMH, POVOH, APPTF, BIGMH, FSBMH, MANMH	None

1. Segments attaining the 30 day mean open water summer dissolved oxygen criterion protective of the designated use.
2. The subset of segments that further pass attainment of the 30-day mean DO criterion using 6.1 mg/L DO threshold for assessing mutual protection of the 7-day mean DO criterion (less 10 percent risk of nonattainment) based on 2 samples each month, June-September 2011-2013.
3. Segments that also pass a 30-day mean using a 6.5 mg/L O₂ threshold.

Application of Conditional Criteria Attainment Assessment

Application of conditional DO criteria attainment assessment is supported by the above documented relationships between assessed and unassessed DO criteria. However, there are key findings that must be considered when applying conditional DO attainment assessments.

Temporal sampling density must be accounted for in order to use conditional DO attainment assessments. Perry's (cited within CBP STAC 2012) conditional probability assessment of summer season dissolved oxygen criteria showed that attaining a 30-day mean DO concentration of 5.3 mg/L O₂ can simultaneously protect open water habitat by ensuring the 7-day mean DO concentrations will remain above 4 mg/L O₂ while allowing for less than 10 percent non-attainment. This result depends on high temporal density dissolved oxygen data (collected every 15 minutes throughout a summer season). By contrast, Perry's (cited within CBP STAC 2012) parametric simulation evaluated the same relationship between 30-day mean and 7-day mean DO when using the Chesapeake Bay long term water quality monitoring program sampling design of 2-samples per month. Due to the uncertainty introduced by variability in DO concentrations coincident with evaluating the means with a low sample density, a 30-day mean DO must now be at least 6.1 mg/L O₂ in order to allow for a less than 10 percent non-attainment. Therefore, the temporal scale of assessment is an essential element of effectively applying the conditional DO attainment assessment methodology.

For a 30-day mean DO criteria attainment assessment using near continuous high frequency (e.g. every 15 minutes) time series monitoring data for assessing the habitat protection of the summer season open water 7-day DO mean criterion, the 30-day mean DO must be equal to or greater than 5.3 mg/L O₂, allowing for no more than 10 percent non-attainment. By contrast, when using the Chesapeake Bay long-term water quality monitoring program sampling design of 2-samples per month, a 30-day mean DO must now achieve a threshold of at least 6.22 mg/L O₂ in order to allow for a less than 10 percent non-attainment to protect the habitat with the 7-day mean DO criterion. However, for deep water which has different criteria thresholds than the open water, Olsen et al. (cited in U.S. EPA 2004a) recommended a direct assessment of the 30-day mean attainment effectively evaluates protection for the 1-day mean and instantaneous minimum DO criteria.

The risk of non-attainment for a short duration criterion relative to a 30-day mean DO concentration varies according to the criterion being protected. Conditional attainment assessment provides a method to assess any short-duration criteria, however, the required 30-day mean DO concentration to achieve mutual habitat protection over a short duration criterion may be impractically high if temporal sampling density of the existing Chesapeake Bay long term water quality monitoring program is used. There are two options available to account for this finding: 1) sample more frequently to better account for DO variability; or 2) define a separate acceptable risk of nonattainment.

USING CONTINUOUS MONITORING DATA FOR ASSESSMENT OF INSTANTANEOUS MINIMUM CRITERIA

The conditional criteria attainment assessment offers the opportunity to assess instantaneous

minimum DO criteria using the 30-day mean DO assessments. However, results of the CBP analysts also show that the DO concentrations needed to find mutual protection between the 30-day mean and instantaneous minimum criterion levels in open water are large (>7.01 mg/L O₂). This finding makes the conditional criteria attainment assessment impractical for expecting to delist a segment when using the existing CBP long term water quality monitoring sampling design that depends on 2-samples per month for assessments.

Continuous monitoring data sensors are in use evaluating shallow water habitat conditions throughout the summer season in Chesapeake Bay (USEPA 2010b). Continuous monitoring data are not currently used in DO criteria assessment as standard practice (U.S. EPA 2010a). There has been a challenge of mixing nearshore high frequency data with low frequency offshore data over multiple depths for an open-water DO criteria attainment assessment. The opportunity to sub-segment out and separately assess attainment in the nearshore habitats where the continuous monitoring sensors are routinely actively monitoring presents the ability to now assess attainment of the open-water instantaneous minimum DO criterion with high frequency dissolved oxygen data.

Published state specific methods for assessing attainment of DO criteria using continuous monitoring data are highly varied:

- Virginia – “10%-10% rule”: a water is impaired if exceedences were observed more than 10% of the time within more than 10% of the 24-hour periods monitored.
- Wisconsin – “10% rule”: a water impaired if exceedences were more than 10% of the time.
- Louisiana – “25% rule”: a water is impaired if violations were observed more than 25% of the time.
- Washington – “3 daily minimum values rule”: a water is impaired if at least 3 daily minimum values are below the instantaneous minimum.
- New Jersey – “2 daily minimum values rule”: a water is impaired if at least 2 daily minimum values are below the instantaneous minimum.

Though these five states’ methods differ, almost all rest on the assumption that monitors will be deployed primarily for short durations (30 days or less). Further, EPA recommends making determinations of impairment for conventional pollutants *when more than “10% of measurements exceed the water quality criterion”* (U.S. EPA 2005). Though not stated explicitly, this recommendation assumes assessments are based on low-frequency discrete monitoring datasets, not continuous monitoring.

The CBP Scientific and Technical Assessment and Reporting Team’s Criteria Assessments Protocol Workgroup considered three options for instantaneous minimum criterion assessment that account for concerns of living resource protection over an entire season at a conservative level.

Rule 1. No more than 10 percent of days during a single season with an exceedance—12 days can

have a single exceedance. This translates into about 30 minutes x 12 or 5 hours total per season, and given 2880 hours in a summer season, about 0.17 percent of the summer season.

Rule 2. No more than 1 day with 10 percent time (>2.5 hours) exceedance during a single season. This translates into 3 or more hours or about 0.1 percent of the summer season.

Rule 2 Alternate. No more than two consecutive days with 10 percent time (>2.5 hours) exceedance during a single season. This translates into 6 or more hours or about 0.2 percent of the summer season.

In a test of applying all three rules to assess impairment in multiple segments, all three rules performed similarly well (Figure II-5). Therefore, based on the assumption that the instantaneous minimum criterion is interpreted as a 1 hour average condition not to be exceeded (U.S. EPA 2008), rule 1 is the least consistent with this assumption by allowing 12 days to experience criterion exceedance. Rules 2 and 2 Alternate more closely approach the interpretation for protecting against an instantaneous minimum violation for a season. Given it is the best option for addressing to the need for separating out a random event from a more persistent event, Rule 2-Alternate is recommended for use by the jurisdictions in assessing attainment of instantaneous minimum criteria using continuous monitoring data.

Segment	Year	Rule 1	Rule 2	Rule 2 (Alt)*	
JMSMH	2006	Pass	Fail	Pass	<p>Rule 1. No more than 10% of days during a single season with an exceedance. (12 days can have a single exceedance). About 30 minutes x 12 or 5 hrs total per season, 2880 hrs in a season or 0.17%.</p> <p>Rule 2. No more than 1 day with 10% time (>2.5 hrs) exceedance during a single season (0.1% of season).</p> <p>Rule 2 Alt. If there are more than two consecutive days in a single season were the DO concentration violated the criterion more than 10% of the time. (0.2% of season)</p> <p>Summary: Annual 11 cases all three rules agree 2 cases where Rule 1 and 2A agree 1 case where Rule 2 and 2A agree</p> <p>Summary: 3-yr assessment 2 of 5 cases are affected by rule choice No bias.</p>
	2007	Pass	Pass	Pass	
	2008	Pass	Fail	Fail	
	2006-2008	Pass	Fail	Fail	
JMSMH	2012	Pass	Pass	Pass	
	2013	Pass	Pass	Pass	
	2014	Pass	Pass	Pass	
	2012-2014	Pass	Pass	Pass	
JMSPH	2006	Pass	Fail	Pass	
	2007	Pass	Pass	Pass	
	2008	Pass	Pass	Pass	
	2006-2008	Pass	Fail	Pass	
LAFMH	2012	Fail	Fail	Fail	
	2013	Pass	Pass	Pass	
	2014	Pass	Pass	Pass	
	2012-2014	Fail	Fail	Fail	
LAFMH	2012	Fail	Fail	Fail	
	2013	Fail	Fail	Fail	
	2011-2013	Fail	Fail	Fail	

Figure II-6. Testing of the three potential rules for assessing instantaneous minimum criterion assessment using continuous monitoring DO data.

Source: Tish Robertson, Virginia Department of Environmental Quality and Will Hunley, Hampton Roads Sanitation District, Virginia.

USE OF DISCRETE MONITORING IN THE ASSESSMENT OF INSTANTANEOUS MINIMUM CRITERIA

Building from the programmatic experience of Virginia Department of Environmental Quality, for those ‘tributary of a tributary’ habitats that fall under the zone 3 definition (see Table II-2)

(VADEQ 2014), the recommended procedure for use in assessing instantaneous criteria attainment is using a discrete monitoring approach to collect data from the waterbody. Specifically, the discrete monitoring approach is based on using sensors at one or more locations in the delineated sub-segment with a minimum of 10 samples per year collected for 3 years. At least 50 percent of the samples must be collected before 9 AM to address diel variability in DO concentrations. Dissolved oxygen attainment is based on 10 percent allowable exceedance of the applicable instantaneous minimum criterion.

ENHANCED MONITORING FOR ASSESSING SHORT-DURATION DISSOLVED OXYGEN CRITERIA ATTAINMENT

Jurisdictions always have the option of collecting water quality profiles of dissolved oxygen concentration at high enough frequencies to support direct assessments of the criterion's temporal period—7-day mean, 1-day mean, instantaneous minimum—at spatial resolutions characteristic of the segment of focus. The high frequency data can be collected using any one or an assortment of methods—e.g., depth transect of water quality sensors, greater manual measurement density in space and or time with water quality sensors, water quality profiler, Underwater Autonomous Vehicles, etc. The jurisdiction would evaluate the high resolution data against the suite of water quality criteria using the published CFD-based Chesapeake Bay water quality criteria attainment assessment methods (U.S. EPA 2003a, 2004, 2007a, 2008, 2010).

RECOMMENDED APPROACHES FOR ASSESSING SHORT-DURATION DISSOLVED OXYGEN CRITERIA ATTAINMENT

Enhanced Monitoring Approach

In taking this recommended approach, jurisdictions would measure water quality profiles of dissolved oxygen concentration at high frequency using any one of an assortment of methods—e.g., depth transect of water quality sensors, greater manual measurement density in space and or time with water quality sensors, water quality profiler, Underwater Autonomous Vehicles, etc.—with increased spatial resolution. Then the jurisdiction would evaluate the high resolution data against the suite of water quality criteria using the present CFD-based Chesapeake Bay water quality criteria attainment assessment methods (U.S. EPA 2003a, 2004, 2007a, 2008, 2010). The enhanced monitoring approach could be used by jurisdictions to directly assess attainment of their 7-day mean, 1-day mean, and instantaneous minimum dissolved oxygen criteria using high frequency, increased spatial and temporal resolution data (Table II-5).

Continuous Monitoring Approach

In utilizing the wealth of continuous monitoring data they have collected through the Partnership's Chesapeake Bay Shallow-water Monitoring Program, the jurisdictions can use this approach to directly assess attainment of their open-water instantaneous minimum criterion within their sub-segmented shallow-water habitats. Attainment would be based on the rule allowing no more than two consecutive days with a 10 percent time (greater than 2.5 hours) exceedance during a single season (Table II-5).

Conditional Criterion Attainment Approach

Two methods are recommended for applying the conditional criteria attainment approach to

assessment of open-water and deep-water designated use DO criteria.

Method 1. This criteria assessment approach is based on the existing Chesapeake Bay Partnership's long-term Chesapeake Bay Tidal Water Quality Monitoring Program sampling strategy. Jurisdictions would define and apply an acceptable risk (e.g., 10 percent) for decisions supporting attainment associated with meeting one or more shorter duration dissolved oxygen criteria in a designated use when using the single 30-day mean threshold dissolved oxygen concentration and criterion assessment under existing, published criteria assessment procedures (U.S. EPA 2003a, 2004, 2007a, 2008, 2010a). The conditional criterion attainment approach can be used by jurisdictions to assess their open water 7-day mean dissolved oxygen criterion (Table II-5). In deep-water designated use segments, assessment of the 30-day mean DO criterion directly serves to protect the 1-day mean and the instantaneous minimum dissolved oxygen criteria.

Method 2. By meeting the instantaneous minimum dissolved oxygen criterion in the sub-segment zones 2 and 3, the defacto decision is that the entire segment meets the instantaneous minimum criterion and is therefore in attainment with this criterion.

Discrete Sampling Approach

For those waterbodies for which sub-segmenting them for their own criteria assessment makes sense due to their isolated nature (see Table II-2), taking a discrete sampling approach which relies on additional sampling beyond that accomplished by the existing Chesapeake Bay Partnership long-term water quality monitoring program is the best choice. The specifications of the discrete sampling are robust enough to provide confidence in the attainment assessment yet not resource intensive enough to prevent its routine application. The discrete sampling approach can be used by jurisdictions to assess their open-water instantaneous minimum dissolved oxygen criteria (Table II-5).

Table II-5. Recommended approaches to assess short duration criteria.

Criteria Assessment	Method	Criteria	Source
All segments, all designated uses	Direct Assessment with Enhanced Monitoring (vertical water quality profilers, autonomous underwater vehicles, citizen science, etc.)	All	U.S. EPA 2003a, U.S. EPA 2004, this document
Open-water designated use <ul style="list-style-type: none"> • OPTION: Segment assessment • OPTION: Subsegment zones and assess <ul style="list-style-type: none"> ○ Offshore ○ Shallow ○ Protected tributaries 	<p>Conditional Attainment with Bimonthly Monitoring Data</p> <p>Meet the 30-day mean dissolved oxygen threshold associated with a less than 10% risk of acceptable nonattainment of the 7-day mean DO criterion</p> <p>Meet the 30-day mean dissolved oxygen threshold for a specified risk greater than 10% acceptable nonattainment for instantaneous minimum</p> <p>Conditional Attainment with Decision Rule. If subsegments Zone 2 and Zone 3 pass, then the offshore water is deemed passing and the entire segment is considered in attainment for IM</p> <p>Conditional Attainment (same as segment assessment above)</p> <p>Continuous Monitoring,</p> <p>15 minute interval data collected over the entire summer season with application of “Rule 2A”</p> <p>Discrete sampling:</p> <p>10 sample events per year, 3 years</p>	<p>7-day mean</p> <p>Instantaneous minimum</p> <p>Instantaneous minimum</p> <p>7-day mean, instantaneous minimum</p> <p>Instantaneous minimum</p> <p>Instantaneous minimum</p>	<p>U.S. EPA 2003a, U.S. EPA 2004, CBP STAC 2012, this document.</p> <p>This document.</p> <p>U.S. EPA 2003a, U.S. EPA 2004, CBP STAC 2012, this document.</p> <p>This document</p> <p>This document</p>
Deep-water designated use	Conditional Attainment with Bimonthly Data. Meeting the deep-water 30-day mean criterion ensures attainment of the short duration criteria.	1-day mean, instantaneous minimum	U.S. EPA 2004

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CHAPTER 3

Accounting for Missing Volumes in the Chesapeake Bay Program Segmentation to Support Clean Water Act 303(d) Listing Assessments

The Chesapeake Bay Program partnership uses a segmentation scheme to organize data collection, analysis and reporting of water quality for the Chesapeake Bay, its tidal tributaries and embayments. However, three segments had not yet been assigned water volumes. Chesapeake Bay long-term water quality monitoring stations are present and active within each segment. Therefore, a gap remained in support of water quality standards attainment reporting for Clean Water Act (CWA) 303d listing assessments of the Western Branch Patuxent River Tidal Fresh (WBRTF), Anacostia Tidal Fresh Maryland (ANATF MD), and the Patuxent River Tidal Fresh (PAXTF) segments. In this chapter, water volumes are assigned and the basis for decisions on the volume assignments provided for the WBRTF, ANATF MD and PAXTF segments.

BACKGROUND

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 monitor 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. Finally, Chapter 2 in U.S. EPA (2008) reviews the 1985, 1997, and 2003 segmentation schemes for Chesapeake Bay and documents the present (i.e., 2008) 92-segment scheme that was the foundation segmentation for the Chesapeake Bay Total Maximum Daily Load (TMDL) (U.S. EPA 2010a).

Currently, the Western Branch Patuxent River Tidal Fresh segment 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 supporting the Chesapeake Bay TMDL due to a lack of bathymetry information. Further, water quality standards attainment assessment could not be conducted without a representation and measure of the water volume to support the analysis. In addition, the Maryland portion of Anacostia Tidal Freshwater segment and the Patuxent Tidal

Fresh have water quality monitoring stations within their boundaries but no segment volumes were on record to support water quality standards attainment assessments. In this chapter, a bathymetric Geographic Information System (GIS) layer and volume are established for the WBRTF management segment. Chesapeake Bay Water Quality/Sediment Transport Model-based segment volumes are assigned to ANATF MD and PAXTF as interim volume values to support their CWA Section 303(d) listing assessments until field measurement data becomes available.

WESTERN BRANCH PATXUENT RIVER TIDAL FRESH SEGMENT

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

Previously, no volume estimate was available for WBRTF (see Table 1 in U.S. EPA 2004) due to an absence of bathymetry data. Without a volume assignment, no CWA Section 303(d)-based list water quality standards attainment assessments could be completed. In 2013, the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team's Criteria Assessments Protocol Workgroup and Tidal Monitoring Analysis Workgroup coordinated with EPA and Maryland Department of the Environment (MDE) staff to use a 2001 record of field measurements to develop a segment bathymetry and establish a volume for WBRTF.

Developing a Volume Estimate for the Segment

MDE provided the CBP Criteria Assessments Protocol Workgroup with transect data collected September 7, 2001 to support development of a bathymetry for segment WBRTF (Appendix D). Chesapeake Bay Program Office (CBPO) 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 the ten transects provided by MDE, six occurred within the boundaries of WBRTF segment (Figures III-1-III-6, Appendix D). Transect lines were created corresponding to the lengths of the individual transects going through the points. In five cases (Stations #1, 2, 4, 5, and 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 III-1 through III-6, each transect is depicted in cross section, shore to shore, from an upriver to downriver perspective. The measurement unit is feet.

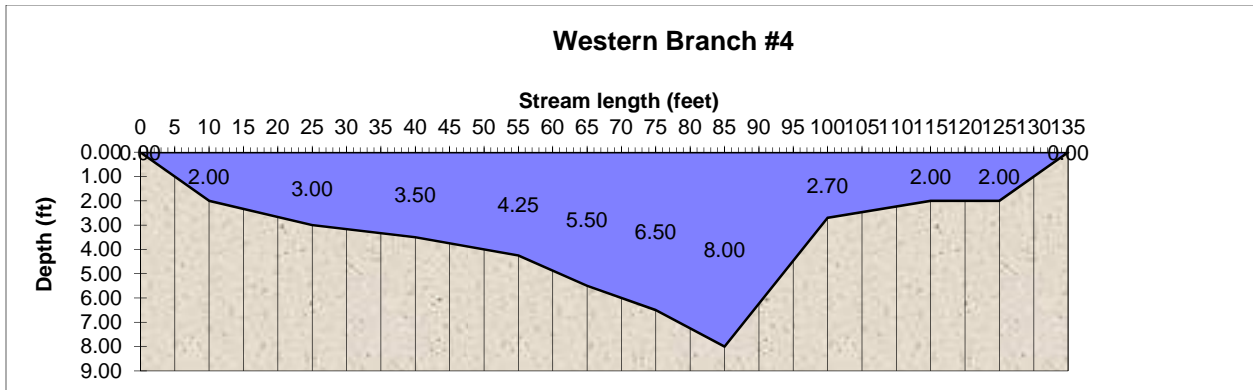


Figure III-4. Station code = Station #4. Site location N 38 47.485 W 76 43.239 located downstream of a small unnamed tributary.

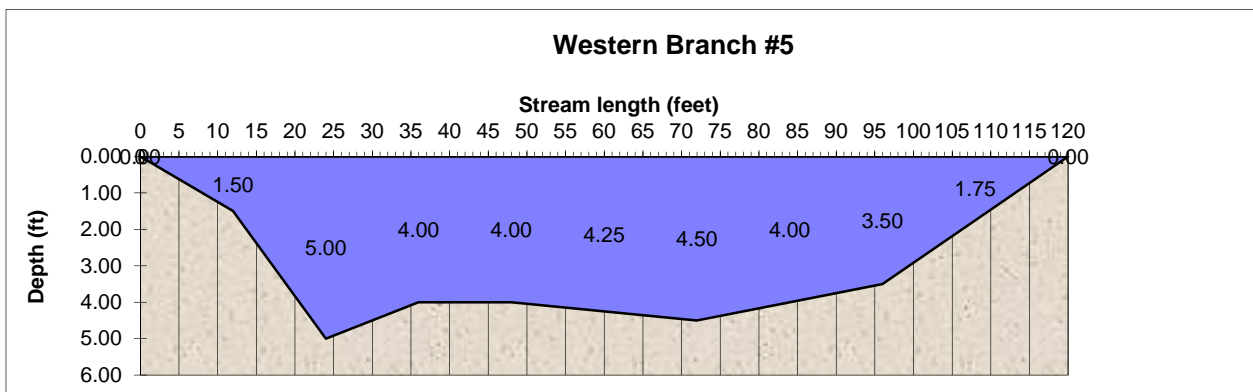


Figure III-5. Station code = Station #5. Site location N 38 47.777 W 76 43.316.

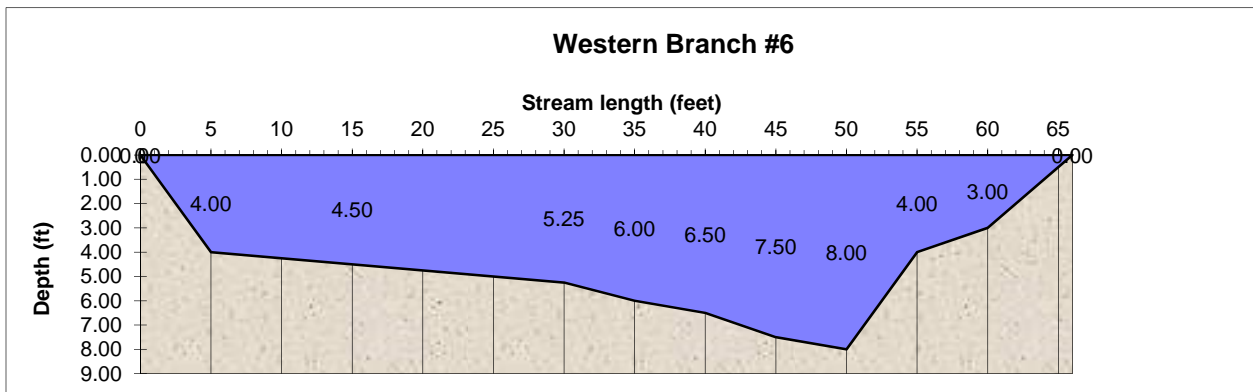


Figure III-6. Station code = Station #6. Site location N 38 47.832 W 76 43.746 located 50 yards downstream of WSSC outfall.

Based on the data tables (Appendix D) 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 Chesapeake Bay Program partnership’s analytical segmentation scheme there was no bathymetry data available 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.

Chesapeake Bay Program Office analysts 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 measured in square feet (ft²) was multiplied by the length of stream in the section measured in feet (ft) to estimate the stream section volume measured in cubic feet (ft³) (Table III-1). The sum of the stream segment volumes provided the total segment volume. Segment volume (ft³) was then converted to cubic meters (m³). Using ArcGIS, CBPO analysts had 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.

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

Length of stream (ft)	Cross sectional area (ft²)	Section volume (ft³)
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 then, the target grid cell volume was 2,500m³ with dimensions 50m² by 1meter (m) deep (Figure III-7). The cell size reflects the smallest cell dimensions being applied in depicting small tidal tributaries in the Chesapeake Bay Water Quality/Sediment Transport Model grid and approximates the average tributary width and depth dimensions of the WBRTF tributary segment from the field measurements. The newly computed total segment volume (111,567m³) was divided by the volume of a single cell to get the number of cells needed to represent the WBRTF in a GIS layer ($111,567\text{m}^3 / 2,500\text{m}^3 = 44.6$ 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 III-8). 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 III-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 sediment transport model used in development of the Chesapeake Bay TMDL. X, Y coordinates were then computed for the centroids of the cell polygons. Finally, a table of centroid coordinates and depths (all = 1m) was exported for use with the Chesapeake Bay Water Quality/Sediment Transport Model (Appendix E).

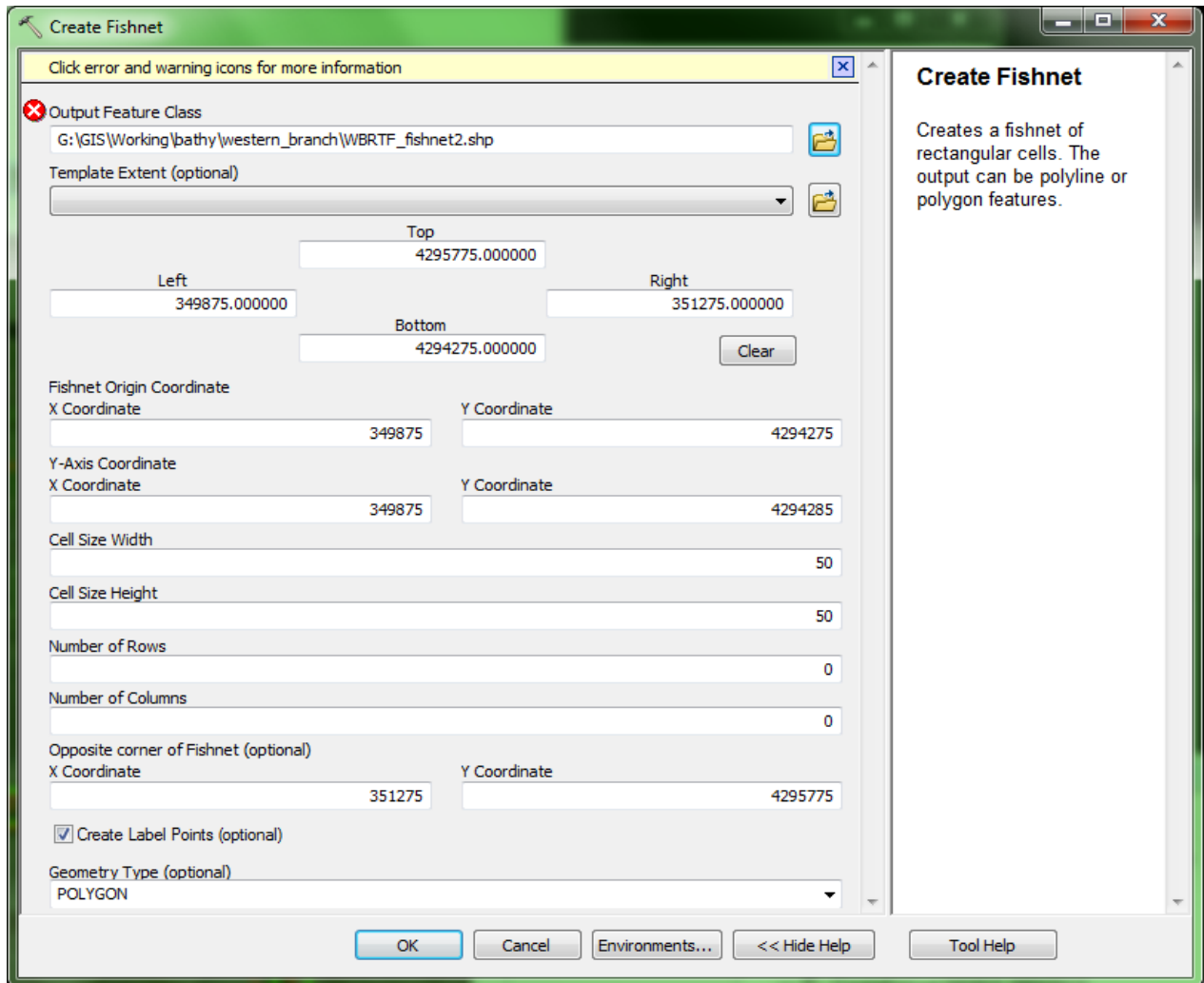


Figure III-7. Screen capture of the grid tool used in ArcGIS to create the 50m x 50m cells of the WRBTF segment. Each cell was established as 1m deep.

ANACOSTIA TIDAL FRESH – MD AND PATUXENT TIDAL FRESH SEGMENT VOLUMES

Insufficient bathymetry data has prevented development of interpolated volume estimates for segments ANATF MD and PAXTF. However, the Chesapeake Bay Water Quality/Sediment Transport Model requires volumes for all segments (U.S. EPA 2010b). The CBP partnership has previously agreed on volumes created for ANAT F MD and PAXTF during model development. Therefore, as interim volume estimates to allow for CWA Section 303(d)-based listing water quality standards attainment reporting of these two segments in Maryland, the CBP Criteria Assessments Protocol Workgroup worked with MDE to reach agreement on using interim segment volumes as they are expressed in the Chesapeake Bay Water Quality/Sediment Transport Model used to support the 2017 mid-point assessment of the Chesapeake Bay TMDL:

- PAXTF segment model-based volume of 11,025,000 cubic meters (m³); and
- ANATF MD model-based volume estimate is 172,500 m³.

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

CHAPTER 4

Development of a Multi-metric Chesapeake Bay Water Quality Indicator for Tracking Progress toward Chesapeake Bay Water Quality Standards Achievement

Until recently, 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 Chesapeake Bay health. However, all of these individual CBP reporting 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 segments in the Chesapeake Bay TMDL (U.S. EPA 2010b), a new indicator was needed. This new indicator needed to be a combined, multi-metric 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 Delaware, District of Columbia, Maryland and Virginia. This chapter documents this water quality standards-based multi-metric Chesapeake Bay water quality indicator for tracking progress in response to management in Chesapeake Bay, its tributaries and embayments.

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 EPA 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/underwater grasses 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 Delaware, Maryland, Virginia and the District of Columbia (DC) with recommendations for establishing water quality standards consistent with Section 303(c) of the Clean Water Act. These four jurisdictions 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 and EPA work collaboratively to assess water quality standards attainment based on the criteria applicable to the designated uses (Figure IV-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”.

Refined Designated Uses for the Bay and Tidal Tributary Waters

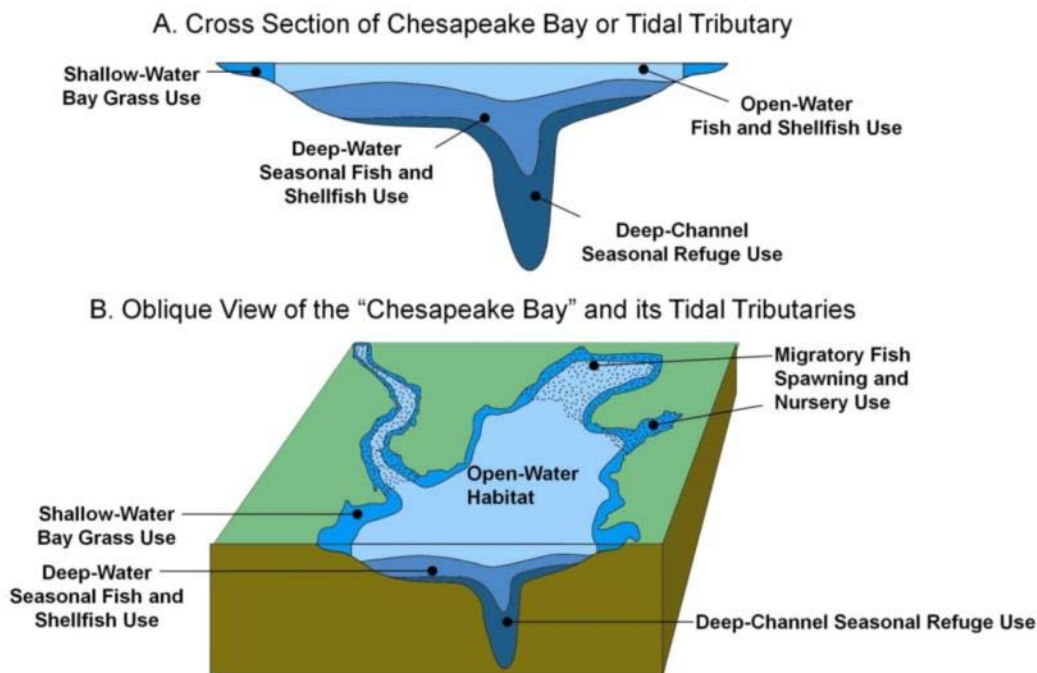


Figure IV-1. Conceptual illustration of the five Chesapeake Bay tidal water designated use zones.

Source: U.S. EPA 2003a

Section 117 of the Clean Water Act authorizes a Chesapeake Bay Program Office to publish information pertaining to the environmental quality of the Chesapeake Bay, as well as to coordinate Federal, State, District and tribal efforts to improve the quality of Chesapeake Bay. Until recently, 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. 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 segments in the Chesapeake Bay TMDL (U.S. EPA 2010b), a new indicator was needed. This new indicator needed to be a combined, multi-metric 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 four tidal Bay jurisdictions.

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 Chesapeake Bay health as expressed by the individual indicator reporting results for dissolved oxygen, water clarity, underwater bay-grasses and chlorophyll *a*.

MULTI-METRIC WATER QUALITY STANDARDS INDICATOR

The 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 Scientific, Technical Assessment and Reporting Team's Criteria Assessment Protocols Workgroup, explored a series of multi-metric indicator options. These analyses considered protocols for water quality standards 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 tidal Chesapeake Bay water quality monitoring results assessed using the Chesapeake Bay water quality standards attainment methodologies. 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 multi-metric score is briefly reviewed and referenced below.

Dissolved Oxygen

The published dissolved oxygen criteria assessment methodology currently used for assessing Chesapeake Bay water quality standards attainment involves the use of cumulative frequency distribution (CFD) curves in a two dimensional space of percent time and percent space to determine compliance with standards. The procedure for assessing dissolved oxygen criteria attainment is described in detail in Appendix A of the 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* (U.S. EPA 2008).

Chlorophyll a

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 (2007b), 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*. The published chlorophyll *a* criteria assessment methodology currently used for

assessing Chesapeake Bay water quality criteria attainment involves the use of cumulative frequency distribution curves in a two dimensional space of percent time and percent space to determine compliance with standards.

Water Clarity

Water clarity/underwater grasses standards may be computed through measured underwater grass bed acres towards the segment goal, water clarity acres or a combination of the two measures. An ArcGIS geodatabase in a Universal Transverse Mercator (UTM) Zone 18 projection is used to calculate area in square meters for all underwater grass beds each year. These areas are summarized in tables by USGS 7.5 minute quadrangle, Chesapeake Bay and segment and zone totals. Segment totals are calculated using an overlay operation of segment and zone regions on the underwater grass beds. 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*.

SCORING THE MULTI-METRIC INDICATOR

Until the three States and District of Columbia's existing Chesapeake Bay water quality standards regulations are revised to reflect the procedures of this latest criteria addendum, for the presentation of this indicator, it is assumed that attainment of the 30-day mean summer 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 is being assessed across all segments, designated uses, and the respective water quality criteria using the criteria framework for making 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 underwater grasses are observed within the segment; or
 2. sufficient acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired underwater grass 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 tidal mainstem James River segments and the District of Columbia's tidal upper Potomac River and Anacostia River segments:

- Tidal mainstem James River segments:
 - criteria attainment assessed during spring (March 1-May 31) and summer (June 1-September 30) 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:
 - criteria attainment only assessed during the summer (June 1-September 30) 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 underwater grass beds throughout the Bay. ArcGIS is also used for computing water clarity acres for the segments containing shallow-water monitoring data in a given year. Further information about each of the methods is highlighted in Appendix F.

There are 289 combinations of Chesapeake Bay water quality criteria and designated uses across Chesapeake Bay's 92 segments. Each segment can have between one (e.g., Eastern Branch of the Elizabeth River which only has open water) and four dissolved oxygen associated designated uses (e.g., Lower Rappahannock River which has migratory fish and spawning nursery, open-water (which includes the area outlined by the shallow-water, bay grasses designated use), deep-water, deep-channel) (U.S. EPA 2008). For water clarity, segments can have a shallow-water bay grass designated uses. Finally, the tidal mainstem James River segments and the District of Columbia's tidal upper Potomac River and Anacostia River segments have applicable numeric chlorophyll *a* criteria.

Area-weighted Approach

Count, volume-weighted and area-weighted approaches were all considered in the analyses, however, the area-weighted approach most effectively factored in the relative size of each segment. This approach gives equal weight to achievement of the applicable criteria protective of each designated use in a segment and prevents any need to weigh differently the importance of restoring dissolved oxygen versus bringing back underwater bay grasses or reducing algae.

Restoring healthy habitats of the Chesapeake Bay ecosystem requires attainment of all applicable Chesapeake Bay water quality standards for dissolved oxygen, water clarity/underwater grasses and chlorophyll *a* in the designated uses across the 92 Chesapeake Bay segments. The decision, approved by the CBP Partnership's Scientific, Technical Assessment and Reporting Team's Criteria Assessment Protocols Workgroup and the Water Quality Goal Implementation Team, was to create the water quality standards indicator based on the following:

- 1) the actual 3-year water quality criteria assessment protocols applied to the water quality data collected annually (i.e. produce the 3 year assessment in annual increments compared to CWA Section 303(d) impairment list reporting every 2 years;
- 2) use proportion of the segment that is in attainment multiplied by the surface area of each of the 92 segments;

- 3) add the results for all the designated use assessments that apply;
- 4) divide the sum of attainment by 289 to standardize the score to a scale of 0 to 1; and
- 5) multiply by 100 to express the result as a percent.

A score of 100 percent would mean all criteria are met in all segments and their applicable designated uses. Therefore, the resulting indicator score 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 IV-1, Figures IV-1 and IV-2).

Table IV-1. A hypothetical example of creating a water quality standards attainment score for a single year using the area-based approach that has been adopted by the Chesapeake Bay Program partnership for this multimetric water quality standards indicator.

AREA-BASED APPROACH			
289 Designated-Use Segments (contained within the 92 Chesapeake Bay segments)			
Chesapeake Bay Tidal Water Designated Use	Total Surface Area of Designated-Use Segments (km ²)	Total Surface Area of Designated-Use Segment Attaining WQS (km ²)	Designated Use Percent Attainment
Migratory Fish Spawning and Nursery	5565101169.36	0.00	0
Open Water-DO	11660174083.95	0.00	0
Open Water-CHLA (spring + summer)	620327627.29	0.00	0
Deep Water-DO	6932558324.18	0.00	0
Deep Channel-DO	4404190644.45	83660695.00	2
Shallow-Water Bay Grasses-SAV/Water Clarity	11558645485.84	2616220341.04	23
Surface area totals (km²)	40740997335.07	2699881036.04	--
Baywide Percentage of WQS Attainment¹ = 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

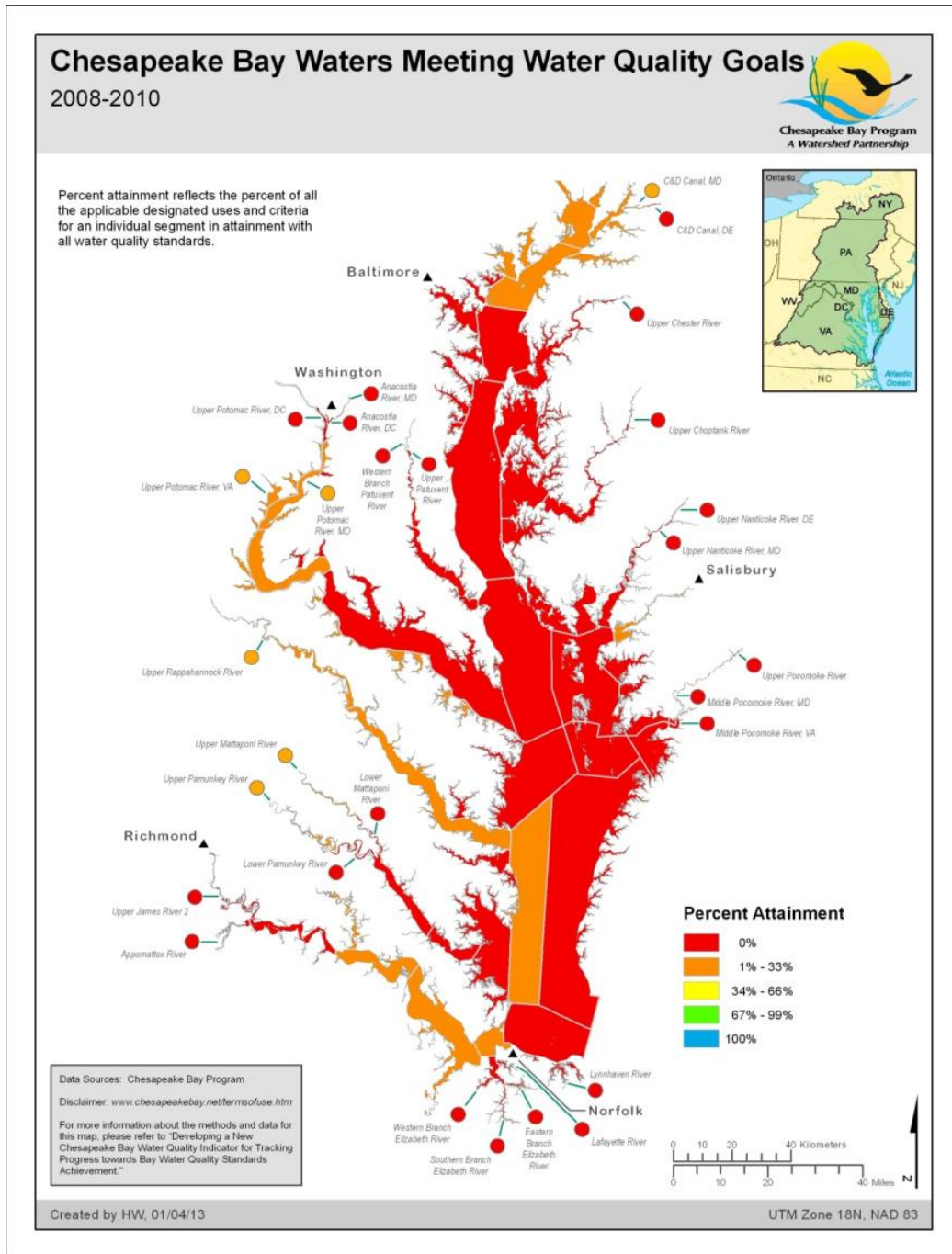


Figure IV-2. Visual illustration of the water quality standards indicator status, expressed as a percentage, for each of the 92 Chesapeake Bay TMDL segments (2008-2010 listing cycle). The number of water quality criteria applied varies across the 92 Bay segments based on the applicable designated uses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

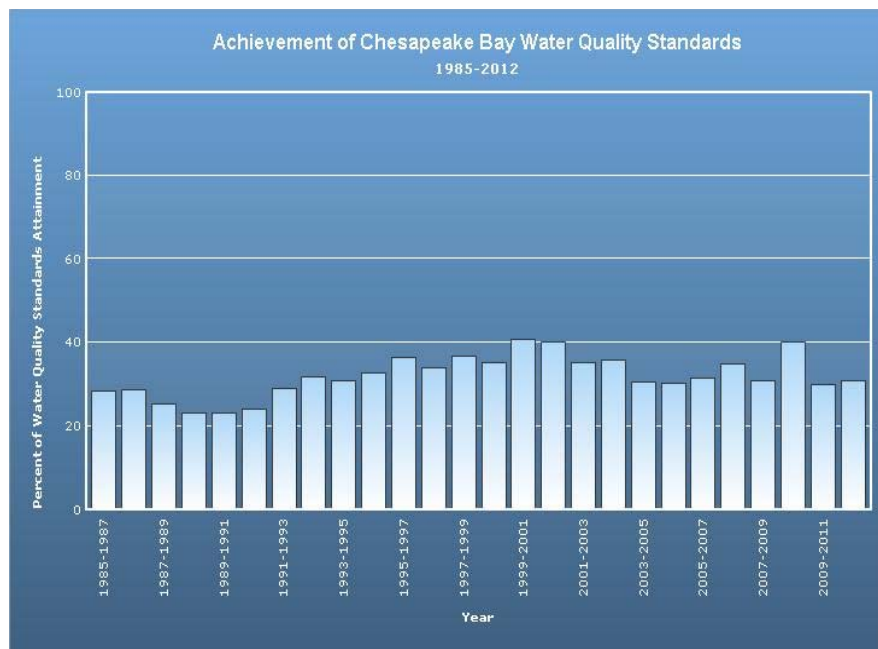


Figure IV-3. Retrospective time series illustration of the Chesapeake Bay Water Quality Standards indicator status, expressed as a percentage of goal attained for each of the 92 Chesapeake Bay TMDL segments (1985-2012). The number of water quality criteria applied varies across the 92 Bay segments based on the applicable designated uses (i.e., migratory spawning and nursery, open-water, deep-water, deep-channel, and shallow water bay grasses) and criteria (e.g., chlorophyll a). Percent attainment reflects all the applicable designated uses and criteria for that individual segment which are in attainment with all water quality standards.

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CHAPTER 5

Update of the Chesapeake Bay Underwater Grasses Restoration Goal: Alignment with Chesapeake Bay Water Quality Standards

Chesapeake Bay Program Office staff identified the difference between the 2003 underwater bay grasses restoration goal target (185,000 acres) adopted by the Chesapeake Bay Program partnership and the subsequent underwater bay grass acreage goal based on the sum of four tidal water jurisdictions' Chesapeake Bay water quality standards for the 92 Chesapeake Bay segments (192,000 acres) as an issue for resolution by the CBP partnership. The 2003 goal setting approach was extensive but included many cases of undercounting bay grass acres due to estimated acres of bay grasses that were 'clipped' from grass beds when applying the GIS analyses. 'Clipped' areas represented the difference between the GIS-based shoreline delineation and actual shorelines in the aerial photographs. This chapter documents the updating the Chesapeake Bay Program partnership's underwater grasses restoration goal. The Chesapeake Bay Program partners have since adopted a "Water Quality Standards-based Goal", presently 192,000 acres, as the partnership's official underwater bay grass restoration goal in place of the current 185,000 acre goal to ensure full consistency with Maryland, Virginia, Delaware and the District of Columbia's Chesapeake Bay water quality standards.

BACKGROUND

The underwater bay grass 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 underwater bay grass 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 acreages supporting the Chesapeake 2000 agreement, the development of Chesapeake Bay water quality criteria (U.S. EPA 2003a) and the adoption of the Chesapeake Bay water quality criteria into State water quality standards regulations by the tidal bay jurisdictions of Maryland, Virginia, Delaware and the District of Columbia.

From 2012 to 2015, the Chesapeake Bay Program's Criteria Assessment Protocol Workgroup conducted a water quality criteria assessment protocols review process in support of the Chesapeake Bay TMDL 2017 mid-point assessment. Chesapeake Bay Program Office staff identified the difference between the 2003 bay grass restoration goal target (185,000 acres) adopted by the Chesapeake Bay Program partnership and the bay grass target acreage goal based on the sum of four tidal water jurisdictions' Chesapeake Bay water quality standards for the 92 Chesapeake Bay segments (192,000 acres) as an issue for resolution by the Partnership. The basis, derivation, revision and adoption of the 185,000 acre bay-wide bay grass restoration acreage goal and associated assessment protocols is provided in the April 2003 publication *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries (Regional Criteria Guidance)* and the October 2003 *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability* (U.S. EPA

2003a, 2003b). The jurisdictions subsequent promulgation of their Chesapeake Bay water quality standards was not, however, based on a direct adoption of the published U.S. EPA (2003a) 185,000 acre underwater bay grasses goal.

The Chesapeake Bay Program partnership and its Submerged Aquatic Vegetation Workgroup assisted the Criteria Assessment Protocol Workgroup in understanding the historical basis for the differences in the two underwater bay grass acreage restoration goal totals. The groups reviewed the details of how the 185,000 acre underwater bay grass restoration goal derived then served as the foundation for setting their Chesapeake Bay water quality standards. In revising the underwater bay grass restoration goal, the jurisdictions 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 jurisdictions' adoption of their Chesapeake Bay water quality standards regulations. In adopting segment-specific water clarity/bay grass restoration acreage-based water quality standards, the Chesapeake Bay Program jurisdictional partners more accurately reflected segment-based underwater bay grass goal acreages. The water quality standards-based acreage goal is better aligned with the methods used in the annual aerial survey of underwater bay grasses to assess the status and track change towards attaining water clarity/shallow water bay grass goals and standards.

The following chapter reviews the history of establishing Chesapeake Bay underwater bay grass restoration acreage 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 underwater bay grass restoration goal to be consistent with the four tidal Bay jurisdictions combined Chesapeake Bay water quality standards-based restoration acreages, presently totaling 192,000 acres.

HISTORY OF DEVELOPING THE UNDERWATER BAY GRASSES RESTORATION GOAL

The original tiered targets supporting an underwater bay grass restoration acreage goal for Chesapeake Bay were first published in the 1992 SAV technical synthesis (Batiuk et al. 1992) 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 underwater bay grass distribution restoration targets was established to provide a measure of incremental progress for Chesapeake Bay restoration in response to improvements in water quality. The Tier I restoration target was the restoration of bay grasses to areas that were currently or previously inhabited by underwater bay grasses 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 restoration targets were supporting the restoration of underwater bay grasses to all shallow water areas delineated as existing or potential shallow water underwater bay grass 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 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 underwater bay grass 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 segment were published in *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis* (see Chapter VIII, Table VIII-1 in Batiuk et al. 2000).

U.S. EPA (2003b, p.118) reported that the *Chesapeake 2000* agreement (Chesapeake Executive Council 2000) committed the Chesapeake Bay Program partners to revising the existing underwater bay grass restoration goals and strategies: “.... to reflect historical abundance, measured as acreage and density from the 1930s to present”. The basis for the goal setting acreages referred to a “historical” underwater bay grass 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 segment and characterized as “historical” or designated a best year in the contemporary Chesapeake Bay underwater bay grass aerial survey monitoring data (1978-2000) (U.S. EPA 2003b). Underwater bay grass abundance was classified according to Chesapeake Bay 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, p. 114) 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 goal¹. 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, p. 119).

RESTORATION GOAL AND WATER QUALITY STANDARDS BAY GRASSES RESTORATION ACREAGES COMPARISON

During 2013 and early 2014, the CBP Habitat Goal Implementation Team’s SAV Workgroup reviewed the goal setting methodology used to derive the 2003 Chesapeake Bay tidal water underwater bay grass restoration acreage goal. Chesapeake Bay Program Office staff, working with the SAV Workgroup, identified differences between the segment-specific underwater bay grass restoration acreage targets supporting the 185,000 acre goal published in 2003 and the more recent 192,000 acres adopted by the four tidal water jurisdictions in their Chesapeake Bay water quality standards. The 185,000 acre underwater bay grass restoration goal setting effort preceded Chesapeake Bay tidal water jurisdiction’s adoption of the Chesapeake Bay water quality criteria into their State’s water quality standards regulations. The Chesapeake Bay Program partnership used data through 2000 for its single best year assessment and considered a 2001 underwater

¹ Also see Appendix A in U.S. EPA 2003 for a statement about the 185,000 acre goal adoption being consistent with the goals of the *Chesapeake 2000* agreement.

acreage total (U.S. EPA 2003b, Figure IV-31) as a potential goal when setting the 185,000 acre restoration target. The subsequent water quality standards promulgation 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 Chesapeake Bay water quality criteria.

The 2003 goal setting approach leading to the 185,000 underwater bay grass acre restoration goal included many cases of undercounting underwater bay grass acres. The undercounting was due to estimated acres of underwater bay grass with ‘clipped’ underwater bay grass beds within the GIS analyses. ‘Clipped’ areas represented the difference between the GIS-based shoreline delineation and actual shorelines in the aerial photographs. The process of clipping these areas produced a loss of this clipped underwater bay grass from a segment as viewed through the lens of GIS because clipped underwater bay grass acres 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, examples being the scale of the data and changes in the shoreline over time not reflected in the shoreline data set (e.g. erosion and sea level rise). At the same time there was a similar problem of undercounting involved with underwater bay grasses on underwater flats around islands due to shifting shorelines. This issue is acknowledged in U.S. EPA (2004, pp. 92-93).

To account for the underwater bay grass 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 (underwater bay grass) 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 recognized 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 adopting their new Chesapeake Bay 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 (underwater bay grasses) 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 (underwater bay grasses) 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 (underwater bay grass) acreages reported through the bay-wide SAV (underwater bay grass) 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 (underwater bay grass) 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 segments. Underwater bay grasses in these ponds, therefore, was excluded from these goal acreages. Lack of bathymetric data affected the accounting for underwater bay grasses in upper portions of the Patuxent River Tidal Fresh (PAXTF) and Anacostia Tidal Fresh (ANATF) segments. The ANATF segment had no underwater bay grass, however, the lack of bathymetry in the upper Patuxent River excluded most of the known underwater bay grasses acres in that area of the tidal river.

With respect to setting water quality standards-based underwater bay grass goal acreages for each of the 92 Chesapeake Bay segments, 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 (underwater bay grass) 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 (underwater bay grasses) 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 QUALITY STANDARDS-BASED SAV RESTORATION ACREAGE.

The Chesapeake Bay Program SAV Workgroup, working with Chesapeake Bay Program Office staff, determined that the basis for the 185,000 acres goal formed the foundation for the water quality standards-based goal. With few exceptions around the Bay and its tidal tributaries and embayments, the jurisdictions' Chesapeake Bay water quality standards segment-specific underwater grasses restoration acreages are equal to or greater than the segment-specific acreage goals supporting the original 185,000 acres goal. The four Chesapeake Bay tidal water jurisdictions Maryland, Virginia, Delaware and District of Columbia, were all consistent in their consideration for adding back previously missing acres into the segment-specific goals due to GIS method-related clipping away of visible underwater bay grass acres on the aerial photographs. Most of these 'clipped' acres were previously 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 that were lacking established restoration goals (Table V-1).

Table V-1. Summary of Chesapeake Bay water quality standards underwater bay grass restoration acreages compared with the original CBP underwater bay grass restoration goal acreages by Chesapeake Bay segment.¹

Water Quality Standards underwater bay grass Restoration Acres Compared with the Original Chesapeake Bay underwater bay grass 185,000 Acre Goal	Segment Count
Segments where the jurisdictions' Chesapeake Bay water quality standards underwater bay grass restoration acres were equal to or greater than the CBP 185,000 acre goal	93
Segments where the jurisdictions' Chesapeake Bay water quality standards underwater bay grass restoration acreages were revised to be lower than the original CBP 185,000 goal	9
Segments with no Chesapeake Bay water quality standard underwater bay grass restoration acres	2
Total	104

1. This table uses the Chesapeake Bay split segments as individual segments. It is a comparison of the four jurisdictions Chesapeake Bay water quality standards underwater bay grass restoration acres to the 2003 CBP underwater bay grass restoration goal segment acres. In 2003 the CBP recognized 104 segments according to U.S. EPA (2008). Appendix G provides a more detailed table that accounts for the decisions made in the assigning of goal acres to segments.

CHESAPEAKE BAY PROGRAM 192,000 ACRE WATER QUALITY STANDARDS-BASED UNDERWATER BAY GRASSES ACREAGE GOAL

The Chesapeake Bay Program partners have adopted the 192,000 acres as the partnership's official SAV restoration goal in place of the current 185,000 acre goal to ensure full consistency with Maryland, Virginia, Delaware and the District of Columbia's Chesapeake Bay water quality standards. The 185,000 acre bay grass restoration goal was recognized by the Partnership as a conservative target affected by undercounting underwater grass acres in a subset of Chesapeake Bay segments. Undercounted acres were due to multiple factors included mismatches between shoreline data layers and present day shorelines that resulted in underwater bay grasses 'on land' that was actually in the water, or missing bathymetry (e.g., PAXTF).

Recognizing that there are still two Chesapeake Bay segments without goal acreages, the "192,000" acre goal should be stated as "The Water Quality Standards-Based Goal", where the underwater bay grass acreage total remains subject to goals being set for segments without goals at this time.

CONSIDERATIONS FOR FUTURE ACREAGE GOAL AND PROTOCOL ASSESSMENT CONSISTENCY

Future consideration could be given for building in additional consistency between the states in their methodologies for basis of setting their water quality standards underwater bay grass restoration goal acreages whereby all jurisdictions only go out to application depth (the Maryland method) or they extend out to include the deep water acres (the Virginia methodology). If, for example, Maryland adopted the Virginia methodology, 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 CBP SAV Workgroup was funded by the Partnership in 2014-15 to produce a third SAV (underwater bay grasses) Technical Synthesis that updates the science, management and assessment of underwater bay grasses and its habitat. This publication could support a future

review regarding any needs to amend the Chesapeake Bay water quality criteria related to water clarity criteria and underwater bay grasses restoration acres and, subsequently, Chesapeake Bay water quality standards for the four tidal Chesapeake Bay jurisdictions.

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CHAPTER 6

Interim Rules for Water Quality Clean Water Act Section 303(d) Listing Status Using the Chesapeake Benthic Index of Biotic Integrity to Support Aquatic Life Use Assessments

Chesapeake Bay tidal water aquatic life designated use assessments that support the Clean Water Act (CWA) Section 303(d) impairment listings showed several segments were consistently classified as unimpaired in spite of having very low Benthic-Index of Biotic Integrity (B-IBI) scores. A B-IBI update was initiated in 2014 through an EPA CWA cooperative agreement to support a B-IBI recalibration. A completed update of the Chesapeake Bay B-IBI, however, is not anticipated before the publication of this technical addendum. Therefore, interim rules addressing the conditions affecting the segment impairment status classifications have been recommended.

BACKGROUND

The annual Chesapeake Bay benthic macroinvertebrate community health assessment supports State's tidal waters Clean Water Act 303(d) 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. B-IBI results provide stand-alone or supplemental information for the states to use in making their CWA Section 303(d) 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 (see Appendix J Chesapeake Bay Estuarine Benthic Communities Assessment Protocol for Maryland and Virginia 305(b)/303(d) Integrated Reports in U.S. EPA 2007). The assessment protocol builds directly on the more detailed assessment method recommended by Llanso et al. (2003) (see Appendix K, 2006 303(d) Assessment Methods for Chesapeake Bay Benthos in U.S. EPA (2007). This methodology assures bay-wide consistency in determinations of estuarine benthic community impairments.

Recent CWA Section 303(d) 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) typically associated with impaired status classification; and 2) high variability in scores producing wide confidence intervals on the B-IBI segment assessment. The Chesapeake Bay Program's Criteria Assessment Protocol Workgroup 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). The limits of the 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 on which salinity habitat the index is being 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. (1997) but are now available can be used today to calibrate the B-IBI for diagnostic purposes.

The CBP's Criteria Assessment Protocol Workgroup recognized that most of these issues were under review. A process to update the B-IBI was initiated in 2014 through the support of a U.S. EPA Clean Water Act cooperative agreement. A complete update of the B-IBI assessment was not completed before the publication of this technical addendum. In order for States to make improved determinations about water quality status in the aquatic life use, interim rules were proposed until the above issues were fully addressed and published updates to the B-IBI assessment protocol made available for adoption into the State's Chesapeake Bay water quality standards.

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. Interim decision rules have been agreed upon. 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.

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. The classification system uses designated uses as the basis for reporting on water quality.

Table VI-1. U.S. EPA 5-category system for classifying water quality status used as the basis for reporting water quality for Clean Water Act Section 303(d) 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.
<ul style="list-style-type: none"> • Category 4a 	A State developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination.
<ul style="list-style-type: none"> • 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.
<ul style="list-style-type: none"> • 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.

Source: Clean Water Act Section 303(d).

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.

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 Chesapeake Bay Program's Criteria Assessment Protocol Workgroup considered the characteristics of B-IBI results used to classify the status of Chesapeake Bay segments aquatic life designated use. The Chesapeake Bay B-IBI assessment methodology incorporates uncertainty in defining 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

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.

Specific considerations in forming the interim rules, therefore, focused on the B-IBI score and variability associated with the confidence intervals on the score. The CAP WG 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 B-IBI score 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, are:

- For segments where the CWA Section 303d listing classification results are “Impaired = No”, jurisdictions would identify those segments that also have a breadth of confidence limits $((\text{Upper confidence Limit}) - (\text{Lower confidence Limit})) \geq 0.5$ of 0.5 or greater.
- Of that subset of segments with confidence limits ≥ 0.5 , those that also have a Mean B-IBI < 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).

The application of this rule affects four Chesapeake Bay 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 affects the Sassafras River Oligohaline (SASOH). These four segments will now be classified as Category 3B.

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 in Table VI-2.

Table VI-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 303(d) listing assessments¹.

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.
<ul style="list-style-type: none"> Category 3a 	<ul style="list-style-type: none"> 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.
<ul style="list-style-type: none"> Category 3b 	<ul style="list-style-type: none"> VA: some data exist but are insufficient to determine support of designated uses. Such waters will be prioritized for follow up monitoring, as needed.
<ul style="list-style-type: none"> Category 3c 	<ul style="list-style-type: none"> 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.
<ul style="list-style-type: none"> Category 3d 	<ul style="list-style-type: none"> 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.
<ul style="list-style-type: none"> Category 4a 	<ul style="list-style-type: none"> A State developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination.
<ul style="list-style-type: none"> Category 4b 	<ul style="list-style-type: none"> Other required control measures are expected to result in the attainment of an applicable water quality standard in a reasonable period of time.
<ul style="list-style-type: none"> Category 4c 	<ul style="list-style-type: none"> 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.

1. Agreed to by the Chesapeake Bay Program’s Criteria Assessment Protocol Workgroup and approved by the Water Quality Goal Implementation Team in 2013.

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 EPA Mid-Atlantic integrated assessment, National Oceanographic and Atmospheric Administration Status & Trends, and EPA National Coastal Condition Assessment data sets.
2. Evaluate the new biological and contaminant data sets for completion, taxonomic consistency, consistency in sample identifiers, uniformity in units of measure, and relevance to project objectives.
3. Reevaluate reference ranges with new reference data.
4. Adjust thresholds and evaluate the performance of new metrics, such as new pollution indicative and sensitive species metrics.
5. Conduct sensitivity and reliability tests using the new metrics and thresholds.
6. After recalibration, compare open waters and creeks, and the new versus the old results by segment, stratum, and salinity regions. Readjust thresholds as necessary

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CHAPTER 7

Protocol for Incorporating Nontraditional Partner Data into Regulatory Clean Water Act Section 303(d) List Chesapeake Bay Dissolved Oxygen Standards 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 used as shorthand 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.

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 Program Partnership, these outside organizations and the public are referred to as "nontraditional partners". "Traditional partners" refers to those State and federal agencies, academic institutions and river basin commissions and entities that have been funded and directly involved in Clean Water Act Section 117 supported long term water quality monitoring programs since the advent of the monitoring efforts by the Chesapeake Bay Program partnership in 1984. There are usually requirements for data collection, quality assurance and submission before state agencies will consider the data.

Many organizations, institutions and citizens collect environmental data across the Chesapeake Bay and its watershed (MRAT 2009). As of 2015 only, a small subset of these nontraditional partners provides water quality monitoring data used in CWA Section 303(d) impairment listing

assessments for tidal water dissolved oxygen criteria attainment (e.g. Alliance for the Chesapeake Bay–Virginia, South River Federation–Maryland). However, additional nontraditional monitoring programs may be viable for partnering opportunities. Water quality monitoring data contributions of sufficient integrity to meet EPA standards and State’s requirements can be used to expand the spatial and temporal coverages in tidal water quality monitoring programs. Such program expansion can help to improve tidal water quality monitoring capacities supporting assessment of water quality criteria attainment.

CWA section 303(d) 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 any water quality sampling program to contribute data suitable for consideration of inclusion into a CWA section 303(d) impairment listing decision assessment on dissolved oxygen standards attainment is described below.

THE MONITORING PROCESS: PROTOCOL FOR DATA COLLECTION AND DATA DELIVERY

Monitoring dissolved oxygen for regulatory water quality attainment assessments involves the following steps and considerations:

1. Development, submittal and approval of a project plan
2. Approved Instrumentation
3. Calibration of instrument sensors
4. Data collection
5. Data management, submittal, review, and approval

This section 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.

Project Plan

The Project Plan must provide the following information:

- Project title
- Project start and end date
- List of individuals and organizations responsible for the program work. Some individuals may serve more than one role. This list includes
 - Principal investigator

- Project manager
- Quality assurance/quality control manager
- Data manager
- Administrative organization
- Data collection organization
- Analytical laboratory or laboratories
- A Scope of Work that includes
 - A table of the stations to be sampled including their latitude and longitude
 - A sampling plan with written standard operating procedures (SOPs) describing
 - What is being measured at a station
 - How is it being measured at a station
 - When (at what frequency during the year) will water quality be measured. with a sampling schedule
- A quality assurance/quality control plan that includes documentation of
 - Calibration procedures
 - Maintaining calibration logs
 - Sample collection procedures
 - Field and laboratory data sheets being used
 - Data management

Scope of Work: SOPs and Quality Assurance Plans

Written standard operating procedures (SOPs) are an important aspect of the quality assurance project plan. SOPs for the collection of water quality data supporting dissolved oxygen standards attainment assessment 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. The key reference containing full details and guidance is Chapter 4 of CBP's Recommended Guidelines for Sampling and Analysis² (CBP 2015). The project plan should contain written procedures that 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's 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 key reference containing full details and guidance is the *EPA Requirement for QA Project Plans* document which describes the necessary elements (U.S. EPA 2001)³.

The Chesapeake Bay Program's Quality Assurance Coordinator will review new partner QAPPs and SOPs for conformance with the Chesapeake Bay Program's protocols and conduct an on-site

² http://www.chesapeakebay.net/channel_files/19225/chapter_4-mainstem_tributary_field_procedures.pdf

³ <http://www.epa.gov/quality1/qs-docs/r5-final.pdf>

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.

Approved instrumentation

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.

Calibration of instrument sensors

Routine calibration of sensors ensures accurate, reliable and dependable water quality measurements. Field personnel must fully calibrate sensors before and after each sampling event, deployment, or 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 VII-1.

Table VII-1. Chesapeake Bay Program 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

Source: Chapter 4 in CBP 2015.

Data collection

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 (CIMS) 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.

Water Quality Profile

An *in-situ* vertical profile for water temperature, dissolved oxygen and conductivity is required at every sampling station to support the data needs of a dissolved oxygen water quality standards attainment assessment. 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 (CBP 2015).

Sampling Effort

Additional considerations for sampling designs including seasons, frequency and spatial distribution 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 in consultation with the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team (CBP-STAR).

Data Management, Submittal, Review and Approval

Potential partners will submit a preliminary dataset to the Chesapeake Bay Program Water Quality Data Manager to establish a basic level of quality. Data submittals must be managed in a seven table Microsoft Access database, although many submittals will require only two of the tables to be populated: 1) WQ_DATA Table (VII-2) and 2) WQ_EVENT (Table VII-3). A partner will receive documentation tools including the DUET Access Database Template, DUET Data Submittal Table Design Template, DUET Data Submittal Lookup Tables (Version 3, 6 February 2014), and the DUET User Guide (URLs to be established). The partner will receive a username/password and upload the dataset to DUET (Data Upload and Evaluation Tool). DUET is the CBP QA tool used to review all data submittals and generate a QA report determining the completeness and quality of the submitted data.

Table VII-2. Water Quality data table example (WQ_DATA).

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 VII-3. Water Quality monitoring event table example (WQ_EVENT).

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 Guide⁴.

⁴ 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.

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 Chesapeake Bay and watershed streams and rivers benthic macroinvertebrate data are examples of data that do not directly fit the water quality standards attainment needs of the 5 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 Watershed Agreement has 10 goals and 31 outcomes with new opportunities for nontraditional partners to contribute data collected according to required protocols to support the status assessment and tracking of Chesapeake Bay and watershed restoration (Chesapeake Executive Council 2014).

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ACRONYMS (Placeholder)

2-D	two-dimensional
B-IBI	benthic index of biotic integrity
CBP	Chesapeake Bay Program
CIMS	Chesapeake Information Management System
CFD	cumulative frequency distribution
CHLA	chlorophyll <i>a</i>
DC	deep channel
DO	dissolved oxygen
DW	deep water
EPA	U.S. Environmental Protection Agency
GLM	Generalized Linear Model
HRSD	Hampton Roads Sanitation District
m	meters
mg/L	milligrams per liter
OW	open water
S	surface
SAS	Statistical Analysis Software
SD	Standard Deviation
STAC	Scientific and Technical Advisory Committee
VIMS	Virginia Institute of Marine Science

APPENDIX A

Rationale for Sub-segmenting Open-Water Designated Use Segments into Zones

The following sections of this appendix discuss the development of a basis for sub-segmenting Chesapeake Bay open-water designated use segments for supporting the Chesapeake Bay Program partners Clean Water Act water quality standards attainment assessments. These five sections:

1. provide a historical review on the comparability of nearshore and offshore water quality in Chesapeake Bay tidal waters;
2. describe characteristics of Chesapeake Bay high frequency dissolved oxygen dynamics with an emphasis on shallow water habitat;
3. document support for a 2-zone sub-segmentation option in the open water designated use based on nearshore-offshore dissolved oxygen relationships;
4. document support for a 3-zone sub-segmentation options in the open water designated use and;
5. provide recommendations regarding sub-segmenting habitats in the open water designated use for water quality monitoring, water quality standards attainment assessment and Chesapeake Bay restoration management decision-making.

Chesapeake Bay Segmentation Scheme

The Chesapeake Bay Program partners have used various forms of a basic segmentation scheme to organize collection, analysis and presentation of environmental data for over three decades. 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.

Factors previously considered in development and revision of the Chesapeake Bay segment scheme include 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-segmenting Chesapeake Bay Segments

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 underwater grasses restoration goals for those segments (U.S. EPA 2004a). 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 underwater grasses and an area with little or no underwater grasses was used to guide where the division boundary lines were drawn (U.S. EPA 2004b). In Virginia, the James River tidal fresh segment (JMSTF) was sub-divided into an upper segment (JMSTF2) and a lower segment (JMSTF1) for application of the new water clarity/underwater grasses 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 published Chesapeake Bay designated use boundary definitions are another form of sub-segmentation within a segment. The designated use boundary definition for open water adopted by Delaware, the District of Columbia, Maryland and Virginia into their water quality standards regulations is:

From June 1 through September 30, the open-water designated use includes 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-water habitat (e.g., >2m in depth) and shallow-water habitats (e.g., <2m in depth) are similar enough to ensure protection of both the open-water and shallow-water bay grasses designated use with a single set of criteria (U.S. EPA 2003a). 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 water column 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 (U.S. EPA 2003a). 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.

Differences in Nearshore vs. Offshore Waters

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. Lyster et al. (2014) highlights management successes in similar shallow-water environments described by Caffrey (2004) 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 there was no scientific basis for a dissolved oxygen-based delineation between the two habitats. Acknowledging that habitat differences do exist, a jurisdiction may, however, specifically delineate sub-segments within a Chesapeake Bay management for purposes of criteria application and criteria attainment assessment (U.S. EPA 2007a).

Recognition of a Three-Zone Approach to Sub-segmentation

The U.S. EPA (2003c) 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 were conducted by the CBP’s Umbrella Criteria Assessment Team 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, Lyster et al. 2014). This combination of new science provides fresh insights and decision-support for options to be considered on sub-segmenting open-water 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 (2003c) 305b guidance for dividing estuarine habitats could be developed for application in Chesapeake Bay and its tidal tributaries and embayments supporting sub-segmenting options for the open-water designated use segments.

Importance of Shallow-water Area in Chesapeake Bay

A supplemental issue was expressed by the CBP partners that the sheer volume of offshore water regions may overwhelm signals of distress in shallow waters for Chesapeake Bay and its tidal tributaries and embayments (MRAT 2009, CBP STAC 2012). Significant differences in

dissolved oxygen behavior for nearshore and offshore open-water 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's tidal waters (Figure A-1).

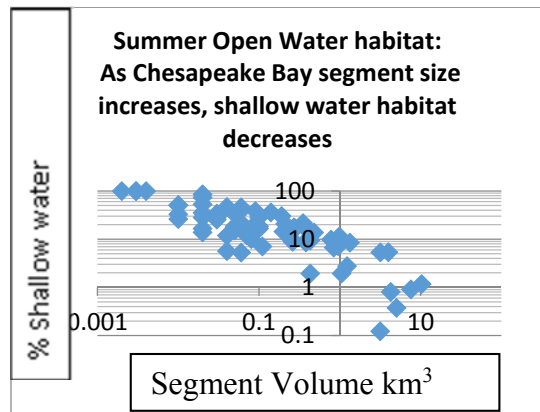


Figure A-1. The relationship of proportion of shallow water habitat as it relates to the size of the Chesapeake Bay segments. Total segment volumes (km^3) were based on the U.S. EPA (2003b). Percent shallow water volumes were calculated from SAV Tier III acres (0-2m), converted to volume by assuming a rectangular volume 3 feet deep is roughly equivalent to a triangular volume with maximum depth of 2m, converted to gallons, then converted to km^3) 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 ≤ 2 meters (p 38, U.S. EPA 2007a). Approximating the area and volume of all such shallow water habitat for the Chesapeake Bay and the tidal tributaries and embayments that are less than 2 meters in depth, there are at least 700,000 acres ($2,833 \text{ km}^2$) less than or equal to 6 feet deep (<http://www.chesapeakebay.net/discover/bay101/facts>). The total surface area of the tidal waters of Chesapeake Bay and its tidal tributaries and embayments is estimated to be $11,601 \text{ km}^2$. Therefore, the shallow water habitat of the tidal Chesapeake Bay waters is approximately 24 percent of its total 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 Chesapeake Bay, tidal tributary and embayment shallow water habitat is 4.6% of the total Bay waters 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 (Figure A- 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, its tidal tributaries and embayments may be exhibiting low dissolved oxygen or hypoxic events, significant examples exist such as occurs in South River, MD (Muller and Muller 2014), Severn River, MD, (see 2008 Severn River Report Card http://ian.umces.edu/pdfs/ian_report_card_212.pdf), and Corsica River, MD (see Figure A-6).

Between 1987 and 2001, fish kill distributions in Maryland (Figure A-3) have been widespread and point to many areas over time where Maryland Department of the Environment attributed the a portion of the observed fish kills potential causal effects may be due to hypoxia. 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.

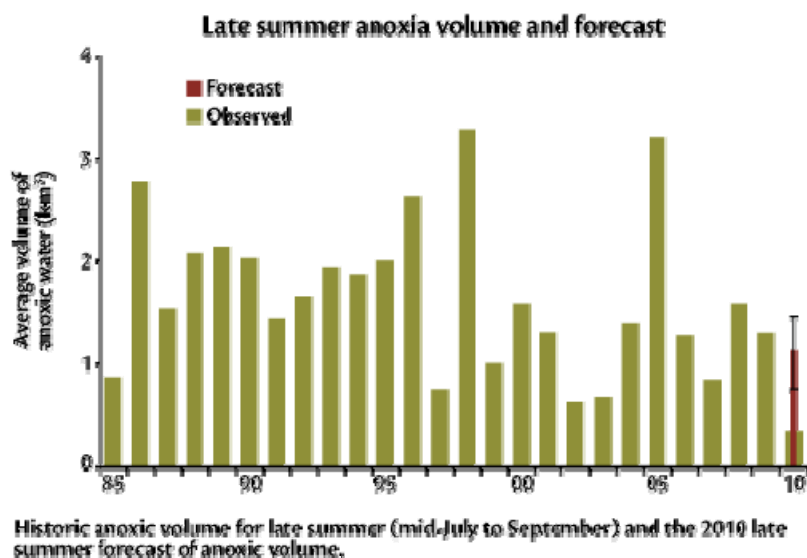


Figure A-2. Historical time series of anoxic volume for late summer also showing the 2010 IAN-Ecocheck forecast.

Source: IAN-ECOCHECK

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 that has been subjected to analysis for decades. 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 the 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 (Karrh 1999). The 13-tidal 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's measurement of 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 Umbrella Criteria Assessment Team used more than a decade of Chesapeake 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. Intra-site, inter-site and inter-annual variability are described within CBP STAC 2012. A foundation of new dissolved oxygen focused analyses was created from the work of the Chesapeake Bay Monitoring Realignment Action Team (MRAT 2009) and the CBP Umbrella Criteria Assessment Team (CBP STAC 2012).

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 A-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 routinely observed day/night diel fluctuations. 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 from the mainstem Bay into shallow water during a seiching event (Figure A-5). Degraded dissolved oxygen conditions persisted beyond a 24-hour 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 illustrated the impact of a nearly week-long water quality and fish kill event involving an algal die off during late September 2005 (Figure 6). 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 57 high temporal density dissolved oxygen data records for full summer seasons showing nearshore locations across Maryland tidal waters can experience a gradient of hypoxia from minutes to weeks.

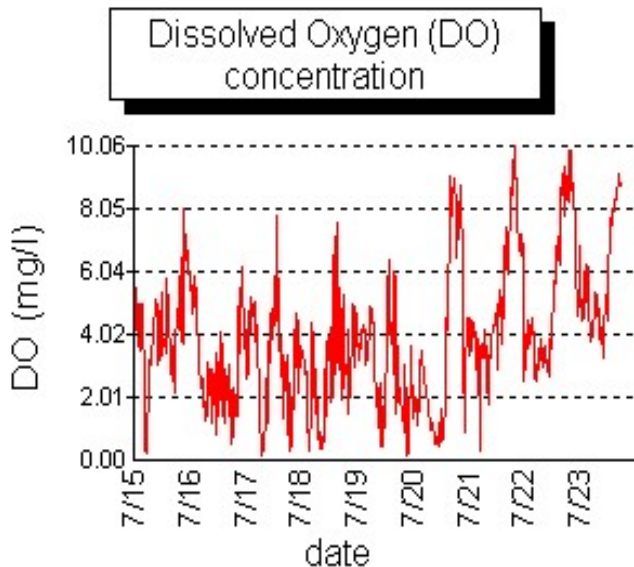


Figure A-4. Ben Oaks, Severn River, MD example of diel hypoxia in shallow water. Data collected every 15 minutes.

Source: Maryland Department of Natural Resources

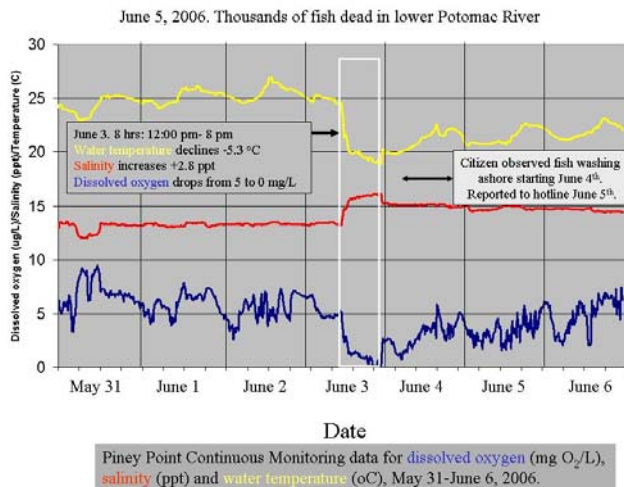


Figure A-5. Lower Potomac River Piney Point Continuous Monitoring data, Maryland Department of Natural Resources, from May 31 to June 6, 2006 shows intrusion of deeper water anoxic waters from the mainstem Chesapeake Bay. Such an intrusion affecting nearshore dissolved oxygen resources was linked with climate forcing effects of wind direction changes on June 3, 2006 and a resulting seiche of bottom waters of the adjoining mainstem Bay.

Source: Maryland Department of Natural Resources

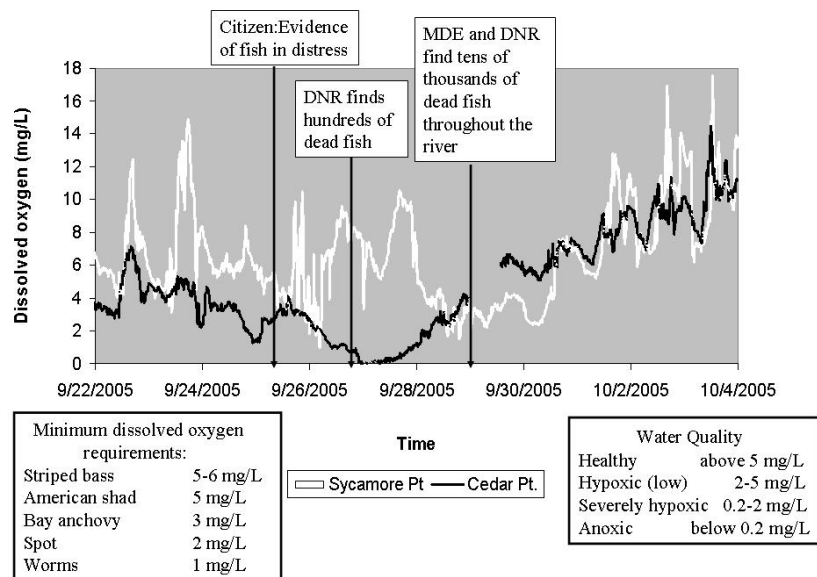


Figure A-6. Corsica River, MD, 2005. Chronology of a fish kill and associated water quality.

Sources: Maryland Department of Natural Resources, 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 (see Buchanan Appendix 1, Perry Appendix 11 in CBP STAC 2012). Perry (Appendix 11 in CBP STAC 2012) combined data from 9 tidal 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 O₂/L, a summer range from 0.36-14.9 mg O₂/L and an autumn range of 3.1-14.0 mg O₂/L. The tidal Potomac River data further showed that the range of diel DO variability experienced in shallow waters reached 11.0 mg O₂/L in spring, 17.52 mg O₂/L in summer and 10.8 mg O₂/L in autumn.

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

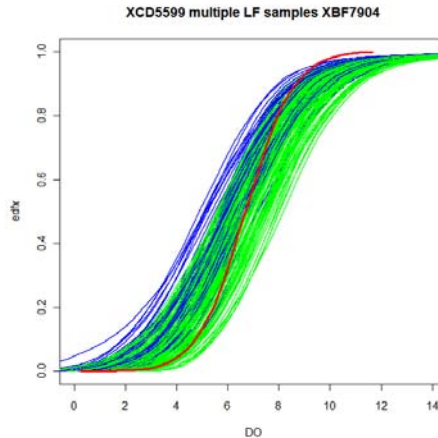


Figure A-7. Empirical distribution functions illustrate variation in dissolved oxygen measurements due to multiple low-frequency samples from the receiving site using a Fourier Series interpolation. The sending site data set was held constant as a single two-week interval. Blue curves are synthetic DO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

SUPPORT FOR A 2-ZONE SUB-SEGMENTATION OF OPEN WATER DESIGNATED USE SEGMENTS

Based on the Umbrella Criteria Assessment Team analysis of high frequency continuous monitoring data from multiple tidal tributaries across the Chesapeake Bay’s tidal waters, the behavior of nearshore dissolved oxygen concentrations was statistically similar to offshore dissolved oxygen concentrations at long time scales (i.e., 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 CBP’s Scientific, Technical Assessment and Reporting Team’s Tidal Monitoring and Analysis Workgroup revisited the question of comparability of nearshore and offshore dissolved oxygen behavior with a paired comparison analysis of the best available high frequency, nearshore and offshore water quality monitoring data sets. Robertson and Lane, as reported in CBP STAC 2012, previously used comparisons of nearshore continuous dissolved oxygen concentration monitoring data with synthesized offshore dissolved oxygen concentration data developed using a spectral casting technique. Robertson (2013 **TMAW**) updated the analysis by replacing synthesized offshore data and using direct measurements from Virginia’s offshore tidal York River and tidal Rappahannock River vertical water quality monitoring profilers to compare with co-located nearshore continuous water quality monitoring measurements. Robertson’s 2013 analyses reconfirmed the initial findings reported by CBP STAC (2012) of similarity between nearshore and offshore dissolved oxygen behavior at the 7-day and 30-day mean scales of comparison but dissimilarity at 1-day and instantaneous minimums scales.

Trice (2013 **TMAW**) provides additional insights into Robertson’s (2013) findings regarding differences in dissolved oxygen patterns at the shortest (daily or less) time scales. Trice

compared 2004 and 2005 summer season hourly average data for co-located monitoring stations of Pin Oak (nearshore) and CBL (offshore) on the lower Patuxent River. Trice (2013) showed nearshore conditions were worse 22 more days nearshore than offshore in summer 2004, and 39 more days nearshore than offshore in summer 2005. 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 between nearshore and offshore habitats for the criteria attainment assessment of the shortest duration dissolved oxygen criteria (e.g., instantaneous minimum) applicable to protection of the open-water designated use.

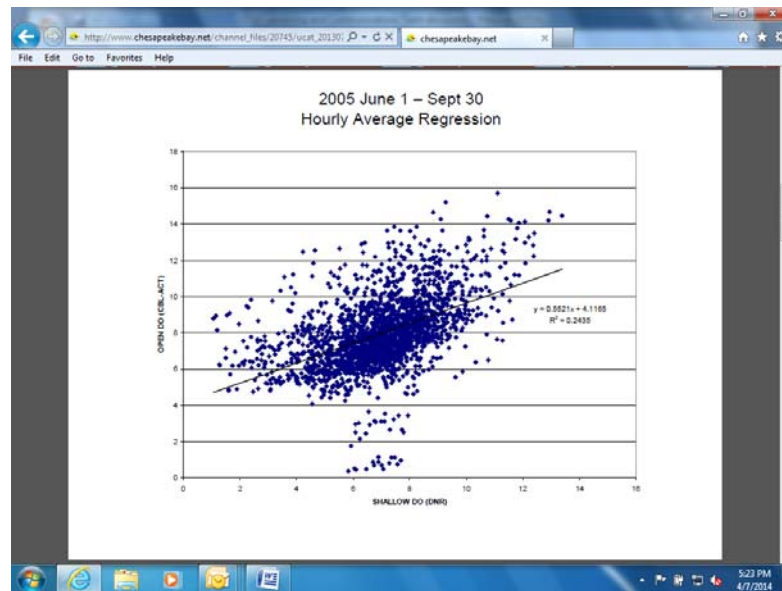


Figure A-8. 2005 example of hourly average comparisons illustrating the tendency for nearshore shallow water conditions to be lower than offshore, Patuxent River.

Source: Maryland Department of Natural Resources

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 by the data analyses described below. Caffrey (2004) and Boynton et al (2014) find that nearshore monitoring sites with greater exposure to mainstem tidal bay and mainstem tidal tributary habitats show better water quality conditions than nearshore sites with more restricted exposures. Boynton et al. (2014) pointed to “tributaries of tributaries” having greater violation rates on average than monitoring stations located in the nearshore zone of the mainstem of a tributary. Both the tributary of tributary sites and the nearshore zones of tributaries had greater violation rates than monitoring sites exposed to the open waters of the mainstem Chesapeake Bay. The findings are consistent with the 3-zone approach recommended 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 the 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 an 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 (e.g., like the highly sheltered bays category suggested by Washington State Department of Ecology) .

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APPENDIX B

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 B-1). 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. 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 B-1. Data sources serving the Umbrella Criterion Assumption analyses.

Program Description	Data Collection and Availability	Sampling Locations and Habitats
<p>CBP long-term water quality monitoring program:</p> <p>Low temporal frequency and spatial resolution, good vertical profile resolution of the data.</p>	<p>1985-present.</p> <p>Biweekly to monthly sampling.</p> <p>Water column profiles taken with grab samples and sensors.</p> <p>Web accessible data: <i>CBP CIMS</i> accessible.</p>	<p>Fixed site, mid-channel, Bay and tidal tributaries, approximately 150 stations. Covers tidal fresh to polyhaline habitat conditions.</p>
<p>USEPA EMAP: Historical short-term buoy deployments with high temporal frequency at a station. Single depth sensor evaluations.</p>	<p>Mix of short term (days to weeks) time series with high temporal frequencies by sensor. See USEPA (2004).</p>	<p>Fixed site, off shore locations, varied depths. Tidal fresh to polyhaline habitat conditions.</p>
<p>CBP Shallow Water Monitoring Program, Continuous Monitoring (CONMON): High temporal frequency at moored locations.</p>	<p>Approximately 2000-present.</p> <p>Mostly seasonally, near continuous (15 min interval) time series April-October.</p> <p>Fixed depth sensor, usually 1m off bottom.</p> <p>Web accessible data: <i>Eyes on the Bay</i> in MD, <i>VECOS</i> in Virginia.</p>	<p>Fixed site, shallow water, nearshore locations, approximately 70 sites Baywide with 1-9 yrs of data. Tidal fresh to mesohaline conditions.</p>
<p>VIMS, MD DNR Vertical Profilers: High temporal frequency in 2 dimensions.</p> <p>VIMS: Bottom sonde .</p>	<p>Approximately 2006-present. Limited seasons. Sensors provide water column profiles at sub-daily scales. Bottom sonde.</p> <p>Web accessible data: MD DNR and VADEQ.</p>	<p>Fixed sites (n<5), offshore locations in MD (Potomac River) and VA (York and Rappahannock Rivers). Dominantly mesohaline lower tidal tributary data.</p>
<p>CBP Shallow Water Monitoring Program, surface water quality mapping with DATAFLOW: High Spatial resolution along temporally dense collection track.</p>	<p>Approximately 2000-present.</p> <p>Biweekly to monthly mapping assessments within April-October season.</p> <p>Multi-year assessments (3 yr sets).</p> <p>Sensor 0.5m below surface</p> <p>Web accessible data: <i>Eyes on the Bay</i> in MD, <i>VECOS</i> in Virginia.</p>	<p>Chesapeake Bay Program management segments. Approximately 40 of 92 segments assessed to date. Tidal fresh to polyhaline habitats.</p>
<p>VIMS Volumetric Assessment with ACROBAT (towed sensor underwater at variable depths). High spatial resolution -</p>	<p>Approximately 2003-present</p> <p>Limited seasons.</p> <p>3-dimensional sensor assessment of water column water quality.</p> <p><i>VIMS data</i>, Brush et al.</p>	<p>York and Rappahannock Rivers (VA) study sites, deep water reaches. Dominantly mesohaline habitat.</p>

APPENDIX C

Conditional Probability Analysis Support

Section 1 of Appendix C reviews the conditional probability analysis of Elgin Perry assessing protection of the 7-day mean dissolved oxygen open water criterion provided by the 30-day mean dissolved oxygen criterion documented in the CBP-STAC 2012 publication on the umbrella criteria assessment. Section 2 of Appendix C furthers the analysis through a parametric simulation approach to assessing the umbrella concept for assessing simultaneous protection of the 30-day mean for the instantaneous minimum dissolved oxygen criterion.

Section 1. Conditional probability analysis between the 30-day mean DO compared with the 7-day mean DO.

E. Perry conducted a conditional probability analysis between the 30-day mean DO compared with the 7-day mean DO (Appendix 2, CBP-STAC 2012) using high temporal density Potomac River continuous monitoring data sets to assess conditions support mutual habitat protection. The results support that it would be a rare situation where the 30-day mean would be satisfied and the 7-day mean would be violated more than 10% of the time.

The method employed is based on the approach (Figure C-1) that if the variability of the 7-day mean about the 30-day mean has a standard deviation less than 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 being met.

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

Table C-1. Names, locations, and years of continuous monitoring data used.

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

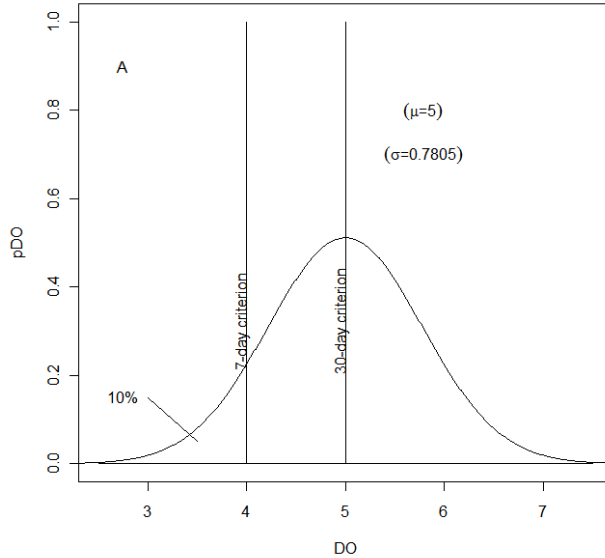


Figure C-1. Illustration of the level of variability of the 7-day mean about the 30-day mean that results in up to 10 % violations of the 7-day mean criterion when the 30-day mean criterion is met.

Beginning with the first collection day for each year at each location, blocks of 30 days were created to represent months. Partial months at the end of each collection year were counted as a month. Similarly, weeks were created by starting with the first collection day of each year and counting off blocks of 7 days. With these definitions, monthly means were computed as the arithmetic average of DO concentration measurements for each month. Weekly means were computed as the arithmetic average of DO concentration measurements for the intersection of month and week. Thus a week that bridges across two months would have its data divided by month and a weekly mean computed for each part. Weekly means and Monthly means were merged by month and a residual computed by subtracting the monthly mean from each weekly mean computed within that month. Various analyses were conducted on these residuals to assess the variability of weekly means about the monthly mean (Appendix 2 in CBP STAC 2012). Graphical analyses were used to assess the uniformity of variation over other factors. Distribution functions and quantile estimation was used to estimate the rate of violation of the 7-day criterion given that the 30-day criterion was satisfied.

The results suggest that we would only see greater than 10% violations of the 7-day criterion given that they 30-day criterion is met if the 30-day mean were hovering at or just above the 30-day criterion. Because the 30-day mean rarely exhibits this behavior, it seems safe to conclude that in most cases the 30-day criterion acts to protect habitat under the 7-day mean criterion measure as well. However, slight increases in the variation of the weekly mean about the monthly mean without corresponding increases in the monthly mean could start to increase the violation rate for the 7-day criterion to above 10 percent.



Figure C-2. Locations of Potomac River continuous monitoring data collection sites used for this analysis.

Sampling Variability: Sampling Effort Effects the Mutual Criteria Attainment Assessment.

As stated above, the Umbrella Criteria Assessment Team under the CBP Scientific, Technical and Reporting Team reviewed the variability of the 7-day mean DO about the 30-day mean DO and concluded that in general, that if the 30-day DO criterion is satisfied by the 30-day mean, then there is less than a 10% chance that the 7-day mean DO criterion will be violated by the 7-day mean DO concentration. This conclusion is based on having very accurate estimates of both the monthly mean and the weekly mean derived from near continuous (e.g. every 15 minutes) high frequency observations of DO. However, in many parts of the bay, the monthly mean is estimated from as few as one to two point observations per month. Because the uncertainty of a 30-day mean from two observations is much greater than the uncertainty of a 30-day mean from near continuous data, it is reasonable to expect that effectiveness of the mutual habitat protection of the 30-day criterion for the 7-day criterion will change when the low sample size mean is employed. The Umbrella Criteria Assessment Team examined the additional uncertainty that is created by the use of small sample size and further evaluate the consequences of this uncertainty for the conditional attainment assessment approach.

This study evaluates the additional uncertainty from low sample sizes by resampling from near continuous records in a manner that simulates the twice monthly sampling of routine cruises. The near continuous DO concentration time series records used are from the Potomac River continuous monitoring data collected by the shallow water monitoring assessment of the CBP water quality monitoring program. For each calendar month in the May through September period of each record, a random day between 1 and 15 was chosen as the first sampling day of

the month. To get a second sampling day, a random increment from 10 to 16 was generated and added to the first. In the event that there was no data on this second day, then the last day of the month with data was used. For each selected day, a random selection from the roughly 24 observations taken between 9:00 a.m. and 3:00 p.m. was chosen as the point estimate. These two estimates were summed and divided by 2 to obtain the monthly mean estimate. This simulation was repeated 20 times to obtain 20 monthly mean estimates for each station and month.

Months were calendar months, and weeks were designated as sequential weeks beginning January 1st of each year. Weekly means were computed for each unique combination of month and week. Thus if a month terminus divided a week, then the week was divided at this point and the resulting partial weeks were assigned to the two months. Deviations of the weekly means about the monthly mean were computed as (weekly mean DO – monthly mean DO) for weeks that occur within a month. In all cases, the weekly mean DO was computed as the mean of all high frequency observations within a week and is referred to as the near true weekly mean. The monthly mean was computed two ways. A near true estimate of the monthly mean uses all observations in the near continuous record; a small sample estimate of the monthly mean uses only two observations as described by the resampling methods above. The root mean square error (rmse) was computed across months, years, and stations for both the near true deviations and the small sample deviations. These root mean square estimates quantify the standard deviation of the weekly mean about the monthly mean for both the near true case and the small sample estimate case. The increase in the rmse for small sample case relative to the near true case illustrates the loss of precision in estimating the monthly mean by small samples. Using these estimates of standard deviation and assuming a normal distribution for these deviations, we estimate the probability that the weekly mean is less than 4.0, the 7-day mean criterion, while the monthly mean is 5.0, the 30 day mean criterion. This probability is a measure of the efficacy of the 30-day mean criterion as a measure of conditional DO criterion attainment for the 7-day mean criterion.

Descriptive statistics for the true weekly deviations and the small sample deviations show a negative bias of small sample deviations relative to the true deviations (Table C-2). This shows that the resampled monthly means which use daytime data only tend to be biased high, but on average this effect is not large. The range of the mean of the deviations over the resampling experiments is (-0.3428 -0.0133). The variability of the small sample deviations is much greater than that of the near true deviations. The true deviations have an rmse very close to 1.0 while the rmse from the small sample deviations always exceeds 1.6 and in one case exceeds 1.9 indicating a 60 to 90 percent increase in variability (Table C-3).

Table C-2. Summary of comparing weekly DO means to monthly DO means for ‘true’ means and monthly means from 20 small sample resampling experiments.

Simulation	Sample size	Mean	Rmse	Minimum	q25	Median	q75	Maximum
true	833	0.0017	1.005	-4.18	-0.4816	0.0125	0.4828	3.2042
1	833	-0.1344	1.6578	-5.1447	-0.9944	-0.0542	0.8052	4.9893
2	833	-0.0247	1.6903	-5.6588	-0.8519	0.0165	0.8543	4.4843
3	833	-0.2745	1.7132	-6.684	-1.1194	-0.1775	0.6852	4.4353
4	833	-0.2187	1.8037	-7.9388	-0.9968	-0.0879	0.7284	5.3265
5	833	-0.1723	1.8766	-8.2638	-0.9699	-0.0726	0.8603	4.9031

6	833	-0.0666	1.6177	-5.379	-0.8897	-0.0173	0.7745	4.6073
7	833	-0.2252	1.7196	-6.8519	-1.066	-0.2264	0.6948	5.3679
8	833	-0.0133	1.6054	-5.4517	-0.7627	0.0211	0.8046	5.1295
9	833	-0.3428	1.7471	-6.3008	-1.1947	-0.2999	0.5542	4.3745
10	833	-0.1639	1.7156	-7.3597	-1.0652	-0.1465	0.8385	4.7042
11	833	-0.0948	1.7555	-5.7288	-1.0169	-0.0054	0.8369	5.0334
12	833	-0.2193	1.9286	-7.2316	-1.0929	-0.0793	0.7621	5.5595
13	833	-0.2014	1.692	-6.5302	-1.0818	-0.0624	0.7351	5.1557
14	833	-0.1747	1.6198	-6.2597	-1.063	-0.1254	0.8021	3.9682
15	833	-0.1424	1.7216	-6.3428	-1.0468	-0.1171	0.8693	4.8051
16	833	-0.1055	1.7055	-6.114	-1.0153	0.0278	0.9094	4.3039
17	833	-0.1663	1.8126	-6.424	-1.1035	-0.107	0.7703	4.6611
18	833	-0.2157	1.8397	-6.3407	-1.1281	-0.1486	0.8262	5.2234
19	833	-0.0624	1.7048	-5.3103	-1.0217	-0.0165	0.8549	4.7011
20	833	-0.2306	1.7493	-8.2242	-1.1226	-0.1713	0.7209	4.2593

The distribution of the true weekly deviations tends to follow the normal distribution closely for the bulk of the observations (Figure C-3). However, there is a small percentage of outliers at both the upper end and the lower end of the distribution that are more extreme than are expected for the normal distribution. Because of this heavy tailed feature of the true deviations, when the normal distribution is used to compute probabilities for this problem, these probabilities may be a slight underestimate of the true probabilities. There appear to be 10 to 15 extreme outliers in the lower tail of the distribution and thus the probability bias may be 1.2 to 1.8 percent.

The weekly deviations computed using the small sample monthly mean estimates appear to fit the normal distribution better than the true week deviations (Figure C-4). The variability of deviations in the small sample experiment is clearly greater than variability for the true deviations. Compare for example the frequency of observation where the weekly mean is greater than 2 units below the monthly mean between Figures C-3 and C-4.

distribution plots

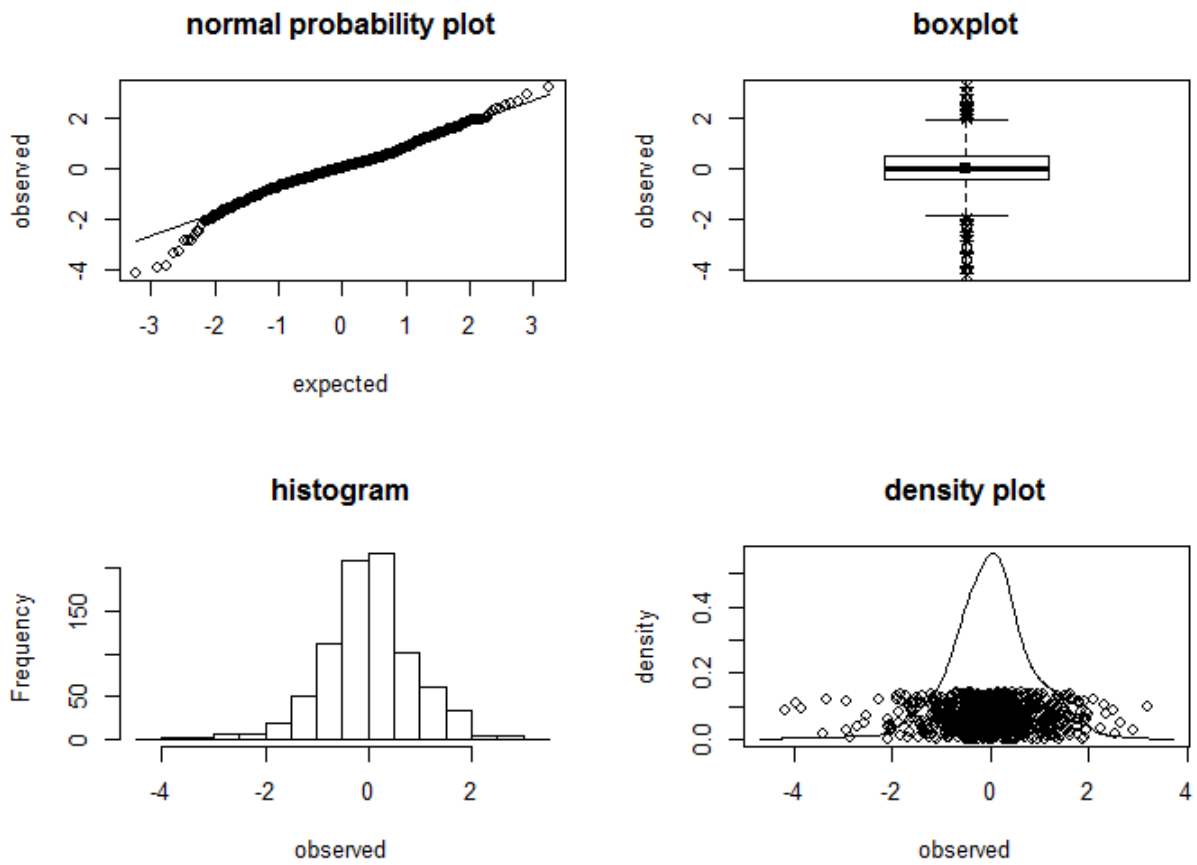


Figure C-3. Distribution plots for the true weekly deviations.

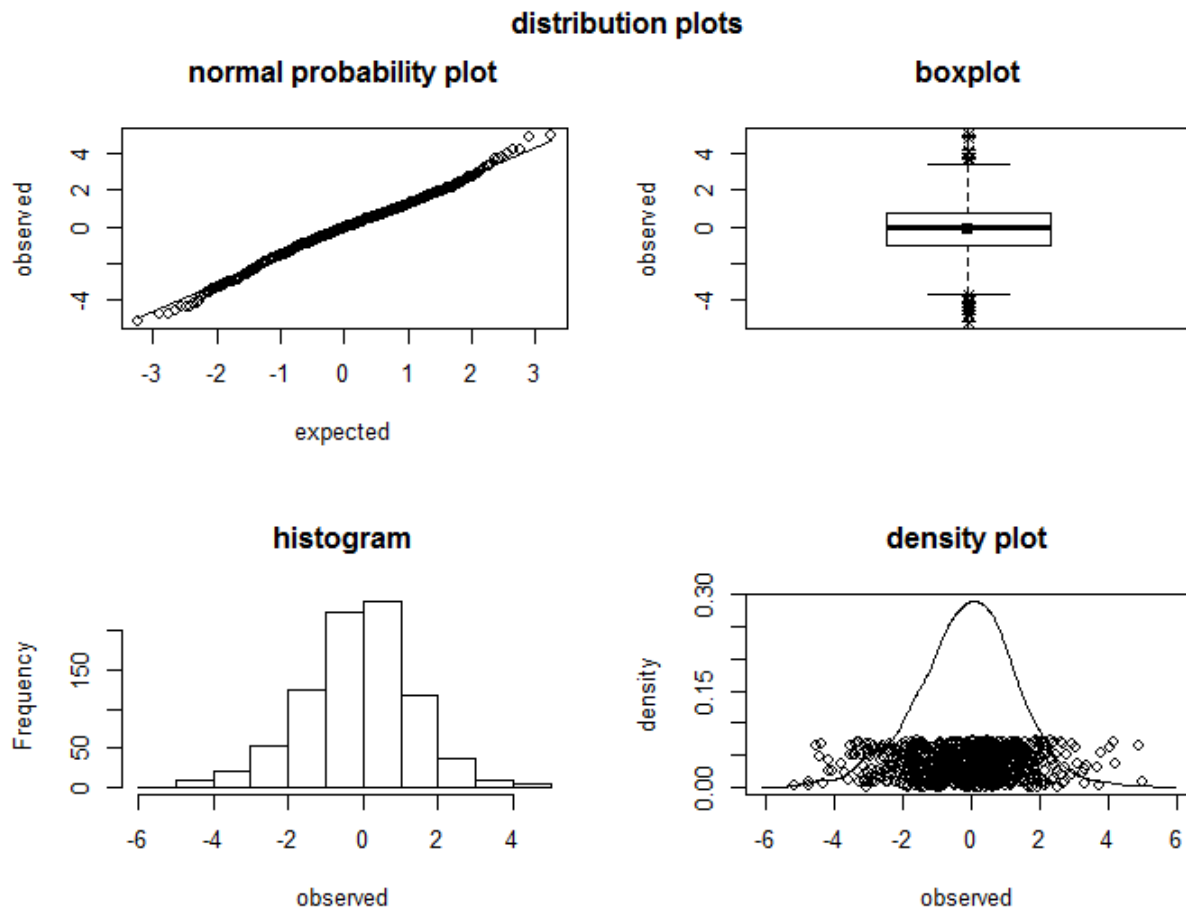


Figure C-4. Distribution plots for weekly deviations computed for the first resampling experiment.

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

Monthly Mean DO	Risk of violating 7-day criterion			
	True ¹	SD=1.7358 ²	SD=1.6054 ³	SD=1.9287 ⁴
5.0	0.1598	0.2822	0.2666	0.3020
5.1	0.1368	0.2631	0.2466	0.2842
5.2	0.1162	0.2446	0.2273	0.2669
5.3	0.0979	0.2269	0.2090	0.2501
5.4	0.0818	0.2099	0.1915	0.2339
5.5	0.0677	0.1937	0.1750	0.2183
5.6	0.0556	0.1783	0.1594	0.2033
5.7	0.0453	0.1636	0.1448	0.1890
5.8	0.0366	0.1498	0.1311	0.1753
5.9	0.0293	0.1368	0.1183	0.1622
6.0	0.0232	0.1246	0.1064	0.1498

6.1	0.0183	0.1131	0.0954	0.1381
6.2	0.0142	0.1024	0.0852	0.1269
6.3	0.0110	0.0925	0.0759	0.1165
6.4	0.0084	0.0833	0.0674	0.1066
6.5	0.0064	0.0748	0.0597	0.0974

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

Section 2. A parametric simulation approach to assessing the umbrella concept for the instantaneous minimum criteria. Elgin Perry 3/10/2011

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

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

- b_int - the intercept which reflects the mean because other covariates are centered.
- b_cday - linear trend term for the week fitted as a coefficient of centered day.
- b_sin, b_cos - coefficients for diel trend fitted to trig-transformed time
- b_ar1, b_ar2 - autoregressive terms at lags 1 and 2
- mse - residual mean square error

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

For the simulation, only data from CB4 in the surface layer (sensor < 10 m depth) were used. A MANOVA model which included terms for Month, Total Water Depth, and Sensor Depth. Coefficients from this model were used to estimate a mean predicted value for the parameter

vector which seeded the parametric simulation. A multivariate normal random number generator (R-package) was used to generate 1000 realizations using this mean vector and the Variance-Covariance matrix estimate from the MANOVA. Each of these 1000 realization of the parameter vector were passed to a function which estimated a 1-week time series based on the simulated parameter vector values. The percent of violations of the instantaneous minimum criterion (3.2 ppt) were tabulated yielding 1000 estimates of this percentage. The range and frequency of these percentages are compared for various mean vectors associated with different conditions specified by different values of the independent variables in the MANOVA model.

Results:

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

Table C-1. Manova test results for dependent vector (b_int, b_cday, b_sin, b_cos, b_AR1, b_AR2,mse).

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

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

Table C-2. P-values for each manova term and for each dependent variable.

Source	b_int	b_cday	b_sin	b_cos	b_AR1	b_AR2	mse
month	0.0861	0.9041	0.3811	0.4845	0.0130	0.0909	0.1277
TotDep	<.0001	0.4168	0.9888	0.7560	0.1728	0.2066	0.1374
SampDep	<.0001	0.4214	0.0381	0.5415	0.1808	0.2711	0.0331
lat	0.2065	0.3651	0.2688	0.0563	0.9958	0.2387	0.1713

long 0.7956 0.0432 0.9265 0.9906 <.0001 0.2204 0.0290

Table C-3. Coefficient estimates for covariates.

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

Table C-3 shows DO seems to improve as water depth increases, DO degrades as sensor depth increases, AR1 terms are stronger in the western bay, mse decreases with sensor depth.

Table C-4. Partial Correlation Coefficients from the Error SSCP Matrix / Prob > |r| DF = 239 .

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

From Table C-4, the partial correlation coefficients from the error SSCP matrix show the strongest correlation is among parameters that model the error process. The autoregressive terms b_AR1 and b_AR2 have an inverse dependence. The mse term is correlated with the AR terms and with b_cos and b_cday . There is little correlation among terms that model the mean (i.e. b_int , b_cday , b_sin , b_cos).

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

The independent variable vector that yields this prediction is

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

for which the predicted vector of time series parameters is

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

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

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

Table C-6.

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

Results at 6.0

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

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

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

Sensor Depth = 5	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous
mean DO = 5.6733			

			minimum
failure Instantaneous	671	4	675
minimum < 10%	71.01%	7.27%	67.5%
failure Instantaneous	274	51	325
minimum > 10%	28.99%	92.73%	32.5%
marginal for failure			
of 7-day mean	945	55	1000

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

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

Sensor Depth = 3 7-day mean 7-day mean marginal failure
mean = 7.0082 > 4.0 < 4.0 instantaneous
minimum

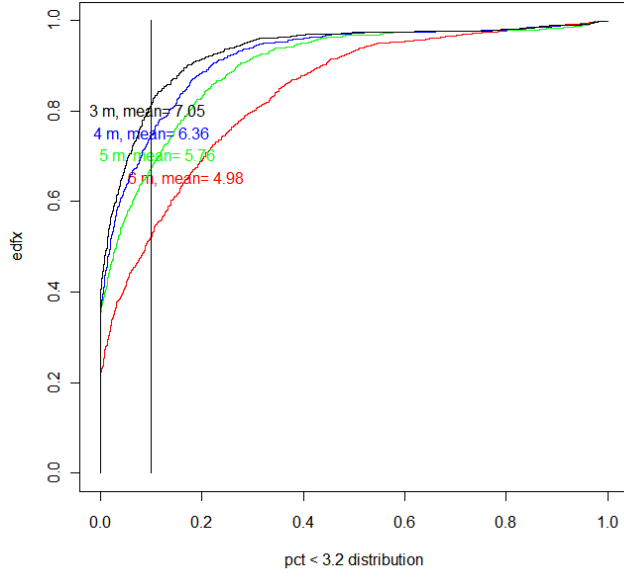
failure Instantaneous	815	0	815
minimum < 10%	81.91%	0%	81.5%
failure Instantaneous	180	5	185

minimum > 10%	18.09%	100%	18.5%	
marginal for failure of 7-day mean	995	5	1000	
sensor depth	6	5	4	3
Monthly Mean DO	5.0058	5.6732	6.3407	7.0082
7 day criterion failure rate	16.6%	5.5%	1.5%	0.5%
rate of instantaneous criterion > 10%	47.6%	32.5%	25.3%	18.5%

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

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

edf of instantaneous minimum violations



APPENDIX D

Western Branch Patuxent River Tidal Freshwater Segment Metadata

Appendix D contains data and metadata on the ten Western Branch Patuxent River Tidal Freshwater segment transects as reported by Maryland Department of the Environment (Matt Stover). Note: Only stations #1-6 were located within the WBRTF segment.

River Name: Western Branch

Station Code: Station #1

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed Description: Soft mud

Site Location: N 38 47.139
W 76 42.794
25 yds upstream of pier at Calvert Manor

Digital Photo Series: Folder 113, images 1-2

Comments: 165 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Western Branch

Station Code: Station #2

Date: 9/7/2001

Scientist(s): DJR/SGL

Riverbed
Description: Soft mud

Site Location: N 38 47.305
W 76 42.898
10 yds downstream of Horse Cavern Branch

Digital Photo Series: Folder 113, images 3-5

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

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Western Branch
 Station Code: Station #3
 Date: 9/7/2001
 Scientist(s): DJR/SGL
 Riverbed Description: Harder more solid mud
 Site Location: N 38 47.490
 W 76 43.022

Digital Photo Series: Folder 113, images 6-8

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

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Western Branch
 Station Code: Station #4
 Date: 9/7/2001
 Scientist(s): DJR/SGL
 Riverbed Description: Harder more solid mud
 Site Location: N 38 47.485
 W 76 43.239
 Downstream of small unnamed trib
 Digital Photo Series: Folder 113, images 9-11
 Comments: 135 ft wide, when measurements were taken there was a 1.5 ft high tide mark visible

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Western Branch
 Station Code: Station #5
 Date: 9/7/2001
 Scientist(s): DJR/SGL
 Riverbed
 Description: Sand/Mud, hard bottom
 Site Location: N 38 47.777
 W 76 43.316

Digital Photo Series: Folder 113, images 12-13

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

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Western Branch

Station Code: Station #6

Date: 9/7/2001

Scientist(s)DJR/SGL

Riverbed Substrate: Sandy
hard mud

Site Location : N 38 47.832

W 76 43.746

50 yds downstream of WSSC outfall

Digital Photo Series: Folder 113, images 14-18

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

Looking downstream
measurements were collected left
to right

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

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

Western Branch

Station Code: Station #7

Date:

Scientist(s):

Riverbed Description:

Site Location:

9/7/2001

DJR/SGL

Sandy

hard mud

N 38 47.858

W 76 44.046

700 yds upstream of
effluent

Folder

113,

images

19-21

Digital Photo Series:

Comments:

48 ft wide

Orientation: Looking downstream measurements were collected left to right

Length	Depth	Cell width	Depth*width
0	0.00	3	0.00
6	4.25	6	25.50
12	4.50	6	27.00
18	5.00	6	30.00
24	5.00	6	30.00
30	5.25	6	31.50
36	5.25	6	31.50
42	4.50	6	27.00
48	0.00	3	0.00

Sum of
(depth*width)
= Area of
streambed = 202.50 (sq.feet)

Western Branch

Station name: Station #8

Date: 9/7/2001

Scientist(s); DJR/SGL

Riverbed Substrate: Sandy hard mud

Site Location: N 38 47.957 W

W 76 43.874

Digital Photo Series: Folder 113, images 22-24

Comments: 48 ft wide

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

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

River Name: Western Branch
 Station Code: Station #9
 Date: 9/7/2001
 Scientist(s): DJR/SGL
 Riverbed Description: Hard mud
 Site Location: N 38 48.550
 W 76 44.435
 Route 301 crossing
 Digital Photo Series: Folder 113, images 25-26
 Comments: 47 ft. wide. Had to do the geometry off the bridge

Orientation: Looking downstream measurements were collected left to right

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

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

River Name: Little Patuxent River
 Station Code: RM-28, LTX0248
 Date: 7/1/2002
 Scientist(s): DJR,GWL,RKN
 Riverbed Description: 10% Silt, 70% Sand, 10% Gravel, 10% Cobble
 Site Location: N 39 12.555
 W 76 51.359
 Digital Photo Series: N/A
 Comments: 29.5 ft. wide

Orientation: Looking downstream measurements were collected left to right

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

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

Appendix E

The centroid coordinates for grid cells used to define the Chesapeake Bay Western Branch Tidal Freshwater segment

Appendix E provides the centroid coordinates for the 45 grid cells used to define the Chesapeake Bay Western Branch Tidal Freshwater segment (WBRTF) segment. The coordinates are in the UTM Zone 18 NAD83 projection.

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

20	350800	4295000	1
21	350850	4295000	1
22	350900	4295000	1
23	350950	4295000	1
24	350550	4295050	1
25	350550	4295100	1
26	350550	4295150	1
27	350550	4295200	1
28	350550	4295250	1
29	350550	4295300	1
30	350600	4295350	1
31	350600	4295400	1
32	350600	4295450	1
33	350550	4295500	1
34	350450	4295550	1
35	350500	4295550	1
36	350350	4295600	1
37	350400	4295600	1
38	350250	4295650	1
39	350300	4295650	1
40	350100	4295700	1
41	350150	4295700	1
42	350200	4295700	1
43	349950	4295750	1
44	350000	4295750	1
45	350050	4295750	1

APPENDIX F

History and considerations supporting development and approval of the Multi-metric Water Quality Indicator

Section 1 of Appendix F provides the history and considerations supporting development and approval of the Multi-metric Water Quality Indicator for tracking water quality progress towards meeting water quality standards attainment with dissolved oxygen, water clarity/bay grasses and chlorophyll *a* in Chesapeake Bay. Section 2 of Appendix F provides details about the data sources, computations and communications supporting the multimetric Chesapeake Bay Water Quality indicator for tracking progress toward bay water quality standards achievement.

Section 1. History and considerations supporting development and approval of the Multi-metric Water Quality Indicator for tracking water quality progress towards meeting water quality standards attainment.

The Chesapeake Bay Program (CBP) Partnership needed to develop a combined indicator to measure progress towards the achievement of the four jurisdictions' Chesapeake Bay water quality standards. As it currently stands, the Partnership chronicles the Bay's health through annual reporting of a series of individual water quality metrics. This new integrated indicator could supplement or replace the individual dissolved oxygen, water clarity and chlorophyll *a* indicators currently reported by the CBP Partnership. The indicator would be fully consistent with how Delaware, the District of Columbia, Maryland, and Virginia currently list their portion of the Bay's tidal waters and provide a means for illustrating improvements through time.

Additionally, this indicator could be used to measure progress toward the Chesapeake Bay Executive Order's water quality outcome in which 60% of segments are achieving Bay water quality standards by 2025 via the implementation of pollution reduction actions for nitrogen, phosphorus and sediment.⁵ The 2009 baseline condition, as documented in the Chesapeake Bay TMDL, was 89 of 92 segments of the Chesapeake Bay and its tidal tributaries and embayments were impaired (USEPA 2010).

There were two sets of decisions to be made by the CBP Partnership in creating this new water quality indicator:

⁵ The Water Quality Outcome, as written on pages 4 and 22 of the Executive Order Strategy, reads as follows: **Water Quality Outcome:** Meet water quality standards for dissolved oxygen, clarity/underwater grasses and chlorophyll-a in the Bay and tidal tributaries by implementing 100 percent of pollution reduction actions for nitrogen, phosphorus and sediment no later than 2025, with 60 percent of segments attaining water quality standards by 2025. (*Current condition: 89 of the 92 segments of the Bay and its tidal waters are impaired.*) The Executive Order Strategy is available for download at: <http://executiveorder.chesapeakebay.net/category/Reports-Documents.aspx>.

- 1) how to address the fact that the CBP Partnership has not fully developed, reached agreement on, published nor adopted into the tidal water jurisdictions' water quality standards regulations a full set of criteria assessment procedures for all the applicable dissolved oxygen criteria; and
- 2) whether to take an area-based (or volume-based) approach versus the count of number of designated-use segments approach as the basis to reporting the water quality indicator.

Criteria Assessment Options and Recommended Resolution

The two criteria assessment options are directly related to the question posed earlier: how to address the fact that the CBP Partnership has not fully developed, reached agreement on, published, nor adopted into the tidal water jurisdictions' water quality standards regulations a full set of criteria assessment procedures for all the applicable dissolved oxygen criteria at the time of this analysis. One option would be only assess attainment for those dissolved oxygen criteria for which criteria assessment procedures have been published and adopted into the jurisdictions' water quality standards regulations. Taking this option, however, would be completely inconsistent with the approach the four tidal water jurisdictions have taken in establishing their lists of impaired Bay tidal waters and provide the public with contradictory information.

In the course of developing the Chesapeake Bay TMDL, CBPO analysts determined that evaluation of the 30-day mean dissolved oxygen criteria was sufficient to determine attainment of the Bay's open-water and deep-water designated uses. This notion became formally known as the Umbrella Criteria Assumption. Questions regarding the validity of the Chesapeake Bay Water Quality Sediment Transport Model (WQSTM)-based assumption by CBP partners led to the formation of the Umbrella Criteria Assessment Team to determine its validity using CBP monitoring data. The CAP workgroup is currently working towards developing recommendations based on the Umbrella Criteria Assessment Team's findings. Until recommendations are fully developed, short-term assessments procedures for dissolved oxygen continue to be lacking.

With the lack of assessment procedures in place for the short-term dissolved oxygen criteria for the various designated uses, where appropriate, Chesapeake Bay segments previously listed as impaired for dissolved oxygen will continue to be impaired until a complete set of dissolved oxygen assessment procedures are developed, agreed upon by the Partnership, and published.⁶ This is in accordance with Maryland, Virginia, Delaware, and the District of Columbia's current

⁶ For the open-water, deep-water, and migratory fish spawning and nursery designated uses, there are no published procedures in place for the assessment of the 7-day mean, 1-day mean, and instantaneous minimum dissolved oxygen criteria. The Partnership is committed to working collaboratively to develop criteria assessment procedures for the remaining dissolved oxygen criteria currently without Partnership approved assessment procedures.

tidal impaired waters listing approach for Chesapeake Bay segments, as published individually in their Integrated Reports and, collectively, within the 2010 Chesapeake Bay TMDL. As such, we recommend to the Partnership's Water Quality Goal Implementation Team that for those designated use criteria where a full suite of dissolved oxygen criteria assessment procedures have not yet been agreed to by the CBP Partnership, the segment is considered to be in non-attainment for that specific tidal water designated use. That is to say that since there are no published procedures for the open-water, deep-water, and migratory fish spawning and nursery designated uses assessment of the 7-day mean, 1-day mean, and instantaneous minimum dissolved oxygen criteria, where applicable, these three designated uses will continue to be considered in non-attainment because the jurisdictions cannot assess attainment for all the dissolved oxygen criteria applicable to these three designated uses.

Work is currently underway, under the leadership and oversight of the CBP Partnership's CAP Workgroup, to develop, submit to independent scientific peer review, seek the review and agreement of the partnership, and publish (by EPA on behalf of the larger partnership) a complete set of dissolved oxygen criteria assessment procedures. The expectation is, upon publication of these criteria assessment procedures, Delaware, District of Columbia, Maryland, and Virginia will amend, as necessary, their water quality standards regulations to adopt these criteria assessment procedures.

Attainment Accounting Options and Recommended Resolution

We considered the choice between a count (e.g., number of attaining segments) or weighted (e.g., by area or volume) approach in computing and reporting the water quality indicator. We determined that strictly using a count of the number of segments, be they the original 92 segments or all the 289 designated-use segments, would not be representative of the true amount of Bay tidal waters achieving water quality standards (Table F1). The sheer size difference, whether measured as surface area or total volume, between the Magothy River segment and the middle central Chesapeake Bay segment is a several hundred fold. Weighting them equally by taking the count approach does not provide the public with an honest measure of how much of the Bay tidal waters are achieving water quality standards.

Table F1. Criteria attainment accounting using the count approach.

COUNT APPROACH			
289 Designated-Use Segments (making up the 92 CBP Segmentation Scheme)			
Chesapeake Bay Tidal Water Designated Use	Total Number of Designated-Use Segments	Number of Designated-Use Segments Attaining WQS	Percent Attainment
Migratory Fish Spawning and Nursery	72	0	0
Open Water – DO	92	0	0
Open Water – CHLA (spring + summer)	7	0	0
Deep Water – DO	18	0	0
Deep Channel – DO	10	1	10
Shallow-Water Bay Grasses – SAV/Water Clarity	90	27	30
Baywide Percentage of WQS Attainment	289	28	10

Note: As the CBP Partnership works through and reaches agreement on the remaining dissolved oxygen criteria assessment procedures, the percentage of designated-use segments attaining will increase.

Then we considered taking a volumetric approach. This approach works well for dissolved oxygen criteria whose attainment is assessed on a volume-basis. However, in the case of the water clarity/bay grasses (i.e., submerged aquatic vegetation or SAV) and chlorophyll *a* criteria, both are assessed on a surface area-basis. We were unable to determine a method for accounting for both volume and surface area within the same metric which would have accounted for the how much of the Bay tidal waters were achieving water quality standards.

Therefore, having narrowed down the choice for the accounting approach to area, we still had to:

- 1) account for the area for those segments with two or more designated uses with depth (e.g., open-water, deep-water, and deep-channel); and

- 2) determine how to factor in the shallow-water Bay grasses designated uses which will have very small areas compared with open-water uses but are equally critical and important habitats.

The proposed solution was using the surface area of each of the 92 segments times the number of applicable designated uses for that segment. This approach factors in the relative size of each segment, ensuring we report the best available measure of how much of the Bay tidal waters were achieving water quality standards. At the same time, this approach gives equal weight to achievement of the criteria protective of each designated use and segment, preventing any need to weigh differently the importance of restoring dissolved oxygen versus bringing back underwater bay grasses. Restoration of a fully functioning Chesapeake Bay ecosystem requires attainment of all five designated uses. The indicator consolidates the baywide results in the final calculations and reports percent of Bay water quality standards meeting attainment (Table F2).

Table F2. Criteria attainment accounting using the area-based approach.

AREA-BASED APPROACH			
289 Designated-Use Segments (contained within the 92 Chesapeake Bay segments)			
Chesapeake Bay Tidal Water Designated Use	Total Surface Area of Designated-Use Segments (km ²)	Total Surface Area of Designated-Use Segment Attaining WQS (km ²)	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
Baywide Percentage of WQS Attainment	40740997335.07	2699881036.04	7

Note: As the CBP Partnership works through and reaches agreement on the remaining dissolved oxygen criteria assessment procedures, the percentage of designated-use segments attaining will increase.

Please note, however, that there can be slight variations in the total number of designated uses reported each year depending on annual climatic conditions. Since designated use boundaries between the open-water, deep-water, and deep-channel designated uses are based on the presence of a stratified water column measured by upper and lower bounds of a pycnocline, the absence of a pycnocline in a specific segment due to a fully mixed water column in a specific year due to seasonal weather conditions means one (or two) less designated uses for that year. In these cases, the total number of designated-use segments would be a number less than 289 for that year within the three-year assessment window.

Finally, this area-based criteria attainment accounting approach also directly lends itself to a visual illustration of the indicator status in a single graphic—the relative shading or different color of each individual segment would reflect the percent of all applicable designated uses in attainment with all the applicable criteria—as well as a single percentage for all Bay tidal waters. (See Chapter 4, Figure IV-2 in this document) represents how the indicator results for each individual segment would be displayed on a baywide basis. Supplemental maps illustrating attainment status of each segment have also been developed for each of the designated uses (Figures F1, F2, F3 and F4). These illustrations would be used for technical and diagnostic purposes, as well as for public communication once the indicator is adopted into the current Partnership’s indicator reporting framework. As we move towards incorporating the indicator into the Partnership, we will continue to work with the CBPO’s Monitoring, Indicator, Communications, and GIS teams on how to best communicate the message to the public audience.

Recommended Water Quality Indicator

The recommended water quality indicator for reporting on progress towards the Executive Order’s water quality outcome as well as future CBP Partnership reporting of water quality restoration progress is as follows:

- The indicator will be based on an accounting of attainment of all Bay water quality criteria—dissolved oxygen, water clarity/underwater grasses, and chlorophyll *a*—applicable to the 289 designated-use segments contained within the 92 Bay segments reported for each three-year assessment period.
- The indicator will be reported annually as a baywide percentage based on the summation of the surface area of each of the designated-use segments determined to be in full attainment of all applicable criteria divided by the summation of the surface areas of the total number of designated-use segments.

- For those designated use criteria where a full suite of dissolved oxygen assessment procedures have not been agreed to by the CBP Partnership and published by EPA, those respective designated-use segments where these dissolved oxygen criteria apply will be considered to be in non-attainment.⁷
- The indicator will be graphically illustrated by coloring each of the 92 Bay segments according to the percent of applicable designated uses and criteria for that individual segment that are in attainment of all the applicable criteria.

Decision Requested and Recommended Next Steps

Management Board agreement to adopt the Water Quality Goal Team’s recommended new Chesapeake Bay water quality indicator for tracking progress towards Bay water quality standards achievement, recognizing that the following work is underway and will come back to the Management Board for further decisions:

- Chesapeake Bay Program Office staff will work with the Communications Workgroup on finalizing the different ways in which the water quality indicator can be publically presented and displayed on the Partnership’s web site; and
- Chesapeake Bay Program Office staff will work with STAR’s Tidal Monitoring and Analysis Workgroup on how the partners can build off indicator information to display additional incremental progress using this indicator, then work back up through the Water Quality Goal Implementation Team and Management Board on partnership adoption of a set of incremental progress Bay water quality indicators.

⁷ By 2015, EPA and its seven jurisdictional partners are committed to working collaboratively on developing, subjecting to independent scientific peer review, agreeing to, and then publishing criteria assessment procedures for the remaining dissolved oxygen criteria currently without Partnership approved assessment procedures.

Chesapeake Bay Waters Meeting Water Quality Goals for the Shallow Water Bay Grasses Use

2008-2010

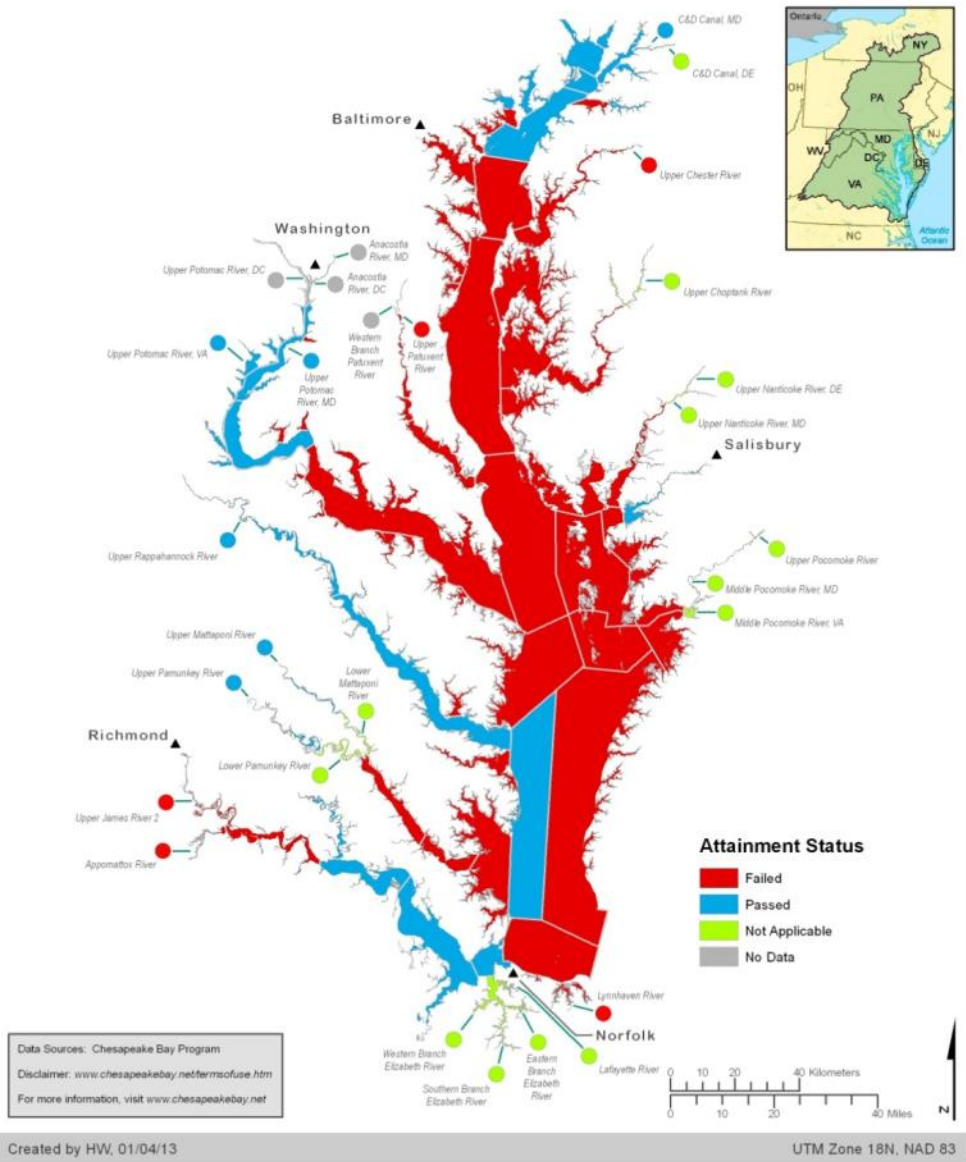


Figure F1: Attainment status of the shallow water bay grasses designated use for each of the Chesapeake Bay segments. This map contains additional split segments beyond the 92 Chesapeake Bay segments strictly for purposes of applying separate water clarity criteria application depths (0.5, 1, or 2 meters) within the same Bay segment for assessing water clarity/SAV criteria attainment only (USEPA 2004).

Chesapeake Bay Waters Meeting Chlorophyll a Criteria Water Quality Goals

2008-2010

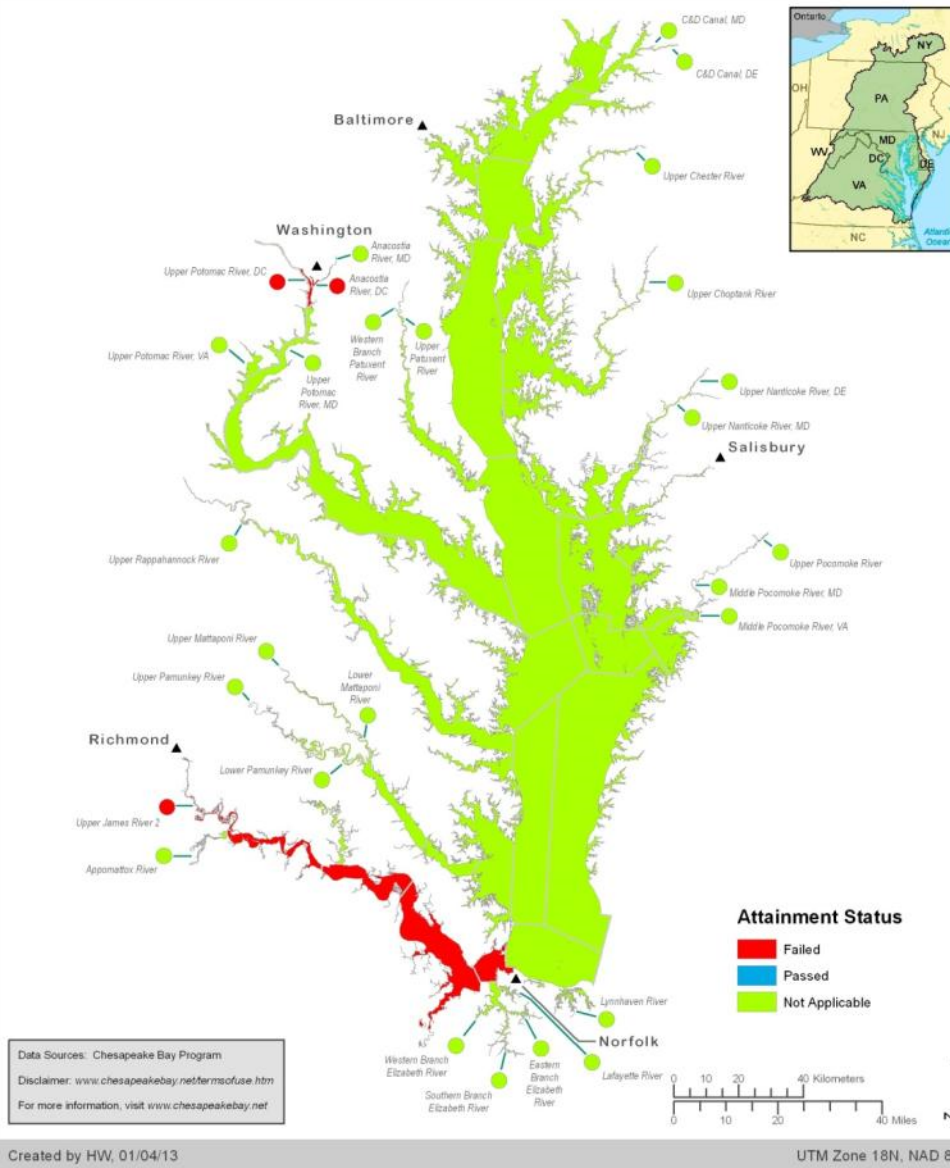


Figure F2: Attainment status of the chlorophyll a numeric criteria as applied as to the open-water designated use of the James and Anacostia Rivers of Chesapeake Bay.

Chesapeake Bay Waters Meeting Water Quality Goals for the Open Water, Deep Water, and Deep Channel Uses

2008-2010

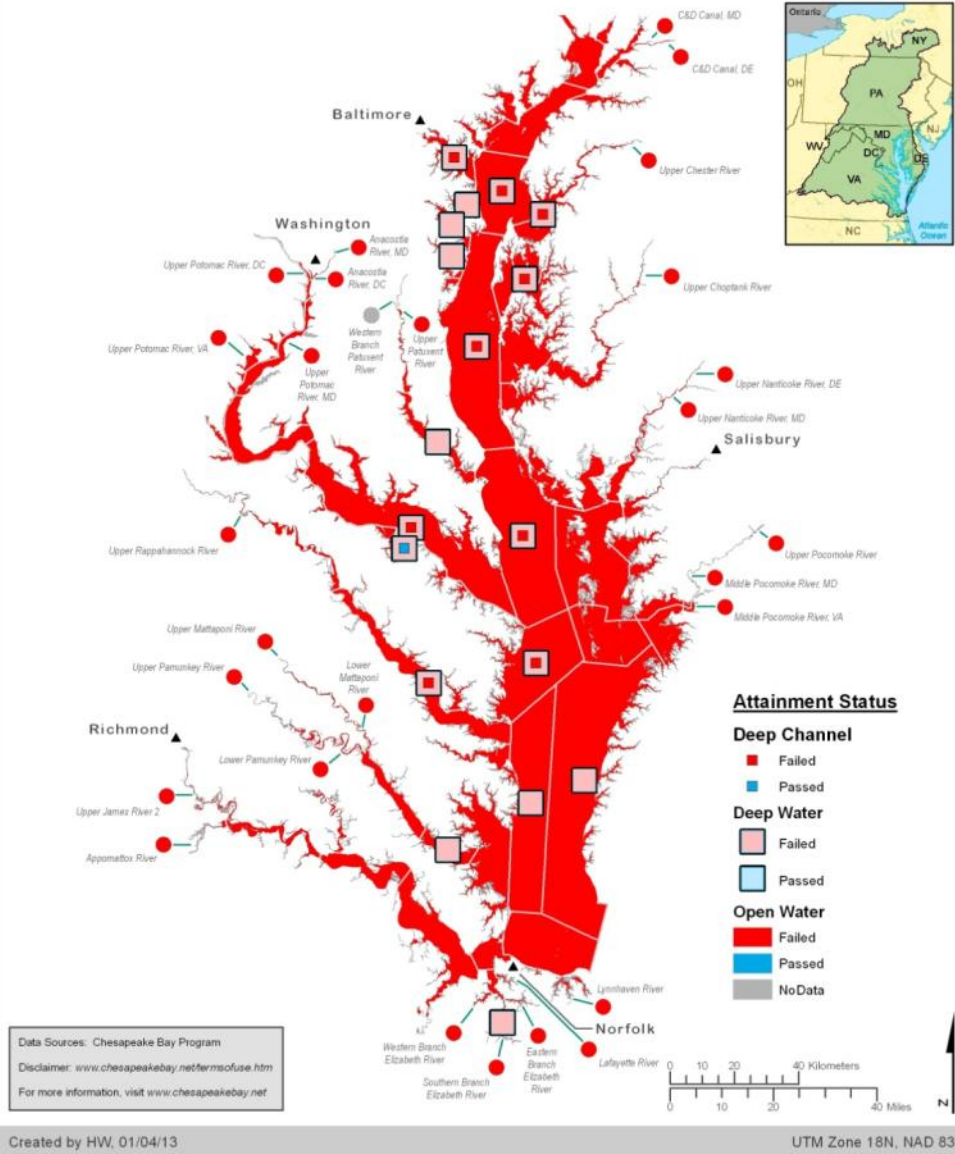


Figure F3: Attainment status of the open-water, deep-water, and deep channel designated uses for each of the Chesapeake Bay segments.

Chesapeake Bay Waters Meeting Water Quality Goals for the Migratory, Spawning and Nursery Habitat Use

2008-2010

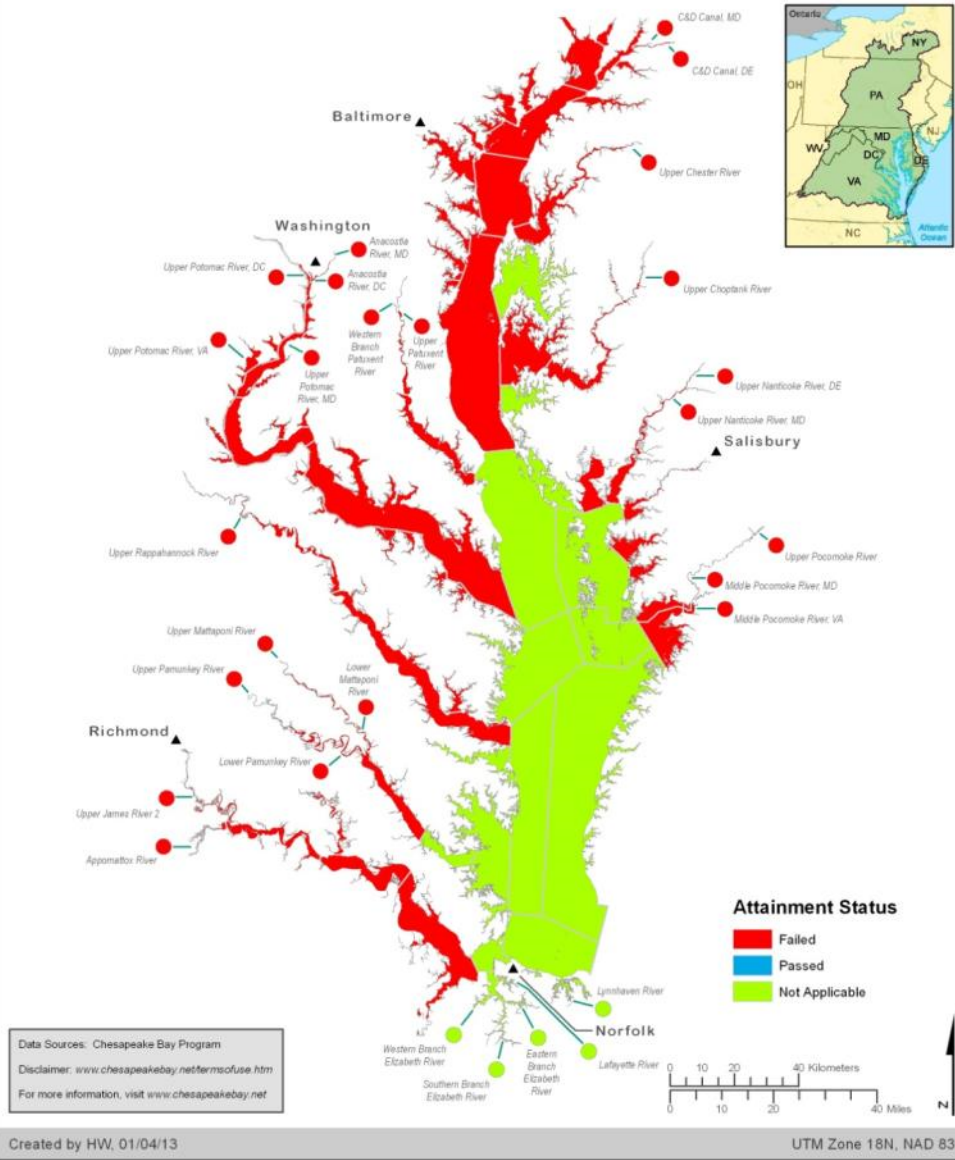


Figure F4: Attainment status of the migratory spawning and nursery designated use for each of the Chesapeake Bay segments.

Section 2. Data sources, computations and communications supporting the multimetric Chesapeake Bay Water Quality indicator for tracking progress toward bay water quality standards achievement.

A. Category/Name/Source/Contact

(1) Category of Indicator

Factors Impacting Bay and Watershed Health

Restoration and Protection Efforts

Watershed Health

Bay Health

(2) Name of Indicator: **Water Quality Standards Achievement**

(3) Description of Dataset used:

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

- For what purpose(s) were the data collected? (e.g., tracking, research, or long-term monitoring.)
Tracking, research, and long-term monitoring
- Which parameters were measured directly?
 - DO concentrations are measured in-situ at surface and depth profiles across the entire Bay.
 - Secchi depths are measured directly during Bay transect cruises.
 - SAV area and percent coverage is measured from photographs during the aerial surveys (after photo-interpretation).
 - Chlorophyll-a concentrations were measured in a lab using bio-matter collected from filtered water samples at fixed stations.
- Which were obtained by calculation?
 - Aggregations of photo-interpreted SAV area data to segment, zone and bay-wide levels.
 - Standards attainment for DO, water clarity, and chlorophyll *a* are calculated according to the April 2003 USEPA publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* (http://www.chesapeakebay.net/content/publications/cbp_13142.pdf) Refinements to these procedures are described in subsequent technical addenda, all of which can be downloaded from <http://www.chesapeakebay.net/publications>.

(4) Source(s) of Data:

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

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

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

Yes.

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

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

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

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

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

- For raw data: Mike Mallonee (ICPRB-CBPO)
- For DO and chlorophyll *a* assessments: Melinda (Mindy) Ehrich (UMCES-CBPO), Jennifer Gunderson (EPA-CBPO) and/or Richard Tian (UMCES-CBPO)

- For SAV acreage data: Bob Orth (VIMS) or David Wilcox (VIMS)
- For Water Clarity assessments: Dave Parrish (VIMS) (VA) or Tish Robertson (VADEQ) (VA) and Mark Trice (MDDNR) (MD)

(6) CBPO Contact:

Melinda (Mindy) Ehrich (UMCES-CBPO) and Jennifer Gunderson (EPA-CBPO)

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

2. Bay Health or Watershed Health indicators only

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

To be updated annually.

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

To be updated annually.

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

(10b) What does this indicator tell us?

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

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

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

described, that when adequately protected, will ensure the protection of the living resources therein.

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

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

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

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

The Chesapeake Bay Program (CBP) Partnership approved the development of this combined indicator to measure progress towards the achievement of the four jurisdictions' Chesapeake Bay water quality standards. The indicator is fully consistent with how Delaware, the District of Columbia, Maryland, and Virginia currently list their portion of the Bay's tidal waters and provide a means for illustrating improvements through time. Additionally, this indicator is being used to measure progress toward the [Chesapeake Bay Executive Order Strategy's](#) and the 2014 Bay Agreement water quality outcome.

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

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

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

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

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

4. All indicators

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

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

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

- To what do you attribute it? N/A
- Is this educated speculation or actual cause? N/A

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

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

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

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

Why and how?

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

1. sufficient acres of SAV are observed within the segment; or
2. enough acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired SAV acreage for that segment.

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

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

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

C. Temporal Considerations

(13) Data Collection **Date(s)**: 1985-2012 at the time of writing. To be updated annually.

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

(a) Source Data:

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

(b) Indicator:

Annual

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

- Raw data is available in the spring of the following year.
- DO and chlorophyll *a* assessments are available in the spring of the following year.
- SAV data is available in the spring of the following year.

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

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

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

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

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

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

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

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

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

The published dissolved oxygen criteria assessment methodology currently used for assessing Chesapeake Bay water quality criteria attainment involves the use of cumulative frequency distribution (CFD) curves in a 2D space of percent time and percent space to determine the volumetric extent of compliance. The procedure for assessing dissolved oxygen criteria

attainment is described in detail in Appendix A of the September 2008 water quality criteria addendum: *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries 2008 Technical Support for Criteria Assessment Protocols Addendum* (http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).

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

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

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

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

- Migratory Fish and Spawning Nursery Habitat: applied the 6 mg/L 7-day mean DO criterion as a 30-day mean
- Open-Water Fish and Shellfish Habitat: 5 mg/L 30-day mean DO criteria,
- Deep-Water Seasonal Fish and Shellfish Habitat: 3 mg/L 30-day mean DO criteria,
- Deep-Channel Seasonal Refuge Habitat: 1 mg/L instantaneous minimum DO criteria
- Shallow-Water Bay Grasses Habitat:
When water clarity assessment data is available the shallow-water bay grasses designated use is considered in attainment if:

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

4. 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:
 - 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:
 - Criteria attainment only assessed during the summer (Jun1-Sep30) season.

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

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

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

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

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

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

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

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

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

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

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

If no, complete questions 28a – 28d:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

G. Additional Information (optional)

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

Table F2 provides Tidal Water designated uses by segment.

Table F2. Tidal water designated uses by Chesapeake Bay segment

Waterbody	CBP Segments & Split Segments	Jurisdiction	Migratory Spawning & Nursery	Open Water	Deep Water	Deep Channel	Shallow Water Bay grasses	Chlorophyll-a (applies to open water)
Anacostia River	ANATF_DC	DC	X	X			X	X
Anacostia River	ANATF_MD	MD	X	X			X	
Appomattox River	APPTF	VA	X	X			X	
Back River	BACOH	MD	X	X			X	
Big Annemessex River, Lower	BIGMH1	MD	X	X			X	
Big Annemessex River, Upper	BIGMH2	MD					X	
Bohemia River	BOHOH	MD	X	X			X	
Bush River	BSHOH	MD	X	X			X	
C&D Canal	C&DOH_DE	DE	X	X				
C&D Canal	C&DOH_MD	MD	X	X			X	
Northern Chesapeake Bay, Turkey Pt. South	CB1TF1	MD	X	X			X	
Northern Chesapeake Bay, Susquehanna River and Flats	CB1TF2	MD					X	
Upper Chesapeake Bay	CB2OH	MD	X	X			X	
Upper Central Chesapeake Bay	CB3MH	MD	X	X	X	X	X	
Middle Central Chesapeake Bay	CB4MH	MD	X	X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_MD	MD		X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_VA	VA		X	X	X	X	
Western Lower Chesapeake Bay	CB6PH	VA		X	X		X	
Eastern Lower Chesapeake Bay	CB7PH	VA		X	X		X	

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

Magothy River	MAGMH	MD	X	X	X		X	
Manokin River, Lower	MANMH1	MD					X	
Manokin River, Upper	MANMH2	MD	X	X			X	
Mattawoman Creek	MATTF	MD	X	X			X	
Middle River	MIDOH	MD	X	X			X	
Mobjack Bay	MOBPH	VA		X			X	
Lower Mattaponi River	MPNOH	VA	X	X				
Upper Mattaponi River	MPNTF	VA	X	X			X	
Lower Nanticoke River	NANMH	MD	X	X			X	
Middle Nanticoke River	NANOH	MD	X	X			X	
Upper Nanticoke River	NANTF_DE	DE	X	X				
Upper Nanticoke River	NANTF_MD	MD	X	X				
Northeast River	NORTF	MD	X	X			X	
Patapsco River	PATMH	MD	X	X	X	X	X	
Lower Patuxent River, Lower	PAXMH1	MD					X	
Lower Patuxent River, Upper	PAXMH2	MD					X	
Lower Patuxent River, Mill Creek	PAXMH3	MD					X	
Lower Patuxent River, Cuckold Creek	PAXMH4	MD	X	X	X		X	
Lower Patuxent River, St. Leonard Creek	PAXMH5	MD					X	
Lower Patuxent River, Island Creek	PAXMH6	MD					X	
Middle Patuxent River	PAXOH	MD	X	X			X	
Upper Patuxent River	PAXTF	MD	X	X			X	
Piankatank River	PIAMH	VA		X			X	
Piscataway Creek	PISTF	MD	X	X			X	
Lower Pamunkey River	PMKOH	VA	X	X				

Upper Pamunkey River	PMKTF	VA	X	X			X	
Lower Pocomoke River	POCMH_MD	MD	X	X			X	
Lower Pocomoke River	POCMH_VA	VA	X	X			X	
Middle Pocomoke River	POCOH_MD	MD	X	X				
Middle Pocomoke River	POCOH_VA	VA	X	X				
Upper Pocomoke River	POCTF	MD	X	X				
Lower Potomac River	POTMH_MD	MD	X	X	X	X	X	
Lower Potomac River	POTMH_VA	VA	X	X	X	X	X	
Middle Potomac River, MD Mainstem	POTOH_VA	VA	X	X			X	
Middle Potomac River, MD Port Tobacco River	POTOH1_MD	MD	X	X			X	
Middle Potomac River, MD Nanjemoy Creek	POTOH2_MD	MD	X	X			X	
Middle Potomac River	POTOH3_MD	MD	X	X			X	
Upper Potomac River	POTTF_DC	DC	X	X			X	X
Upper Potomac River	POTTF_MD	MD	X	X			X	
Upper Potomac River	POTTF_VA	VA	X	X			X	
Rhode River	RHDMH	MD	X	X			X	
Lower Rappahannock River	RPPMH	VA	X	X	X	X	X	
Middle Rappahannock River	RPPOH	VA	X	X			X	
Upper Rappahannock River	RPPTF	VA	X	X			X	
Sassafras River, Lower	SASOH1	MD	X	X			X	
Sassafras River, Upper	SASOH2	MD					X	
Southern Branch Elizabeth River	SBEMH	VA		X	X			
Severn River	SEVMH	MD	X	X	X		X	
South River	SOUMH	MD	X	X	X		X	
Tangier Sound	TAHMH_VA	VA		X			X	

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

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

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

Appendix G

Decision cases that supported the creation of the bay grass acreage goal of 192,000 acres

Appendix G contains a summary of decision cases that supported the creation of the bay grass acreage goal of 192,000 acres. Each table references alternative segmentation schemes used through time by the Chesapeake Bay Program partnership.

Table G1. This table is based solely on the segment accounting in the two SAV tables. It recognizes 89 segments when 2 missing segments are included. In 1997 CBP had 89 segments.

Comparison of WQ Stds acres to the 2003 CBP SAV Restoration Goal Segment Acres		
Decision cases where WQ Standards acres in a segment were increased above CBP 185K goal basis		
WHOLE (non-split) segments		63 segments
Unclipped CBP segment goal and then may or may not have chosen attainment depth limitations.	45 of 77 (There are 3 cases of extra acres that add an additional +1, +1, +27 acres)	
New Single Best Year in the 1978-2002 data set	8 of 77	
Goal established where none existed	3 of 77	
<i>Cases identified as SPLIT SEGMENTS</i>		
<i>Combined split segment acres >CBP adopted acreage for the pre-split segment</i>	7 of 10	
Decision cases where Segments had no change from CBP goals basis		

Acres same goal as the CBP goal	4 of 77	18 segments
No grow zone	9 of 77	
No goal to date	5 of 77	
Decision cases of WQStds acres revised lower than the CBP goals basis		
WHOLE (non-split) segments		6 segments
Model attainment revisions (2004 Linker et al)	3 of 77	
<i>SPLIT SEGMENT cases:</i>		
<i>Combined split segment acres < CBP adopted acreage for the pre-split segment (2 segments due to application depths, 1 model attainment affected)</i>	3 of 10 (-5 acres, - 6 acres, -400 acres)	
<i>Other segments - missing</i>		
<i>Unaccounted for 303d list segments in the SAV table based on 89 segment list in U.S. EPA (2008)</i>	<i>2: ANATF-MD and C&DOH-DE</i>	2 segments
<i>SAV table-specific accounting of Total segments</i>		<i>89 segments</i>

To summarize history in the table above:

- Segments (the non-split segments) in the chart total 77
- There are 10 split segments.

At this point we accounted for 87 segments out of the stated 92 segments assessed for WQ Standards. There appear to be 5 unaccounted for segments. However, there are split segments.

In the 303d list 92 segment listing, 8 of the 10 segments that are in the split list are NOT split in the 303d listing 92 segment list based on U.S. EPA 2008. Those segments are:

- CBTF1
- GUNOH
- PAXMH
- ELKOH
- SASOH
- MANMH
- BIGMH
- TANMH

The 2 segments with recognized subsegments in the 92 segment 303d list per U.S. EPA 2008 are

- JamesTF as JMSTF1 and TF2
- POTOH as POTOH1, OH2 and OH3.

Therefore, these 2 segments are counted as 5 segments.

Revising our counting, the next level of math then shows 77 non-split segments + 8 segments on the Split segment list that in the 303d listing of 92 segments are not indicated as split segments + 5 recognized split segments on the 303d list (JMSTF1 and 2; POTOH1, 2 and 3) = 90 segments. We still need to account for 2 more segments to reach the present day 92.

Going back to the table and comparing it to the U.S. EPA 2008 92 segment list, there were 2 segments missing from the table:

- ANATF-MD (the SAV table only identified this as a segment for DC. U.S. EPA (2008) recognizes ANATF-DC and ANATF-MD as part of the 92 TMDL segments)
- C&DOH-DE (the SAV table only recognizes C&DOH for MD while U.S. EPA (2008) recognizes a MD and DE segment)

Add in the two missing segments and we can account for the present day 92 segments.

Table G2. This table follows U.S. EPA (2008) segment listing that identifies 92 segments. This table uses the submerged aquatic vegetation tables information and accounts for 10 Split Segment cases where 2 segments became 5 (JMSTF as JMSTF1 and TF2 and POTOH as POTOH1, OH2 and OH3 per U.S. EPA (2008)).

Comparison of WQ Standards SAV acres to the 2003 CBP SAV Restoration Goal Segment Acres		
Decision cases where WQ Standards acres in a segment were increased above CBP 185K goal basis		
WHOLE (non-split) segments		65 segments
Unclipped CBP segment goal and then may or may not have chosen attainment depth limitations.	45 of 77 (There are 3 cases of extra acres that add an additional +1, +1, +27 acres)	
New Single Best Year in the 1978-2002 data set	8 of 77	
Goal established where none existed	3 of 77	
<i>Cases identified as SPLIT SEGMENTS</i>		
<i>Combined split segment acres > CBP adopted acreage for the pre-split segment</i>	6 of 8	
<i>Goal established for newly recognized segments. The sum of the new segments is > the CBP adopted acreage of the pre-split segment</i>	3 of 5 (POTOH1, 2, and 3)	
Decision cases where Segments had no change from CBP goals basis		
Acres same goal as the CBP goal	4 of 77	

No grow zone	9 of 77	18 segments
No goal to date	5 of 77	
Decision cases of WQStds acres revised lower than the CBP goals basis		
WHOLE (non-split) segments		7 segments
Model attainment revisions (2004 Linker et al)	3 of 77	
<i>SPLIT SEGMENT cases:</i>		
<i>Combined split segment acres < CBP adopted acreage for the pre-split segment (2 segments due to application depths, 1 model attainment affected)</i>	2 of 8 (-5 acres, - 6 acres)	
<i>Goal established for newly recognized segments. The sum of the new segments is < the CBP adopted acreage of the pre-split segment</i>	2 of 5 JMSTF1 and JMSTF2	
<i>Other segments - missing</i>		
<i>Unaccounted for 303d list segments in the SAV table based on 92 segment list in U.S. EPA (2008)</i>	<i>2: ANATF-MD and C&DOH-DE</i>	2 segments
<i>Total segments accounted for using the U.S. EPA 2008 as a guide</i>		
<i>To which split segments are recognized and which are not</i>		<i>92 segments</i>

Table G3. This table uses the split segments as individual segments. Segment total = 104. In 2003 the CBP recognized 104 segments according to U.S. EPA (2008).

Comparison of WQS acres to the 2003 CBP SAV Restoration Goal Segment Acres		
Decision cases where WQ Standards acres in a segment were increased above CBP 185K goal basis		
WHOLE (non-split) segments		75 segments
Unclipped CBP segment goal and then may or may not have chosen attainment depth limitations.	45 of 77 (There are 3 cases of extra acres that add an additional +1, +1, +27 acres)	
New Single Best Year in the 1978-2002 data set	8 of 77	
Goal established where none existed	3 of 77	
<i>Cases identified as SPLIT SEGMENTS</i>		
<i>Goal established for newly recognized segments. The sum of the new segments is > the CBP adopted acreage of their respective pre-split segment</i>	19 of 25	
Decision cases where Segments had no change from CBP goals basis		
Acres same goal as the CBP goal	4 of 77	18 segments
No grow zone	9 of 77	
No goal to date	5 of 77	
Decision cases of WQStd's acres revised lower than the CBP goals basis		

WHOLE (non-split) segments		9 segments
Model attainment revisions (2004 Linker et al)	3 of 77	
<i>SPLIT SEGMENT cases</i>		
<i>Goal established for newly recognized segments. The sum of the new segments is < the CBP adopted acreage of the pre-split segment</i>	6 of 25	
<i>Other segments - missing</i>		
<i>Unaccounted for 303d list segments in the SAV table based on 104 segment list in U.S. EPA (2008)</i>	<i>2: ANATF-MD and C&DOH-DE</i>	2 segments
<i>Total segments accounted for when all split segments are recognized as individual segments.</i>		
		<i>104 segments</i>